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Controlling Emissions from Light-Duty Motor Vehicles at Higher Elevations

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Controlling Emissions from Light-Duty Motor Vehicles at Higher Elevations

A Report to Congress

Prepared by

U. S. Environmental Protection Agency
Office of Air, Noise and Radiation
Office of Mobile Sources
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Standards Development and Support Branch

in cooperation with
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Region VIII
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Executive Summary

I. INTRODUCTION

This report evaluates various strategies for controlling high-altitude emissions from light-duty motor vehicles. It was prepared in response to section 206(f)(1) of the Clean Air Act, as amended (the Act). That section requires all light-duty vehicles (passenger cars) made during or after the 1984 model year to meet the requirements of section 202 of the Act regardless of the altitude at which they are sold. Section 202 establishes the current gaseous exhaust emission standards for light-duty vehicles (LDVs): 0.41 gram per mile (g/mi) for hydrocarbons (HC), 3.4 g/mi for carbon monoxide (CO), and 1.0 g/mi for oxides of nitrogen (NOx). This section was also used to promulgate evaporative emission and particulate standards for these vehicles. The evaporative standard for gasoline-fueled LDVs is 2.0 g/test HC and the particulate standards for diesel-powered LDVs are 0.6 g/mi beginning in the 1982 model year and 0.2 g/mi beginning in the 1985 model year.

Section 206(f)(2) requires the U.S. Environmental Protection Agency (here after referred to as EPA or the Agency) to report to Congress regarding the economic impact and technical feasibility of the above "all-altitude" requirement, in addition to the technical feasibility and health consequences of proportional high-altitude emission standards that reflect a percentage reduction in emissions comparable to that achieved in low-altitude areas. For 1982 and 1983 model year LDVs, EPA established proportional high-altitude standards of 0.57 g/mi HC, 7.8 g/mi CO, 1.0 g/mi NOx, and 2.6 g/test evaporative HC at 5,300 feet above sea level. No proportional diesel particulate standard was promulgated, but this report examines the possibility of such a standard.

One problem in developing this report was that the exact emission control requirements of the all-altitude passenger car provision are not clear. The statute and accompanying legislative history can plausibly be interpreted in various ways. The two basic areas where interpretation of the statute is necessary are:

1) the altitude or altitudes where compliance with the standards of section 202 is specifically required; and

2) whether exemptions from the all-altitude requirement are permissible.

The Agency will formally establish the exact requirements of the statute in the future. This report responds to the Congressional mandate by analyzing various control scenarios which encompass possible interpretations of the all-altitude provision. The report also explores some alternatives not currently allowed in the statute, but does not evaluate all of the many possible options. High-altitude emission control alternatives are directly influenced by several factors, and probably most importantly by the low-altitude standards. There is also significant uncertainty in the prediction of in-use emission factors from new technologies only recently introduced, and this uncertainty bears directly on the Agency's ability to make firm conclusions regarding the relative merits of some alternatives. Certain conclusions can be confidently made and have been. Other conclusions are highly uncertain and have been qualified as such. Hopefully, however, the options analyzed provide an indication of the complexity of the various interactions and a frame work for further analysis.

This document also investigates other areas of interest. The most important of these other areas include:

1) the consequences of controlling light-duty trucks (LDTs) in addition to LDVs; and

2) the consequences to high-altitude emission control strategies of possible revisions in the current statutory (low-altitude) standards.

II. CONTROL SCENARIOS BASED ON CURRENT STANDARDS

A. Analytical Methodology

For this report, EPA evaluated seven emission control scenarios representing a wide range of options (see Table ES-1 for a summary). Six of these control strategies were analyzed in detail for their economic and environmental impacts relative to the base scenario (i.e., the current fixed-point proportional standards). Therefore, the six control scenarios are evaluated as alternatives to continuing the base scenario.

The economic analysis included the costs of the capital investment, the hardware, and changes in fuel economy and maintenance. The environmental impact was measured through projected changes in lifetime emissions from motor vehicles sold during the first 5 years of the regulation, and through estimates of future ambient air quality in several high-altitude cities.

The analysis of alternative emission control strategies was conducted in two parts. The primary analysis was conducted for light-duty gasoline-fueled vehicles (LDGVs) and was used to reject unacceptable emission control strategies from the various alternatives. The secondary analysis further considered the most desirable control scenario for its effects on light-duty gasoline-fueled trucks (LDGTs) and light-duty diesel-powered motor vehicles (LDDs) before a final assessment of the desirability of any alternative scenario was made.

Table ES-1

Summary of the Seven Control Scenarios Evaluated in the Report

	Standards[a]		Compliance Strategy			Exemptions[d]	
			Continuous[b]		Fixed-Point[c]		
Scenario	Statutory	Proportional	10,200 Ft	6,000 Ft	5,300 Ft	Yes	No
1a	X		X				X
1b	X			X		X	
1c	X			X			X
2	X				X	X	
3a		X		X		X	
3b		X		X			X
Base[e]		X			X	X	

[a] See Table ES-2 for numerical values.

[b] Continuous strategies require that a vehicle automatically comply with the appropriate standards at all elevations up to a certain maximum altitude.

[c] Fixed-point strategies allow a modified or recalibrated vehicle to be sold above 4,000 feet. Compliance with the appropriate standards must be demonstrated at the single elevation of 5,300 feet.

[d] Exemptions or waivers from the high-altitude requirements would be available for some vehicles to reduce the economic burden of the standards or to prevent negatively affecting model availability at all altitudes.

[e] Scenarios 1 through 3 are evaluated as additional requirements to continuing the 1982-83 proportional high-altitude standards.

B. Description of the Control Scenarios

1. Base Scenario

The base scenario is primarily a continuation of the high-altitude requirements currently in place for 1982 and 1983 model year vehicles sold above 4,000 feet. Collectively, these requirements are termed a "fixed-point proportional strategy" because compliance with the proportional high-altitude standards must be demonstrated only at 5,300 feet (Table ES-2).* Such a standard allows vehicles to be modified to meet the high-altitude requirements after production if they will be sold above 4,000 feet.

Exemptions to these current high-altitude standards are available to reduce the economic burden of compliance. At present they are granted for certain low-power LDVs which are expected to perform unacceptably at high altitude and which may have technical difficulty in meeting the standards cost effectively. Such exempted vehicles cannot be sold at high altitudes.

Future regulations could, of course, include other types of exemptions, or perhaps waivers that allow some vehicles certified only at low altitude to be sold at high altitude. Performance-based exemptions appear to work satisfactorily, however, and they are the only type of exemptions considered in this study.

As previously stated, the six remaining control strategies in this report were examined as increments to the base scenario. The Agency believes that these regulations were justified during the final rulemaking process and that little benefit would result from again presenting the detailed supporting analyses. Therefore, the primary purpose of this report is to determine which alternatives to the current standards warrant further consideration.

2. Scenario 1

This alternative scenario is termed a "continuous statutory strategy" because it would require compliance with the low-altitude (statutory) standards at <u>all</u> altitudes up to a maximum elevation (Table ES-2). Every vehicle sold in the nation would have to <u>automatically</u> meet the standards (i.e., no modifications are allowed). The variations of this scenario are:

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* Technically, any place over 4,000 feet is currently considered high altitude. Compliance is demonstrated at 5,300 feet because that is the altitude of Denver, Colorado which has appropriate test facilities.

Table ES-2

Proportional and Statutory Standards for High-Altitude Vehicles at 5,300 Feet (based on current low-altitude standards)

Standard Type	Vehicle[a]	Gaseous Standards HC (g/mi)	CO (g/mi)	NOx (g/mi)	Evap. HC[b] (g/test)	Particulate Standards[c] (g/mi)
Proportional	LDV	0.57	7.8	1.0	2.6	[d]
	LDT	1.0	14	2.3	2.6	[d]
Statutory	LDV	0.41	3.4	1.0	2.0	0.2
	LDT	0.8	10	2.3	2.0	0.26

[a] Light-duty vehicle.
Light-duty truck. Although not required by the Act, statutory LDT standards were included in this report for completeness.

[b] Evaporative standards apply only to gasoline-fueled motor vehicles.

[c] Particulate standards apply only to diesel-powered motor vehicles.

[d] Exact level to be determined in the future. In this report, we estimated that a proportional particulate standard would be approximately 50 percent more than the corresponding low-altitude standard.

1) 1a - Compliance is up to 10,200 feet without exemptions;

2) 1b - Compliance up to 6,000 feet with exemptions; and

3) 1c - Compliance up to 6,000 feet without exemptions.

Exemptions can significantly reduce the economic burden of the standards. Under control strategies such as scenario 1 where vehicles must meet emission standards without modification, however, they also appear important in preventing an adverse impact on model availability at all elevations. For many low-power, high fuel economy LDVs, compliance with the statutory standards at high altitude may degrade performance to such a degree that these vehicles may actually become unsafe to use at higher elevations. Rather than market such potentially unsafe vehicles, manufacturers would likely decide to remove them from the national market. This would affect model availability and fuel economy throughout the nation. Exempting these low-power vehicles for sale only at low altitude would generally not affect model availability at high altitude, since these vehicles would normally not be sold in these areas because of their poor performance, even in the absence of high-altitude standards.

3. Scenario 2

This is termed a "fixed-point statutory strategy" and is similar to the base scenario except that it would require vehicles to meet the statutory (low-altitude) standards at 5,300 feet rather than proportional standards (Table ES-2). Modifications to vehicles sold above 4,000 feet would be allowed and exemptions would be available.

4. Scenario 3

This is termed a "continuous proportional strategy." At 1,800 feet, the standards are the low-altitude (statutory) standards. At 5,300 feet, the standards are the proportional standards shown in Table ES-2. In between these elevations and up to 6,000 feet the standards would vary linearly with altitude. Scenario 3, like scenario 1, would require all vehicles in the nation to meet the standards without modification. The variations of this scenario are:

1) 3a - Exemptions; and

2) 3b - No exemptions.

C. Comparison of the Alternative Control Scenarios

Each alternative scenario was analyzed in detail for LDGVs to determine its emission control technology, economic, and environmental impacts beyond the base scenario (i.e., the current fixed-point proportional standards). (See summary in Table ES-3). Based on this analysis, one alternative was further evaluated for LDGTs and LDDs.

1. Control Technology

The costs of each alternative scenario vary with the technical requirements they impose for controlling exhaust emissions. The emission control technology requirements for reducing gaseous pollutants are primarily based on three factors:

1) the maximum elevation for which control must be demonstrated;

2) the extent of exemptions, if any; and

3) the level of the standards.

Emission standards based on scenario 1a represent the most stringent interpretation of the Act's requirements. Requiring compliance up to 10,200 feet with no exemptions, these statutory standards would require the use of sophisticated electronic equipment and turbochargers, and are the most technically difficult alternative. Standards based on scenario 2 would require the least complex emission control hardware. These statutory standards would require the use of either specifically calibrated control modules, or an expansion of the capabilities of existing units on high-altitude vehicles equipped with electronic control systems. Less sophisticated aneroids (pressure sensing devices) would be required on high-altitude vehicles equipped with non-electronic control systems. Standards based on the remaining alternatives would fall between the hardware estimates for scenarios 1a and 2.

2. Economic Impact

Scenario 2 is by far the least costly of the alternative scenarios (Table ES-3). Even without the estimated fuel-economy benefit, the incremental cost of this control strategy is only $17 million during the first 5 years of the regulations. In comparison, the incremental costs for the other alternatives range from $187 million to $4.97 billion. The primary reason for this is that scenario 2 is a two-car strategy, so only those vehicles sold at high altitude need additional emission controls. The other scenarios are one-car strategies and require high-altitude emission control hardware on all vehicles nationwide, regardless of where they are sold.

Table ES-3

Costs and Beneifts of Alternative LDGV Control Strategies[a]

Scenario	Aggregate Costs (5-year total)[b] (10^6 dollars) Low	High	Total Reductions (5-year total) (10^3 metric tons) HC	CO	Incremental Cost Effectiveness (dollars/metric ton)[c] HC Low	HC High	CO Low	CO High
1a	4,151	4,974	24.6	-425	101,000	121,000	[d]	[d]
1b	524	1,010	24.6	-425	12,600	24,500	[d]	[d]
1c	1,384	1,907	24.6	-425	33,600	46,200	[d]	[d]
2	Uncertain[e]		17.9	331	neg.	575	neg.	30
3a	187	224	1.1	18.0	95,000	115,000	6,200	7,500
3b	449	636	1.1	18.0	230,000	325,000	14,900	21,100

[a] Each control scenario is examined as an increment to continuing the 1982-83 proportional high-altitude standards. For comparison, over the first two years of the regulation, these standards will cost the nation about $24 million (1981 dollars discounted to 1982), and reduce HC and CO emissions by about 33 and 1,200 tons, respectively. The cost effectiveness of these standards is $365 per metric ton for HC and $10 per metric ton for CO. (These costs and benefits are relative to the total absence of high-altitude regulations.)

[b] 1981 dollars discounted to the effective date of the regulations (1984).

[c] Cost effectiveness was determined on a per vehicle basis. For scenario 2 the high-cost estimates exclude the estimated fuel economy benefit.

[d] The cost-effectiveness values for CO under scenario 1 were not presented in the table since emissions of this pollutant may increase under this strategy. However, it is also possible that CO emissions may decrease by about the same total amount listed for both scenarios 2 and 3. Using this assumption, the cost effectiveness would range $535 to $5,100 per metric ton for CO.

[e] A net savings can result if the incremental purchase price increase (about $15 per high-altitude vehicle) is offset by a potential fuel economy benefit (about $25 per high-altitude vehicle). If the potential fuel economy improvement is excluded for scenario 2, the cost would range up to $17 million. The estimated fuel savings is tentative at this time because of the limited data base.

3. Environmental Impact

Significant differences are possible in the environmental impacts associated with each of the alternative scenarios. Scenario 1 (all options) predicts the greatest incremental reduction in HC emissions, although it also appears to increase CO emissions in high-altitude areas. These projections are based on tentative emissions factors, however. In the future as more complete data are collected, it is possible that scenario 1 may substantially reduce CO emissions in areas above 1,800 feet instead of producing an adverse environmental impact. Therefore, a final judgment on the impact of scenario 1 must await additional information.

The incremental emission reductions predicted for scenarios 3a and 3b are relatively small. Scenario 2 appears to offer the largest incremental emission reductions of all the alternatives. Again, the uncertainty in predicting emission factors discussed above applies here also.

Air quality modeling projections show that scenario 2 has a positive impact on the ambient air quality in high-altitude regions, although the affect is relatively small. This is not surprising, however, because scenario 2 is an incremental control strategy and future improvements in air quality will only come by combining several incremental controls, each having a small benefit of its own. More detailed analysis is needed before a firm conclusion can be made regarding whether these more stringent controls are needed, or if those provided by the base scenario are sufficient to attain the NAAQS in particular areas.

4. Cost Effectiveness

Table ES-3 shows that scenario 2 is predicted to be the most cost effective of the alternatives analyzed. The incremental cost effectiveness of reducing HC emissions ranges from less than $0 to $575 per metric ton, compared to $12,600 to $325,000 per metric ton for scenarios 1 and 3. The incremental cost effectiveness of reducing CO emissions under scenario 2 ranges from less than $0 to $30 per metric ton, compared to $535 to $21,100 per metric ton for the other alternative scenarios.

Scenario 2 is the only alternative scenario with cost-effectiveness values comparable to those for other mobile source emission control regulations. Even with high-cost estimates, scenario 2 appears to be a cost-effective approach to reducing high-altitude emissions from LDGVs, using the assumptions previously discussed.

5. Rationale for the Consideration of Scenario 2

The complexity of analyzing alternative high-altitude standards for 1984 and later model year motor vehicles requires the use of simplifying assumptions. However, these assumptions may affect the consideration of scenario 2 as an alternative to continuing the current standards. It is, therefore, important to examine the sensitivity of scenario 2 to the underlying analytical assumptions.

Five potentially important assumptions underlay the economic and environmental impact chapters of this report:

1) the estimated fuel economy saving;

2) the number of exemptions;

3) the levels of the emission standards;

4) the use of low-altitude vehicles in high-altitude areas; and

5) the fleet mix of electronic (feedback) and non-electronic (nonfeedback) systems.

The first three assumptions are most important and are briefly discussed below.

a. Estimated fuel economy savings. Scenario 2 is sensitive to changes in fuel consumption caused by the use of high-altitude emission control hardware. In fact, the incremental net cost is so sensitive to this aspect of the analysis that the lower limit of the possible fuel economy benefit (i.e., no improvement) was included in the previous discussion of cost and cost-effectiveness values. If the upper limit of 4 percent improvement were used in the analysis, the potential net savings would be even greater. Because of the sensitivity of the analysis to projected changes in fuel economy, this subject area should be carefully reevaluated as additional information becomes available so that the total cost associated with this scenario can be more accurately determined.

b. Number of exemptions. The desirability of scenario 2 may depend on the number of vehicles needing exemptions. Desirable high fuel-economy vehicles, which theoretically could be sold in the absence of scenario 2 (or any scenario providing exemptions), might easily become unavailable at higher elevations. Such vehicles could represent as much as about 10 percent of the market, possibly reducing model availability in these areas. On the other hand, the absence of the exemption provision may well prevent the availability of such vehicles nationwide.

Further technical achievements, however, may reduce the need for exempted vehicles. Also, as better information becomes available, the exemption criteria may be refined to resolve apparent problems regarding the number and type of exempted vehicles. Finally, other options could include waiving the high-altitude requirements for some vehicles to allow their continued sale at higher elevations, or allowing these vehicles to meet a somewhat less stringent high-altitude standard. Therefore, the desirability of scenario 2 depends on including appropriate exemptions or waivers to mitigate any adverse effects on model availability.

c. Level of emission standards. The incremental costs and benefits of scenario 2 are based on the assumption that statutory standards would be promulgated at high altitude. The previous discussion in this section demonstrated that high-altitude regulations, as with any requirement, must be chosen to moderate or eliminate a complex mixture of potentially adverse impacts (e.g., environmental, economic, energy, and model availability). The most efficient standards, therefore, may be at some level other than the statutory standards. While it appears that more stringent control beyond the proportional standards is feasible perhaps down to the levels of the statutory standards, less control may provide the majority of the needed environmental benefit in a more cost-effective manner. Only further study can identify the optimum level of control.

D. Application Scenario 2 to LDGTs and LDDs

This report assumed that scenario 2 should also be applied to gasoline-fueled light trucks and diesel-fueled vehicles. As with LDGVs, the analyses for these other vehicle types were conducted to determine the incremental costs and air quality improvements of scenario 2 beyond those achieveable by continuing the current standards (base scenario) for 1984 and later model year vehicles.

1. LDGTs

a. Control technology. The technical requirements of meeting the statutory LDGT standards in scenario 2 are essentially the same as for LDGVs equipped with non-electronic (nonfeedback) emission control systems.

b. Economic impact. The incremental economic impact under scenario 2 should not be substantial. Depending on whether the estimated fuel economy benefit is included, this scenario would either result in a net savings or a cost of $7 million for the first 5 years of the regulations. As with LDVs, this potential fuel economy benefit should be carefully reevaluated as additional data become available.

c. Environmental impact. The air quality projections show a positive impact from adding LDT control to that for LDVs. Controlling LDGTs under scenario 2 would provide a 50 percent greater reduction in HC and a 40 percent greater reduction in CO from vehicles sold during the first 5 years of the regulations than if LDGVs were the only class of motor vehicles subject to more stringent high-altitude standards.

d. Cost effectiveness. The addition of LDGTs to scenario 2 makes it a slightly more cost-effective HC control strategy than controlling only LDGVs, but does not change the cost effectiveness of reducing CO under worst case assumptions.

2. LDDs

a. Control technology. Under the statutory gaseous emission standards of scenario 2, light-duty diesel-powered vehicles (LDDVs) would probably require a recalibration of their exhaust gas recirculation (EGR) system by changing the electronic control module at high altitude. Similarily, light-duty diesel-powered trucks (LDDTs) would require a recalibration of their non-electronic EGR systems at high altitude.

The analysis of both proportional and statutory particulate standards for light-duty diesel-powered vehicles and trucks shows that a proportional particulate standard, when definitively determined, will be readily achievable (there are currently no such standards). In addition, the application of gaseous emission control may achieve further reductions in particulate with little or no addition effort. However, it is not possible to determine if the 1985 low-altitude particulate standards will be fully achieveable at high altitude due to the severe limitations of the data base. Additional data is needed before a conclusive judgment can be made regarding the technical feasibility of the 1985 statutory particulate standards at high altitude.

b. Economic impact. The incremental cost of complying with gaseous emission standards or proportional particulate standards at high altitude during the first 5 years of the regulations will be small.

c. Environmental impact. Adding control of diesel-powered motor vehicles to scenario 2 should be beneficial in further reducing HC emissions and should also help reduce CO emissions.

d. Cost Effectiveness. Controlling gaseous emissions from LDDs makes scenario 2 more cost effective than if LDGVs and LDGTs are controlled separately.

III. CONTROL SCENARIOS BASED ON REVISED STANDARDS

Although revisions to the current statutory (low-altitude) standards remain speculative, EPA has tried to anticipate the effects of less-stringent standards on the previously identified alternative scenarios. While there are a number of different options for low-altitude standards, this study assumes that if the statutory emission standards (g/mi) are changed, the levels will be revised:

From	To
0.41 HC	0.41 HC
3.4 CO	7.0 CO
1.0 NOx	1.5-2.0 NOx

The corresponding revised proportional standards (g/mi) at 5,300 feet would be:

From	To
0.57 HC	0.57 HC
7.8 CO	16.0 CO
1.0 NOx	1.5-2.0 NOx

However, the technical requirements of meeting an 16 g/mi CO standard appear the same as those for meeting an 11 g/mi CO standard. The Agency, therefore, assumed proportional standards (g/mi) of:

1) 0.57 HC
2) 11.0 CO
3) 1.5-2.0 NOx

Revisions to the current low-altitude evaporative HC and diesel particulate standards are not being considered by Congress, hence, they were not analyzed in this report.

To be consistent with the previous analysis the control technologies, costs, and benefits of the alternative revised high-altitude scenarios were evaluated relative to a revised base scenario (fixed-point proportional standards based on revised statutory standards). This approach is valid because compliance with the revised proportional standards is expected to be similar to compliance with current proportional standards. In both cases, leaning the excessively rich fuel/air mixtures at high altitude is the primary emission control technique.

A. Comparison of the Alternative Revised Scenarios

Several findings in the earlier analyses remain valid even under revised standards. All continuous control strategies evaluated continue to be unreasonably burdensome and are not cost effective primarily because they would either seriously restrict model availability at high altitude, require expensive and complicated emission control technology on all vehicles, or unnecessarily control emissions at elevations which are not expected to have an air quality problem (above 6,000 feet). Also, exemptions continue to be valuable in reducing the economic burden of the standards or preventing model availability problems at all elevations. Therefore, the fixed-point standards associated with the revised base scenario (proportional standards) and the revised scenario 2 (statutory standards) are the scenarios analyzed in this portion of the study.

B. Evaluation of the Revised Scenario 2

1. Control Technology

Complying with revised statutory standards at low and high altitude would require essentially the same control hardware as previously estimated for complying with current statutory standards. For LDGVs, this hardware includes the use of two aneroids in addition to the one aneroid that would already be in place to meet the revised proportional standards, for a total of three. However, with revised statutory standards, the change in low-altitude emission control technology may require that the air pump system, which may be eliminated at low altitude on some LDGVs, be replaced when these vehicles are sold at high altitude. This may affect 40 percent of all high-altitude LDGV sales and is included in the analysis as a worst case assumption. For LDDVs sold at high altitude, manual adjustments will be needed in addition to those that may already be needed for proportional standards to limit the maximum fuel rate further and also to recalibrate the fuel injection timing.

2. Economic Impact

Complying with the revised scenario 2 would slightly increase the purchase price of an average high-altitude LDGV. The purchase price of LDDVs should not increase.

The incremental cost of fixed-point statutory standards with revised levels is greatly influenced by the fuel economy benefit the Agency expects from the use of high-altitude control technology. Including this fuel savings in the cost of the standards would result in a net incremental savings to the nation during the first 5 years of the regulations. Excluding the estimated fuel economy benefit from the calculation would cost the nation up to $40 million during the first 5 years. Because of this great variability, the fuel economy benefit should be reevaluated as additional information becomes available.

In comparison to the incremental cost of fixed-point statutory standards based on the current low-altitude requirements, implementing the revised statutory standards could be more costly to the nation if the estimated fuel economy benefits of the standards are excluded. If the fuel benefits are included, both types of standards will provide a net savings to the nation.

The incremental purchase price for the average high-altitude LDV should not affect a dealer's sales or a consumer's ability to purchase a vehicle. One aspect of the revised scenario 2, however, may have a significant negative impact on trading between low- and high-altitude dealers. As discussed earlier, EPA has made a worst case assumption that 40 percent of the high-altitude fleet may require the addition of an air pump to meet the statutory standards in the revised scenario 2. If true, these particular vehicles may be prohibitively expensive to modify for high-altitude use <u>after</u> production. This could result in model availability problems in some high-altitude areas. However, more data is needed to confirm this potential effect.

2. <u>Environmental Impact</u>

Implementing statutory standards at high altitude over proportional standards would reduce HC and CO emissions somewhat less under the revised low-altitude standards than under the current low-altitude standards.

There are no significant differences for ozone between the high-altitude standards based on: 1) the revised low-altitude standards, and 2) the current low-altitude standards. This is to be expected, since the emission standards for HC are the same for the respective statutory (0.41 g/mi) and base (0.57 g/mi) control scenarios.

The same conclusion can be reached for CO with Inspection/Maintenance, that is, there is no difference between the number of violations under the two types of standards. Without I/M, however, the number of CO NAAQS violations under the scenarios based on revised standards is generally less than that under the previous scenarios based on current standards. This difference in CO NAAQS violations is a function of the assumed catastrophic failure rates for currently used feedback emission control systems. If these failure rates are significantly reduced in the future as more experience is gained with these new systems, then the observed difference in CO levels between the two types of standards could be eliminated or even reversed.

For NOx, high-altitude standards based on revised low-altitude standards will have a small negative impact on NAAQS violations near the end of this century.

3. <u>Cost Effectiveness</u>

Implementing revised fixed-point statutory standards with exemptions rather than revised fixed-point proportional standards with exemptions would either provide further HC and CO emission reductions at no net cost, or cost up to $1,250 per metric ton of HC and up to $85 per metric ton of CO. The wide range of incremental cost-effectiveness values is caused by the inclusion or exclusion of the estimated fuel economy benefit that may accompany implementating the revised statutory standards at high altitude. In the worst case analyzed (i.e., no fuel economy improvement) this scenario is nearly twice as costly per ton of HC than the most expensive emission control strategy that has already been implemented. For CO, it is more comparable to the other strategies. On the other hand (i.e., inclusion of the estimated fuel economy benefit) the revised scenario 2 is very cost effective in relation to the other control strategies.

IV. CONCLUSIONS AND RECOMMENDATIONS

The existing proportional high-altitude standards have proven valuable in improving the air quality of high-altitude areas in a cost-effective manner. This report has analyzed various high-altitude control scenarios to determine their incremental costs and air quality benefits relative both to the current standards and to less stringent revised standards. The evaluated scenarios covered control options for both gasoline and diesel-powered vehicles.

A. Control Scenarios Based on Current Standards

The major conclusions for each vehicle type are presented separately below.

1. LDGVs

The Agency considered six alternative scenarios to continuing the current fixed-point proportional standards. The costs of these alternatives vary with their technical requirements, which in turn are based on three basic factors:

1) the maximum elevation for which control must be demonstrated;

2) the extent of exemptions, if any; and

3) the level of standards.

Based on these three factors, EPA concludes that:

1) Continuing the current statutory high-altitude requirements, as mandated in section 206 of the Act, is extremely costly, may significantly limit model availability at both low and high altitudes, and is extremely cost ineffective;

2) there is no air quality justification for controls above 6,000 feet;

3) statutory standards at high altitude can provide a small incremental improvement in air quality;

4) exemptions, or similar waivers, can significantly reduce compliance costs, while maintaining acceptable model availability at higher elevation;

5) exemptions, or similar waivers, can prevent the potential for adversely affecting model availability throughout the nation that may accompany implementing statutory standards at higher elevations in 1984, as required by the Clean Air Act; and

6) fixed-point statutory standards which require vehicles sold above 4,000 feet to comply with the standards when tested at 5,300 feet and which provide for some exemptions are the most cost-effective alternative beyond the current requirements, of the six alternatives analyzed. Of course, there are many other possible alternatives, one of which may be better than any of the six analyzed here.

2. LDGTs

In the case of LDGTs, EPA finds that controlling these vehicles in addition to LDVs results in a positive impact on the ambient air quality of high-altitude areas. Controlling light trucks to statutory standards, while not specifically required by the Act, would reduce vehicle emissions of HC by 50 percent more and of CO by 40 percent more than if LDGVs were controlled alone. In addition, the Agency finds that controlling light truck emissions under fixed-point statutory standards is more cost effective than the same degree of control for LDGVs.

3. LDDs

The Agency analyzed both gaseous emissions and particulate emissions from LDDs. For gaseous emissions, EPA concludes that achieving fixed-point statutory standards should be no more difficult for diesel engines than for gasoline engines, and that the cost over a 5-year period should be small. The Agency finds that particulate emissions will be reduced by the same techniques that reduce gaseous emissions, although it is too early to determine if the statutory particulate standards can be met with these techniques alone. Also, controlling the gaseous emissions from LDDs to statutory high-altitude standards is expected to be more cost effective than controlling LDGVs.

B. Control Scenarios Based on Revised Standards

The Agency also considered the effects of the same six alternative scenarios under revised standards. The major difference is that under revised fixed-point statutory standards, the control options might tend to reduce model availability somewhat more than they would under the current fixed-point statutory standards. Otherwise, EPA concludes that:

1) the technical difficulties of compliance would remain about the same;

2) exemptions, or similar waivers, would retain their positive effects of overall costs and model availability; and

3) fixed-point statutory standards would likely be the most cost-effective alternative to proportional standards.

Based on the assumption that revised LDV standards at low altitude are as stated above (i.e., 0.41 g/mi HC, 7.0 g/mi CO, and 1.5-2.0 g/mi NOx), these conclusions would remain valid for both gasoline-fueled and diesel-powered cars and trucks. Nevertheless, different conclusions are possible under scenarios which assume other revised low-altitude standards.

C. Recommendations

EPA recommends that section 206 of the Clean Air Act be amended to:

1) Provide the Administrator the flexibility to adopt two-car compliance strategies, and to establish high-altitude standards, within the range from proportional to statutory, for any class of motor vehicles that is necessary to attain the NAAQS for ozone and carbon monoxide after considering the technical feasibility, impact on model availability, and economic impact of any such requirements; and

2) Confirm the Administrator's authority to exempt certain vehicles from the high-altitude certification requirements or waive the high-altitude standards for certain vehicles, and to decide on the maximum number of such exemptions or waivers.

Chapter I

Introduction

I. AIR QUALITY IN HIGH-ALTITUDE AREAS

Many metropolitan areas located at higher elevations have significant air quality problems. The automobile is an important source of air pollution in these regions. For example, in the rapidly growing automobile-oriented cities of Denver, Albuquerque, and Salt Lake City, motor vehicles account for more than half of all hydrocarbon (HC) emissions and almost all of the carbon monoxide (CO) emissions. In combination with summer sunlight and stable winter atmospheric conditions, these emissions cause serious air pollution problems.

II. PAST AND PRESENT STANDARDS AFFECTING HIGH-ALTITUDE VEHICLES

To combat these problems, the U.S. Environmental Protection Agency (hereafter referred to as EPA or the Agency) established several programs to control emissions from motor vehicles in high-altitude locations. As part of these past and present regulatory programs, EPA has defined a high-altitude location as any county with most of its land area located 4,000 feet above sea level.[1] This description includes much of Colorado, Utah, Wyoming, New Mexico, and Idaho, and parts of Nevada, Montana, Nebraska, Arizona, Oregon, and Texas. Though California has counties above 4,000 feet, it sets its own emission standards for motor vehicles.[1]

For the 1977 model year, EPA promulgated gaseous emission regulations requiring all dealerships in high-altitude counties (i.e., essentially areas above 4,000 feet) to sell only light-duty vehicles (LDVs) and light-duty trucks (LDTs) that were certified to meet special high-altitude standards when tested at 5,300 feet (i.e., the location of test facilities at Denver, Colorado). These standards were numerically identical to the applicable emission standards at low altitude. The numerical values of the 1977 standards were 1.5 grams per mile (g/mi) HC, 15 g/mi CO, and 2.0 g/mi NOx for LDVs and 2.0 g/mi HC, 20 g/mi CO, and 3.1 g/mi NOx for LDTs.

During the first model year these regulations were in effect (1977), many vehicle models and optional engine configurations available at low altitudes were unavailable at high altitudes. Manufacturers chose to limit model availability at higher elevations because the small percentage (3 to 4 percent) of the market represented by high-altitude sales did not justify the costs required to develop high-altitude emission control capabilities for all of their vehicle configurations. Thus, high-altitude consumers could not readily purchase approximately 50 percent of the vehicle configurations offered at lower elevations.

These limitations on model availability affected high-altitude consumers primarily in two ways: 1) some consumers were unable to purchase the specific vehicle configuration they wanted, and 2) if the desired model was unavailable, the consumer may have had to pay significantly more for an alternative, certified model. This additional cost was as high as $500 in a small proportion of cases. A lesser economic impact on consumers was the incremental cost of high-altitude emissions control hardware, typically $20-40, although it was as high as $194 on some imported models.[1]

Limited model availability affected manufacturers and dealers to a lesser degree. Although it did not reduce total vehicle sales at higher elevations, some dealers thought it prevented the expected 10-20 percent growth in sales. Moreover, some dealers complained that fleet sales were reduced and that employee morale suffered. Also, near the perimeter of high-altitude areas there was some difficulty in trading vehicles between low- and high-altitude dealers.

As a result of these problems, Congress vacated the 1977 high-altitude regulations when the Clean Air Act (the Act) was amended on August 7, 1977. The Act also authorized EPA in section 202(f) to reestablish high-altitude requirements, but no sooner than the 1981 model year.

In response to these amendments, EPA revised the 1977 standards so that in 1978 and later model years, manufacturers could voluntarily certify special high-altitude vehicles. In 1978, another voluntary program was also established. Under this program, manufacturers could provide, with EPA's approval, instructions explaining how vehicles operated at higher elevations could be adjusted to improve performance, significantly reduce emissions, and, in some cases, increase fuel economy. These instructions were made mandatory on October 8, 1980, under the authority of section 215 of the Act.[2]

For 1981 model year vehicles, the year in which the low-altitude standards became more stringent, EPA established a voluntary program so that manufacturers could certify their vehicles to separate "proportional" standards at high altitude.[3] These voluntary gaseous emission standards were the same as those promulgated on October 8, 1980, as the current mandatory standards for 1982 and 1983 model year LDVs and LDTs.[4]

According to section 202(f) of the Act, proportional high-altitude standards require a percent reduction in emissions from 1970 vehicles at high altitude comparable to that from the same vehicles at low altitude. In no case, however, may the standard at high altitude be numerically less than the corresponding standard at low altitude. This last requirement is significant for NOx emissions which, unlike HC and CO emissions, generally decrease with increasing altitude.

Table I-1 presents the current proportional high-altitude standards for 1982 and 1983 model year LDVs and LDTs, and the equally stringent, but numerically smaller, low-altitude standards for 1981 and later model years.

The current high-altitude regulations are structured to minimize any negative impact on model availability by requiring nearly all 1982 and 1983 models to either automatically meet or be capable of being modified to meet the high-altitude standards. Thus, each manufacturer's product line can be made available to high-altitude purchasers if the manufacturer so chooses. The Agency expects manufacturers will make almost all models available once they have been certified.

The 1982 and 1983 regulations also reduce the potential economic impact on the automotive industry by providing exemptions for certain low-power vehicles, which perform poorly at high altitude. Controlling the emissions of these vehicles in a cost-effective manner is expected to be difficult. In addition, by virtue of their poor performance, these vehicles are not expected to be in demand by high-altitude consumers. Therefore, by exempting low-power vehicles and allowing them to be certified for sale at low altitude only, model availability is not significantly affected in either low- or high-altitude areas of the country and the cost of high-altitude regulation is reduced without reducing the benefits.

III. REQUIREMENT TO ASSESS AND IMPLEMENT STANDARDS FOR 1984 AND LATER MODEL YEARS

Section 206(f)(1) of the Clean Air Act, as amended in 1977, provides future high-altitude LDV standards by mandating that:

> All light-duty vehicles and engines manufactured during or after model year 1984 shall comply with the requirements of section 202 of this Act regardless of the altitude at which they are sold.

Section 202 contains the current low-altitude gaseous exhaust emission standards for LDVs. This section also contains the authority used to promulgate the evaporative emission and

Table I-1

Current High- and Low-Altitude Emission Standards for Light-Duty Vehicles and Light-Duty Trucks

			Gaseous Standards				Diesel
Altitude	Vehicle	Year	HC (g/mi)	CO[a] (g/mi)	NOx[b][c] g/mi	Evap. HC[d] (g/test)	Particulate Standards[e] (g/mi)
High	LDV[f]	1982-83	0.57	7.8	1.0	2.6	[g]
	LDT[h]	1982-83	2.0	26.0	2.3	2.6	[g]
Low	LDV	1981-84	0.41	3.4	1.0	2.0	0.6
		1985 and later	0.41	3.4	1.0	2.0	0.2
	LDT	1982-83	1.7	18	2.3	2.0	0.6
		1984	0.8	10	2.3	2.0	0.6
		1985 and later	0.8	10	2.3	2.0	0.26

[a] If the CO standard for 1982 LDGVs is waived to 7.0 g/mi at low altitude, the standard is 11.0 g/mi at high altitude.
[b] If the NOx standard for 1982 and 1983 LDDVs is waived up to 1.5 g/mi at low altitude, the high-altitude standard is the same numerical value.
[c] For 1982, American Motors Corporation must only meet an NOx standard of 2.0 g/mi at both high and low altitude.
[d] Only applies to gasoline-fueled vehicles.
[e] Only applies to diesel-powered vehicles.
[f] Light-Duty Vehicle.
[g] No particulate standard was promulgated for high-altitude vehicles, but such a standard is analyzed in this report.
[h] Light-Duty Truck.

diesel particulate standards applicable to these vehicles. These 1984 and later model year standards are summarized in Table I-1.

In section 206(f)(2), the Administrator of EPA is required to report to Congress on the economic impact and techological feasibility of the "all-altitude" requirements found in subparagraph (1) of that subsection. The report is also to evaluate the technological feasibility and the health consequences of separate proportional emission standards for light-duty vehicles and engines in high-altitude areas, as described earlier.

In preparing this report, the Agency has found that while the nature of proportional requirement is clear, the exact nature of the all-altitude requirement is not. Section 206(f)(1) and the accompanying legislative history can plausibly be interpreted in various ways. For example, EPA must determine whether vehicles must meet the standards of section 202 at the highest altitude where they are sold, even though there are no air quality problems in such areas, or at a lower altitude, which can be justified on the basis of air quality concerns. Another issue is whether exemptions from the high-altitude standards (i.e., the all-altitude requirement) are allowable.

Because the Agency has not yet taken a formal position on these matters, the exact emission control requirements of section 206(f)(1) are not clear at this time. Nevertheless, this document responds to the Congressional mandate for such a study by analyzing various control scenarios that encompass all the possible interpretations of the all-altitude provision.

The report also explores some alternatives not currently allowed in the statute, but does not evaluate all of the many possible options. High-altitude emission control alternatives are directly influenced by several factors, and probably more importantly by the low-altitude standards. There is also significant uncertainty in the prediction of in-use emission factors from new technologies only recently introduced, and this uncertainty bears directly on the Agency's ability to make firm conclusions regarding the relative merits of some alternatives. Certain conclusions can be confidently made and have been. Other conclusions are highly uncertain and have been qualified as such. Hopefully, however, the options analyzed provide an indication of the complexity of the various interactions and a frame work for further analysis.

Furthermore, in an effort to identify the most effective high-altitude regulatory strategy, we have examined other areas of interest. The additional areas of investigation include:

1) controlling light-duty trucks in addition to light-duty vehicles; and

2) evaluating the consequences of possible revisions in the current statutory (low-altitude) emission standards on the control of emissions in high-altitude areas.

IV. ORGANIZATION AND SCOPE OF THE REPORT

Because light-duty gasoline-fueled vehicles (LDGVs) dominate the motor vehicle fleet nationwide, any control scenario that is unacceptable for them should be unacceptable for the entire national fleet. Using LDGVs to screen the various control scenarios reduces the complexity of the report, but does not compromise identifying the most desirable strategy for controlling emissions at high altitudes.

Thus, after the potential control scenarios are identified in Chapter II, LDGVs are used to screen various strategies in Chapters III through IV with regard to the requisite control technology, the environmental and economic impacts, and their cost effectiveness. Using this information, the most reasonable scenario of those analyzed is selected in Chapter VII. Chapters VIII and IX then determine how the selected scenario would effect controlling gaseous emissions from light-duty gasoline-fueled trucks and light-duty diesel-powered vehicles and trucks. Chapter X specifically evaluates the selected scenario for its effect on controlling particulate emissions from light-duty diesel-powered vehicles and trucks.

Recently, the debate concerning amending the Clean Air Act has included the possibility of revising the statutory low-altitude emission standards for LDVs upward from the current levels. Although such a revision remains speculative at this time, Chapter XI evaluates the effect of less stringent low-altitude standards on potential high-altitude standards.

The final chapter (Chapter XII) presents EPA's conclusions and recommendations.

References

1. "Final Regulatory Analysis - Environmental and Economic Impact Statement for the 1982 and 1983 Model Year High-Altitude Motor Vehicle Emission Standards," U.S. EPA, OANR, OMS, ECTD, SDSB, October, 1980.

2. "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; Submission of Altitude Performance Adjustments," U.S. EPA, 45 FR 66952, October 8, 1980.

3. "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; High-Altitude Emission Standards, Voluntary Compliance Program for 1981 Model Year Light-Duty Motor Vehicles," U.S. EPA, 45 FR 20402, March 27, 1980.

4. "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; Final High-Altitude Emission Standards for 1982 and 1983 Model Year Light-Duty Motor Vehicles," U.S. EPA, 45 FR 66984, October 8, 1980.

Chapter II

Identification of the High-Altitude Control Scenarios

I. INTRODUCTION

The high-altitude control scenarios analyzed in this document will be chosen from a variety of possibilities. This screening is necessary to limit the analysis to manageable proportions and to avoid needless elaboration on less likely control options. The selection process in this chapter will be conducted in two steps. First, the relevant variables that form the basis for the alternative scenarios will be discussed to provide a thorough understanding of the control strategies and to introduce information that will be used to select the specific scenarios for the study. Second, these variables will be combined into the various potential scenarios, and those not justifying further consideration at this time will be eliminated. At this point in the selection process, the scenarios that represent what currently appears to be the range of possible interpretations of the section 206(f)(1) "all-altitude" requirement will also be identified.

II. THE BASIS FOR THE CONTROL SCENARIOS

There are many possible strategies for controlling motor vehicle emissions in high-altitude areas of the country. These strategies are a combination of variables which include: 1) the philosophy of high-altitude emission control, 2) the maximum altitude at which the standards will apply, 3) the allowable emission levels for each standard, and 4) the availability of exemptions for certain low-power vehicles. Each of these variables is discussed below.

A. The Philosophy of High-Altitude Control

This report considers two basic certification options. The first option requires that motor vehicles be certified to meet the applicable standards continuously at all elevations without modification. Scenarios that require demonstrating compliance in this manner are referred to as "continuous" standards in this document.

The second option is primarily patterned after the certification program that was promulgated in the 1982 and 1983 high-altitude regulations.[1] This rule specifies that all vehicles subject to the regulations must be capable of meeting high-altitude standards either automatically or by modification. Furthermore, demonstrating compliance with these standards is limited to a single fixed-point of 5,300 feet. If modifications are necessary to meet the emission standards at 5,300 feet, those modifications must be made to all such vehicles sold above 4,000 feet. Scenarios which incorporate this type of certification program are referred to as "fixed-point" standards.

B. The Maximum Elevation Required for Control

This variable applies only to the continuous standards, since the fixed-point standards analyzed in this report only require compliance with high-altitude regulations at a single elevation of 5,300 feet. Under fixed-point standards "high-altitude" vehicles are sold at any elevation above 4,000 feet.

Continuous standards require that a vehicle be designed to compensate automatically for the effects of reduced air density as altitude increases. Therefore, choosing the maximum altitude at which emission control must be demonstrated is important, since the wrong decision could either: 1) cause manufacturers to equip their cars with costly control hardware to reduce emissions at altitudes where such reductions are not warranted by air quality needs, or 2) lead to the absence of additional control in a significant number of regions that do indeed need it. Because this issue affects the entire analysis, it is discussed at length below.

A literal reading of the Act implies that vehicles must be certified up to the highest altitude at which sales occur, approximately 10,200 feet. However, the intent underlying the provision may be satisfied with an alternative interpretation. That interpretation, which is supported by the applicable legislative history, requires compliance only up to a certain elevation. A key purpose of section 206(f) is to improve the air quality in high-altitude areas of the country that violate the National Ambient Air Quality Standards (NAAQS). The air quality monitoring data currently available indicate that future violations will be limited to high-altitude areas substantially below 10,200 feet.

Colorado Springs, Colorado, at 6,012 feet and the Tahoe Air Basin in California and Nevada at 6,225 feet are the two highest areas designated as nonattainment areas for carbon monoxide (CO) or ozone (O_3) as specified by section 107 of the Clean Air Act. That is, they are violating one or more of the NAAQSs referred to in Table II-1. Thus, an elevation of approximately 6,000 feet forms a logical upper boundary above which all regions are likely to be attaining the NAAQSs.

This is especially true with regard to ozone since it normally is only a problem in areas that are more densely populated (and that have higher emission densities of hydrocarbons (HC) and nitrogen oxides (NOx)) than those found above 6,000 feet. Another factor that is critical to the formation of ozone but that is not prevalent in these high elevations is the presence of stagnated high-pressure cells,

Table II-1

National Ambient Air Quality Standards

Pollutant	Averaging Time	Standards
Ozone	1 Hour	235 ug/m^3 [a]
Carbon Monoxide	8 Hour	10 mg/m^3 [b]
	1 Hour	40 mg/m^3
Nitrogen Dioxide	Annual Average	100 ug/m^3
Sulfur Dioxide	Annual Average	80 ug/m^3
	24 Hour	365 ug/m^3
Suspended Particulate Matter	Annual Geometric Mean	75 ug/m^3
	24 hour	260 ug/m^3
Lead	Quarterly	1.5 ug/m^3

[a] Micrograms per cubic meter.
[b] Milligrams per cubic meter.

such as those common to the Los Angeles area. These meteorological conditions are characterized by long periods of cloudless skies and essentially no winds, which combine to provide ideal conditions for producing and retaining ozone.

CO, however, is a more localized problem. CO violations can occur whenever localized traffic is heavy enough for a sufficient time period. To determine the extent of CO violations between the altitudes of approximately 6,000 feet and 10,000 feet, EPA's, Region VIII monitored ambient CO levels at these elevations during the 1978-79 winter season.[2]

Two CO monitors were available for this study. Region VIII used the following criteria to select the best locations: 1) the level of CO emissions in the area, 2) the frequency and severity of unfavorable meterological dispersion conditions, 3) the altitude, 4) the availability of suitable monitoring sites, and 5) the availability of local support for the monitoring.

One site was chosen at 10,500 feet near the Loveland Basin ski area. Being near the east entrance of the Eisenhower Tunnel, this site was exposed to one of the largest sources of CO emissions in the Rocky Mountains. It was also near two other significant sources of CO emissions: the highway to Loveland Pass and the Loveland ski area parking lot. The ski area complex also provided a significant source of population exposure. The monitor was located in a trailer approximately 20 meters south of U.S. Highway 6, 50 meters south of I-70, 300 meters east of the ski area parking lot, and 1,000 meters east of the tunnel's entrance. This site, operated during the high traffic ski season, was expected to measure the highest ambient CO levels at an altitude of 10,000 feet or above.

At the elevation 8,150 feet, Vail, Colorado was selected for the other CO monitoring site for three primary reasons. One, Vail is a major ski area located near a major traffic artery (I-70) and has a high level of CO from automobile emissions. A significant additional source of CO is wood burning in residential fireplaces. Two, Vail is located in a deep, narrow valley and experiences some of the poorest atmospheric dispersion conditions in the Rockies. Three, Vail has an ongoing program that monitors air quality. It is headquartered in City Hall approximately 50 meters south of I-70 and 50 meters west of one of Vail's major intersections. Established quality control procedures were followed.

No violation of the CO standard was observed at the Loveland Basin site. Thus, controlling CO to altitudes of 10,000 feet or above should be unnecessary. However, there were 27 violations of the CO 8-hour running average NAAQS of 10 mg/m^3 during December 1978 and January 1979 at the Vail site. The highest measured 8-hour concentration was 12.6 mg/m , 26 percent above the NAAQS. (The term 8-hour running average means that a new 8-hour average is taken every hour; thus, as many as 24 violations could occur in a given day.) The first five violations occurred immediately after the instrument became operational on December 11, 1978. Therefore, more violations might have been recorded if the analyzer had been put into operation sooner. Also, many of the 27 violations occurred on the same day.

This sampling was done when the low-altitude CO emission standard for light-duty vehicles (LDVs), the largest source of CO emissions, was 15 g/mi. In high-altitude areas, CO emissions from in-use 1978-79 LDVs averaged 53.69 g/mi halfway through their expected 100,000-mile lifetime.[3] In 1980, the low-altitude CO standard for LDVs dropped to 7 g/mi and was further lowered to 3.4 g/mi beginning with the 1981 model year. These two reductions have lowered the average CO emission level from in-use 1980 and 1981 LDVs to an average of 32.52 g/mi and 26.13 g/mi in high-altitude regions, respectively (Appendix II).[3] Implementing the 1982 and 1983 (interim) high-altitude standards will further reduce the in-use LDV CO emission level to an average of 23.54 g/mi. This will be a net reduction of approximately 56 percent from the 1979 model year level (Appendix II). Thus, as newer, cleaner vehicles replace the pre-1980 models (those affecting the results from the Loveland and Vail studies), CO concentrations at these sites will significantly decrease. Therefore, in all likelihood, Vail will be in compliance with the CO NAAQS in the future without more stringent high-altitude control.

It should be pointed out that the Motor Vehicle Manufacturers Association (MVMA) monitored CO in Leadville, Colorado, from January to March 1980.[4] However, because the quality control procedures it used were not documented, the study's findings are questionable. The results seem to indicate that the CO levels in Leadville are less than those of Vail. Leadville was considered as a test site for this study since it is the highest U.S. city with an automobile dealership and, hence, is the altitude up to which manufacturers may have to comply with the low-altitude standards. It was rejected for the EPA study, however, for two reasons: 1) low traffic densities (i.e., low CO emission production), and 2) generally good atmospheric dispersion characteristics.

In conclusion, no region above approximately 6,000 feet is expected to have an ozone problem mainly because the emission density is not high enough. The only identified automotive-related air quality problem at these elevations concerns CO and is in Vail, Colorado, at an elevation of 8,150 feet. This problem, however, should definitely disappear when cleaner 1980 and later model year vehicles replace their older, higher-emitting counterparts, particularly given the presence of interim high-altitude standards. Thus, there do not appear to be significant air quality problems above approximately

6,000 feet which would warrant control in these areas. The maximum control altitudes for scenarios with continuous standards are, therefore, limited to 10,200 feet (the highest elevation where control may be required by the Act), and 6,000 feet (the highest elevation where emission controls appear to be justifiable based on air quality concerns).

C. The Levels of the Standards

This report considers two types of high-altitude emission standards. The first type are called "statutory" standards. Section 206(f)(1) of the Act requires that, beginning in the 1984 model year, all LDVs must comply with the statutory emission standards as authorized in section 202 regardless of altitude. Thus, statutory high-altitude standards would be the same numerical value as the existing low-altitude standards.

For LDTs, the Agency has the option of promulgating emission standards under the general provisions of section 202(a) of the Act. This section authorizes the Administrator to establish regulations that are necessary to protect the public health and welfare. In the 1984 model year, statutory HC and CO standards for LDTs become more stringent than in previous years. These statutory standards could also be implemented at high altitude. In this analysis, statutory high-altitude standards for LDTs are considered for implementation beginning in the 1984 model year.

The current gaseous and particulate emission standards are shown in Table II-2. Under the current Congressional mandate, it is clear that the numerical values for the LDV standards would remain unchanged regardless of the altitude at which compliance is required.

The second type of emission standards are referred to as "proportional" standards. These standards generally represent the same reduction in vehicle emissions at high altitude as the statutory standards require at low altitude. The levels of the proportional gaseous emission standards for 1984 and later model year LDVs were determined in the recent interim (1982 and 1983) high-altitude rulemaking action for an elevation of 5,300 feet.[1]

With regard to proportional gaseous emission standards for LDTs, it was previously stated that the statutory (low-altitude) light truck standards for HC and CO become more stringent in 1984. These new standards will cause manufacturers to redesign and, in turn, recertify every LDT in their product lines at low altitude. Although at the time this document is being prepared no high-altitude standards have been promulgated for 1984 and later LDTs, the Agency intends to have some type of requirement in force beginning in that year. (This is consistent with President Reagan's recent announcement

Table II-2

Current Statutory and Corresponding Proportional Emission Standards for Light-Duty Vehicles (LDVs) and Light-Duty Trucks (LDTs)

Type of Standard	Vehicle	Year of Implementation	Gaseous Standards HC (g/mi)	CO (g/mi)	NOx (g/mi)	Evap. HC[a] (g/test)	Diesel Particulate Standards (g/mi)[b]
Statutory	LDV[c]	1984	0.41	3.4	1.0	2.0	0.6
(Low-		1985	0.41	3.4	1.0	2.0	0.2
Altitude)	LDT[d]	1984	0.8	10	2.3	2.0	0.6
		1985	0.8	10	2.3	2.0	0.26
Propor-	LDV	1984	0.57	7.8	1.0	2.6	[e]
tional		1985	0.57	7.8	1.0	2.6	[e]
(High-	LDT	1984	1.0	14	2.3	2.6	[e]
(Altitude)		1985	1.0	14	2.3	2.6	[e]

[a] Evaporative emission standards do not apply (N/A) to diesel-powered vehicles. The low volatility of diesel fuel produces few evaporative emissions.
[b] Particulate standards apply only to diesel-powered vehicles and trucks.
[c] Light-duty vehicle.
[d] Light-duty truck.
[e] No particulate standards have been set for high-altitude vehicles or trucks (see Chapter X).

concerning regulatory relief for the automobile industry.) Regardless of the stringency of such standards, manufacturers will have to develop and certify their newly designed LDTs at high altitude also.

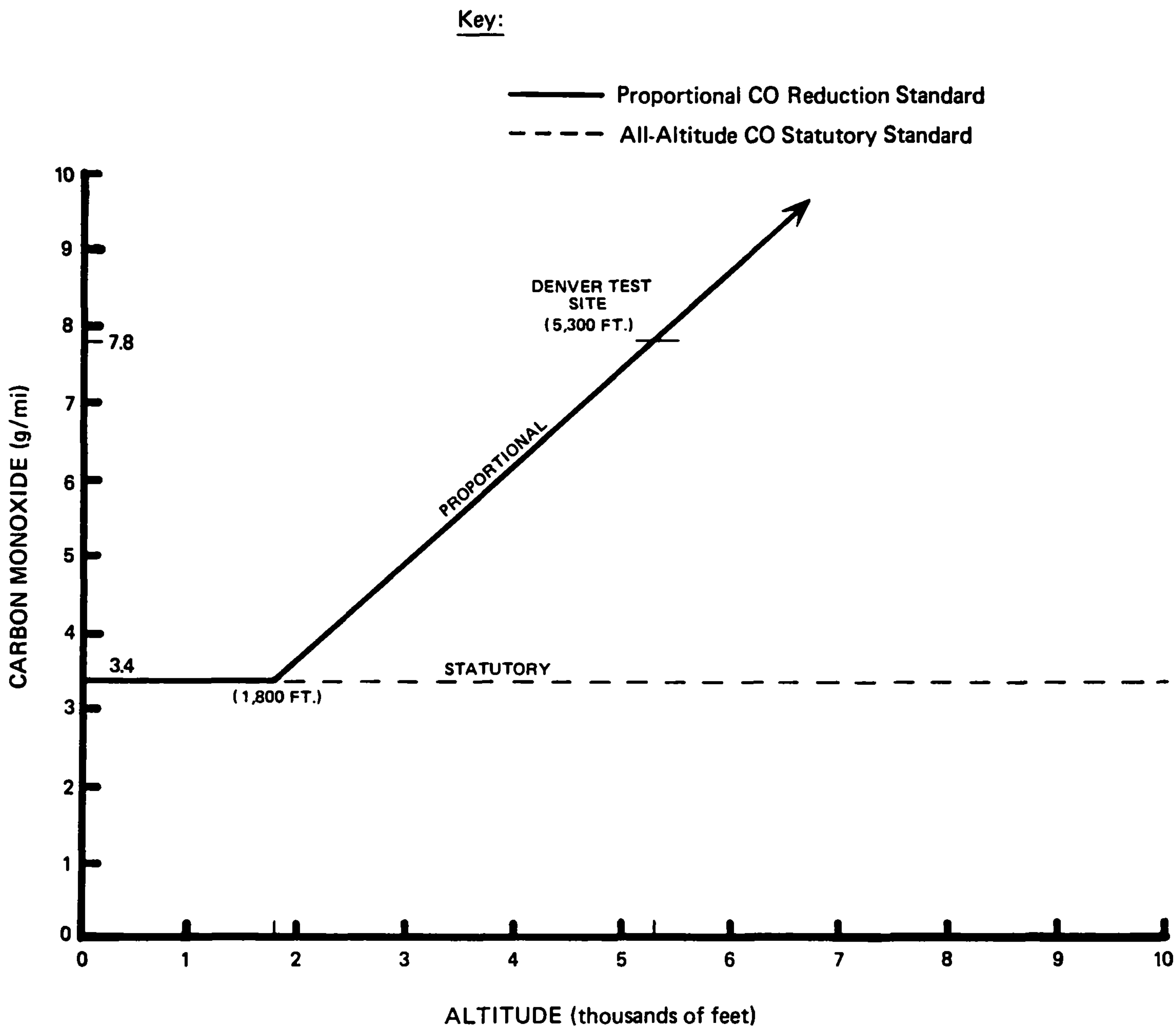
EPA believes that the incremental cost of complying with proportional standards, which are based on the more stringent 1984 low-altitude LDT standards, should be relatively inexpensive. This should be true because compliance with the interim standards for LDTs is relatively inexpensive and those standards reflect approximately the same level of high-altitude control technology as would be required to meet the more stringent proportional standards beginning in 1984 for LDTs.[3,5] Therefore, proportional control relative to the new statutory standards should be cost effective. EPA determined the proportional gaseous emission standards for LDTs that are equivalent to the 1984 statutory requirements in the proposal for interim high-altitude regulations.[5] Thus, proportional high-altitude standards for gaseous emissions have already been established for LDVs and LDTs.

The interim high-altitude rulemaking action, however, did not consider particulate emissions from diesel-powered vehicles. Such standards now exist for both LDVs and LDTs under the authority of section 202(a) of the Act. Although the Act does not specify a procedure for setting proportional particulate standards, if the guidelines of section 202(f) for determining proportional gaseous emission standards were followed, particulate standards would be based on high-altitude emissions from diesel-powered vehicles manufactured during the 1970 model year. Such a study has never been performed. Even if it were, it would be of limited usefulness since the great majority of diesel-powered vehicles sold today were not produced in 1970. (Only a few of diesel models were available in 1970 and these were sold in relatively small quantities.) Unfortunately, no comprehensive study of the effect of high altitude on later model year diesels is available, either. Thus, proportional particulate standards will have to be estimated from the available data. This will be done in Chapter X.

Table II-2 summarizes the proportional gaseous emission standards which are used in analyzing fixed-point scenarios. For continuous scenarios, the numerical value of the proportional standard is different at each elevation. Since emission standards have only been determined for two elevations at this time (i.e., low altitude up to 1,800 feet and high altitude at 5,300 feet), the proportional standard at any other altitude can be found by assuming that a linear relationship exists between elevation and vehicle emissions. In other words, the proportional standard for altitudes between 1,800 feet and 5,300 feet lies along a straight line between the known emission standards at these two altitudes. This is graphically depicted for CO in Figure II-1, which also shows that the

FIGURE II-1

Graphic Example of All-Altitude and Proportional Reduction Standards Based on Current Automobile Requirements



proportional standard for altitudes above 5,300 feet is found by extending the line to the desired elevation.

The statutory CO standard is included in Figure II-1 for comparison. As shown, this type of standard represents an increasingly more stringent requirement at higher elevations when compared to the proportional standard.

D. High-Altitude Exemptions

It may be technically difficult to modify some vehicles to meet the various high-altitude standards shown in Table II-2 in a cost-effective manner or, as might occur in some instances, in a safe manner. These vehicles generally should be low-power, high fuel economy cars and trucks that perform acceptably at low altitude but poorly at higher elevations. Their poor performance arises from using smaller engines and low numerical axle ratios for improved fuel economy.

The less dense air at high altitude provides less oxygen (per unit of volume) to combust the fuel/air mixture in the engine's cylinders. This reduces the engine's ability to produce power. Some of this lost power, however, can be recovered by adding extra fuel to the engine through the power-enrichment system of the fuel-metering device. This results in a richer fuel/air ratio which, in turn, produces more power when it is burned. Unfortunately, richer fuel/air mixtures also produce excessive HC and CO emissions.

At low altitude, the deleterious effects on emissions from using power-enrichment rarely affects compliance with emission standards because the system is seldom engaged during the Federal Test Procedure (FTP), the test used to measure compliance. Power-enrichment operation is increasingly more frequent as altitude increases and drivers attempt to compensate for lost vehicle performance. Therefore, it can become much more difficult to control emissions and maintain acceptable vehicle operation at successively higher elevations.

There are two principal reasons for exempting such low-power vehicles from high-altitude standards, as briefly alluded to above. The first reason is to reduce the economic burden of the standards by saving manufacturers the needless expense of developing and certifying these vehicles for high altitude when they are either not normally sold there or are sold there in only small numbers because of their poor or unacceptable performance. For this reason, exemption criteria were included in the 1982 and 1983 high-altitude regulations.

The second and more compelling reason primarily affects control strategies that require vehicles to meet the stringent statutory standards at higher elevations without modification. For many low-power vehicles, compliance with these standards at high altitude may degrade performance to such low levels that the vehicles may actually become unsafe to use at higher elevations. Rather than market such potentially unsafe vehicles, manufacturers would probably remove them from the national market. This would adversely affect model availability and fuel economy at low altitude, which accounts for about 97 percent of the total market.

Regardless of the reason for exemptions, such vehicles would not be allowed to be sold in high-atitude areas with air quality problems in order to maximize the environmental benefits of the regulations. In most cases, however, these exemptions would not seriously affect model availability at high altitude because such low-power vehicles would not normally be sold in these areas, as noted above.

For theses reasons, this analysis evaluates exemptions based on performance. As more information becomes available, however, it may actually be preferable to implement other types of exemption schemes. For example, waivers could be granted to certain vehicles that could then be sold at high altitude. Such an important determination, however, is not within the scope of this study. It is more appropriately made as part of the rulemaking process used to establish any new regulations, depending on available statutory authority.

At present, estimating the number of exemptions that may be required in the 1984 high-altitude regulations is speculative. Not enough data are available from the 1982 and 1983 high-altitude program to estimate the number of vehicles needing exemptions accurately. In addition, fuel economy pressures are forecast to significantly change to the motor vehicle fleet in the future. Such changes may include continued downsizing (weight reduction) of the fleet, which could manifest itself in the need for more exemptions than may currently be expected. Conversely, as described in Chapter III, EPA estimates that to comply with the current statutory (low-altitude) emission standards, vehicle manufacturers will increasingly rely on more sophisticated electronic control systems having the inherent capability to significantly control emissions at high altitude significantly with little or no modification. Such systems could reduce the need for exemptions in the future. In fact, the beneficial aspects of these new emission control devices may more than offset the negative effects that vehicle downsizing has on exemptions.

The following estimates for the various control scenarios are, therefore, based primarily on: 1) experience in developing the 1982 and 1983 high-altitude standards, 2) the knowledge that at successively higher elevations the technical difficulty of achieving the standards is greater, and 3) the fact that compliance with more stringent standards is more difficult to achieve (i.e., statutory versus proportional standards, or continuous versus fixed-point requirements).

EPA estimates the following maximum (i.e., worst case) volume of exemptions for each scenario:

1. Five (5) percent of the fleet for scenarios with fixed-point proportional standards;

2. Ten (10) percent of the fleet for scenarios with continuous proportional standards up to 6,000 feet;

3. Fifteen (15) percent of the fleet for scenarios with fixed-point statutory standards;

4. Twenty-five (25) percent of the fleet for scenarios with continuous statutory standards up to 6,000 feet;

5. Forty (40) percent of the fleet for scenarios with continuous proportional standards up to 10,200 feet; and

6. Sixty (60) percent of the fleet for scenarios with continuous statutory standards up to 10,200 feet.

III. IDENTIFYING AND SELECTING THE CONTROL SCENARIOS

This report could analyze 12 possible scenarios, as presented in Table II-3. They are combinations of the four variables just discussed: 1) continuous or fixed-point certification requirements, 2) the maximum elevation of control, 3) the levels of the standards, and 4) the possibility for exemptions.

A. Eliminating Five Scenarios

Of the 12 scenarios that have been identified, several can be discarded without compromising the analysis. All of the scenarios requiring emission control up to 10,200 feet are likely candidates for elimination. The air quality information previously presented in this chapter showed that no future NAAQS violations are likely in areas above approximately 6,000 feet. In addition, only one of the four possible scenarios with a ceiling of 10,200 feet need be retained to represent what is widely believed to be the most stringent of the possible interpretations of the Congressionally mandated program. This scenario is shown as Number 1 in Table II-3 and requires continuous statutory standards without exemptions and a ceiling of 10,200 feet. Finally, the continuous statutory and continuous proportional standards that may require exempting 60 and 40 percent, respectively, of the motor vehicle fleet are

Table II-3

Potential High-Altitude Control Scenarios

Number	Description
1-4	Continuous Statutory Standards: 1. Without exemptions and a ceiling of 10,200 feet. 2. With exemptions (60 percent) and a ceiling of 10,200 feet. 3. Without exemptions and a ceiling of 6,000 feet. 4. With exemptions (25 percent) and a ceiling of 6,000 feet.
5-8	Continuous Proportional Standards: 5. Without exemptions and a ceiling of 10,200 feet. 6. With exemptions (40 percent) and a ceiling of 10,200 feet. 7. Without exemptions and a ceiling of 6,000 feet. 8. With exemptions (10 percent) and a ceiling of 6,000 feet.
9-10	Fixed-Point Statutory Standards (certification at 5,300 feet): 9. Without exemptions. 10. With exemptions (15 percent).
11-12	Fixed-Point Proportional Standards (certification at 5,300 feet): 11. Without exemptions. 12. With exemptions (5 percent).

not viable options because they could severely restrict model availability at higher elevations (above 1,800 feet). This would negate the reason Congress vacated the 1977 high-altitude standards. Therefore, three control scenarios are eliminated from further study:

1. Continuous statutory standards with exemptions and a ceiling of 10,200 feet (Number 2 in Table II-3);

2. Continuous proportional standards without exemptions and a ceiling of 10,200 feet (Number 5 in Table II-3); and

3. Continuous proportional standards with exemptions and a ceiling of 10,200 feet (Number 6 in Table II-3).

Two additional scenarios can also be eliminated. The fixed-point proportional standards are evaluated as a continuation of the 1982 and 1983 high-altitude regulations. Since exemptions already have been found to be necessary in these regulations, it is likely that exemptions will remain necessary in 1984 and later model years. Also, the fixed-point statutory standards are considered in this report primarily to represent a variation of the 1982 and 1983 high-altitude regulations. As such, it is relevant to consider implementing statutory standards at 5,300 feet with exemptions, while retaining the provision of the 1982 and 1983 program that allows vehicles to be specifically modified for sale at high altitude (this latter provision would likely require statutory changes). This scenario is shown as Number 10 in Table II-3. Thus, the two scenarios which can be eliminated are:

1. Fixed-point proportional standards without exemptions (Number 9 in Table II-3); and

2. Fixed-point statutory standards without exemptions (Number 11 in Table II-3).

B. Categorizing the Remaining Scenarios

With this elimination, seven scenarios remain to be analyzed. For clarity, the scenarios can be grouped into four broad categories with specific variations listed under each category. This hierarchy is presented in Table II-4 and will be referred to throughout this document.

One further remark concerning the analytical methodology of the report is necessary before proceeding with the analysis. All alternative strategies are evaluated by comparing them with a continuation of the 1982 and 1983 (interim) high-altitude standards. EPA believes that the value of these interim regulations was proved during the recent final rulemaking process, and that little benefit would result from

Table II-4

Control Scenarios Selected for Evaluation

1. Continuous Statutory Standards:

   a. Without exemptions and a ceiling of 10,200 feet.[a]
   b. With exemptions and a ceiling of 6,000 feet.
   c. Without exemptions and a ceiling of 6,000 feet.

2. Fixed-Point (5,300 feet) Statutory Standards, with exemptions.

3. Continuous Proportional Standards:

   a. With exemptions and a ceiling of 6,000 feet.
   b. Without exemptions and a ceiling of 6,000 feet.

4. Fixed-Point (5,300 feet) Proportional Standards, with exemptions (referred to as the "base" scenario).

[a] Scenario 1a appears to be consistent with the most stringent interpretation of section 206(f)(1) of the Act.

again presenting the detailed analyses that support those standards.[3,7,8] The technical requirements of fixed-point proportional standards were found to be readily feasible. In fact, some vehicles could already comply with the emission levels with no changes to their original low-altitude hardware designs or control settings. A significant air quality improvement was also forecast to occur by reducing the pollution from 1982 and 1983 high-altitude vehicles. For example, in Denver, Colorado, the total HC emissions would be reduced by up to 1.0 percent and CO emissions would be reduced up to 3.4 percent. The proportional standards were also found to be cost effective, at $393 per metric ton for HC and $12 per metric ton for CO. Therefore, through the remainder of the analysis the fixed-point proportional standards are referred to as the "base" scenario (Table II-4), and are specifically analyzed in this report as is required to complete the analysis of alternative control scenarios. Appendix I contains more information on the costs and benefits of the base scenario.

References

1. "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines Final High-Altitude Emission Standards for 1982 and 1983 Model Year Light-Duty Motor Vehicles," U.S. EPA, 45 FR 66984, October 8, 1980.

2. "High Altitude and Street Canyon Carbon Monoxide Monitoring in Region VIII During the Winter of 1978-79," U.S. EPA, Region VIII, Denver, CO.

3. "Final Regulatory Analysis - Environmental and Economic Impact Statement for the 1982 and 1983 Model Year High-Altitude Motor Vehicle Emission Standards," U.S. EPA, OANR, OMS, ECTD, SDSB, October 1980.

4. "Carbon Monoxide Data - High Altitude, January-March 1980," Motor Vehicle Manufacturer's Association, April 1980.

5. "Proposed High-Altitude Emission Standards for 1982 and 1983 Model Year Light-Duty Motor Vehicles," U.S. EPA, 45 FR 5988, January 24, 1980.

6. Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines: Gaseous Emission Regulations for 1985 and Later Model Year Light-Duty Trucks and 1986 and Later Model Year Heavy-Duty Engines," U.S. EPA, OANR, OMS, ECTD, SDSB, 45 FR 5838, January 19, 1981.

7. "Summary and Analysis of Comments on the Notice of Proposed Rulemaking for High-Altitude Emission Standards for 1982 and 1983 Model Year Light-Duty Motor Vehicles," U.S. EPA, OANR, OMS, ECTD, SDSB, October 1980.

8. "Technical Feasibility of the Proposed 1982-83 High-Altitude Standards for Light-Duty Vehicles and Light-Duty Trucks," U.S. EPA, OANR, OMS, ECTD CTAB, August 1980.

Chapter III

Technology Assessment

I. INTRODUCTION

In this chapter, the control technology expected to be required for light-duty gasoline-fueled vehicles (passenger cars) to comply with the various high-altitude control scenarios under consideration will be discussed. In particular, the control technology required by each alternative scenario over and above that required by the base scenario will be identified. The potential control scenarios were determined in the previous chapter and are summarized below for convenience.

A. Base Scenario: Fixed-Point Proportional Standards with Exemptions

This scenario will require vehicles to comply with high-altitude standards of 0.57 g/mi HC, 7.8 g/mi CO, 1.0 g/mi NOx, and 2.6 g/test evaporative HC at only one elevation (i.e., 5,300 feet). It is essentially a continuation of the current high-altitude requirements for 1982 and 1983 model year vehicles.[1] Exemptions may be granted for certain low-power vehicles that would perform unacceptably at high altitude and that may have technical difficulty in meeting the standards cost effectively.

B. Scenario 1: Continuous Statutory Standards

This alternative scenario will require vehicles to comply with standards of 0.41 g/mi HC, 3.4 g/mi CO, 1.0 g/mi NOx, and 2.0 g/test evaporative HC (the current low-altitude standards) is required at all elevations up to a maximum altitude. This scenario is subdivided further, depending on the maximum altitude to which compliance must be demonstrated and on whether performance-based exemptions are provided.

1. 1a - Compliance required up to 10,200 feet and no exemptions allowed;

2. 1b - Compliance required up to 6,000 feet with exemptions allowed; and

3. 1c - Compliance required up to 6,000 feet and no exemptions allowed.

C. Scenario 2: Fixed-Point Statutory Standards with Exemptions

This strategy is similar to the base scenario, except that at 5,300 feet vehicles must meet the low-altitude statutory emission standards (0.41 g/mi HC, 3.4 g/mi CO, 1.0 g/mi NOx and

2.0 g/test evaporative HC) instead of the proportional standards presented in the base scenario.

D. Scenario 3: Continuous Proportional Standards

Under this control strategy, vehicles must meet standards that increase proportionally with altitude up to 6,000 feet. At 1,800 feet, the emission standards are the low-altitude standards; at 5,300 feet, they are the high-altitude standards outlined in the base scenario. The standards vary linearly in between these two altitudes and up to 6,000 feet. Like scenario 1, this scenario has two variations:

1. 3a - Exemptions are allowed.

2. 3b - No exemptions are allowed.

The above scenarios differ with respect to their basic approach to solving the high-altitude emissions problem. The base scenario and scenario 2 are termed "two-car" strategies since they allow vehicle modifications to be performed on vehicles sold for principal use above 4,000 feet. This is not the case for scenarios 1a, 1b, 1c, 3a, and 3b. Any modifications which are necessary to satisfy the high-altitude requirements in these scenarios must be performed on all vehicles regardless of the altitude at which they are sold. These scenarios are termed "one-car" strategies.

The technical analysis of the various control scenarios is presented in three separate sections. First, the effect of the reduced air density found at higher elevations on regulated gaseous emissions from current automotive systems will be discussed. In addition, the ability of current low-altitude control systems to meet the alternative standards and the techniques available to reduce high-altitude emissions will be described. Second, the requisite control technology for each scenario will be estimated. Finally, any potential adverse effects of high-altitude standards on low-altitude control technology will be assessed.

II. THE EFFECTS OF INCREASING ALTITUDE ON EXHAUST EMISSIONS

As altitude increases, the density of air decreases. In a conventional (e.g., carbureted) fuel-metering system (the type found on most cars today), the amount of fuel metered is a function of the velocity of air passing through a venturi tube. Since the density of air is lower at high altitude, the mass of air (and oxygen) corresponding to a given mass of fuel is less than that occurring at low altitude. Therefore, as altitude increases, the fuel/air ratio that enters the combustion chamber will increase, or become richer.

The production of emissions from a gasoline engine is very sensitive to this fuel/air ratio. As the ratio increases, HC and CO emissions increase markedly, because not enough oxygen is available to burn the fuel completely. At the same time, NOx emissions decrease, because the peak combustion temperature is lower with rich fuel/air mixtures. Thus, in order to meet emissions standards for HC and CO at high altitude, one of the primary considerations is to prevent excessive enrichment of the fuel/air ratio.

A. Basic Types of Exhaust Emission Control Systems

The degree to which reduced air density at high altitude affects emissions depends on the type of emission control system already on the vehicle. By 1984, nearly all light-duty gasoline-fueled vehicles will be equipped with three-way catalysts to reduce HC, CO, and NOx emissions to the current statutory levels. The term three-way comes from the fact that all three of the regulated pollutants are controlled by this catalyst.

While it is fairly easy for the catalyst to oxidize the HC and CO in the exhaust to carbon dioxide and water, it is more difficult to remove the NOx in the exhaust. Effective NOx control depends on keeping the level of oxygen in the exhaust to a fairly low level. Otherwise, any excess level of oxygen will react with the HC and CO, preventing the CO from reducing the NOx to elemental nitrogen.

One basic method for controlling the level of oxygen in the exhaust is called "feedback" (or closed-loop) control, where the oxygen level in the exhaust is measured by an oxygen sensor. The electrical signal produced by this sensor is sent to a minicomputer (microprocesser) which makes the appropriate adjustment in the fuel/air mixture setting. While requiring fairly sophisticated electronics, this type of system is fairly easy to set up to work efficiently. Also, changes in engine operating conditions due to temperature, engine wear, and, to some extent, altitude are automatically compensated for since the exhaust oxygen level is measured directly.

Due to the predominance of feedback control systems and their unique way of controlling the engine's fuel metering device, all other types of control systems can be grouped together in a single category termed "nonfeedback" (or open-loop) control systems. These systems are used on vehicles equipped with three-way catalysts and on smaller vehicles using only oxidation catalysts to control only HC and CO.

Unlike feedback systems, nonfeedback systems have no inherent ability to control the fuel/air mixture automatically (and oxygen concentration for three-way catalysts) in response to changing engine-related parameters. Instead, "fixed" settings meter the fuel into the engine.

The effect of reduced air density (i.e., high altitude) on the effectiveness of these two types of exhaust emission control systems will now be examined. The nonfeedback control systems will be examined first and the feedback control systems second. Brief discussions of the high-altitude control techniques available for each of these two types of systems will also be included.

B. Nonfeedback Control Systems

The effects of increasing altitude on exhaust emissions from typical nonfeedback systems are shown in Table III-1. The high-altitude data were obtained from emission tests conducted near Denver, Colorado at 5,300 feet. The fact that nonfeedback systems have no inherent ability to compensate for the increasingly rich fuel/air mixture at higher elevations is reflected by the significantly greater levels of HC and CO emissions at high altitude compared with their low-altitude performance. The increase for HC emissions is 31 to 625 percent, and for CO emissions, 195 to 924 percent. Emissions of NOx generally decrease by 4 to 75 percent, although for one vehicle they actually increased.

There are several conventional methods to compensate for the increasingly rich fuel/air ratio at high altitude. Some of these methods were used to comply with the initial high-altitude emission standards, which were only in effect for the 1977 model year. Manufacturers might again use such techniques, in varying degrees of sophistication, to comply with the requirements of the various control scenarios being analyzed here. In general, for the 1977 program, manufacturers used different carburetors on their high-altitude vehicles that were designed for the air densities found at higher elevations.

These carburetor changes were generally accomplished by either a different jet size to reduce the amount of fuel metered, or by providing an air bleed separate from the main fuel metering system. The air bleed allowed fresh air to enter the intake manifold without introducing additional fuel. It could be introduced manually at high altitude, for example, by opening a separate air bypass with a screwdriver. However, the same air bleed (or bypass) could be automatically opened or closed by using an aneroid control device. An aneroid is a pressure-sensing device usually consisting of a diaphragm that expands with decreasing pressure and contracts with increasing pressure. The diaphragm can be constructed so that when it expands at high altitude it forces the air bleed to open, allowing additional air to flow into the engine. At low altitudes, the diaphragm keeps the air bleed closed.

Aneroids also can be employed to control the operation of essentially any other parameter on the vehicle. For example,

Table III-1

Low- and High-Altitude Emissions From Various Nonfeedback Vehicles for Past and Present Model Years

Manufacturer	Car	Low Altitude (g/mi) HC	CO	NOx	High Altitude (g/mi) HC	CO	NOx	Comment
Nissan[2]	510	0.34	4.1	0.51	0.94	31.5	0.13	[a]
	210	0.34	2.4	0.98	0.51	12.9	0.94	[a]
Ford [2]	4.2L	0.39	1.9	0.87	0.51	5.6	0.57	[a,b]
Subaru[3]	97 CID	0.89	4.2	3.09	1.54	8.0	2.63	[a,c]
Volkswagen[3]	97 CID	0.16	2.9	0.35	1.16	29.7	1.14	[c,d]

[a] Carburetor system.
[b] Values include assigned deterioration factors of 1.3 for HC, 1.2 for CO, and 1.1 for NOx (Reference 4).
[c] In-use vehicle tests.
[d] Fuel injection system.

aneroids can be adapted to adjust continuously (or in steps) the operation of the exhaust gas recirculation (EGR) system, the spark advance, the transmission shift points, the flow from the air injection system into the exhaust, the deceleration valve calibration, and many other engine parameters as well.

C. Feedback Control Systems

As discussed earlier, the feedback control system uses an oxygen sensor to measure the concentration of oxygen in the engine exhaust which then sends an electrical signal to an electronic control unit indicating whether the system is operating too rich (too much fuel) or too lean (not enough fuel). The control unit adjusts the amount of fuel being metered accordingly. Thus, the sensor will automatically compensate for the natural enrichment of the fuel/air mixture when a vehicle is driven at high altitude.

However, this system has two basic limitations in its ability to maintain good air/fuel ratio control at all altitudes. The first occurs during certain portions of vehicle operation in which the feedback system operates in what is termed "open-loop." This means that the feedback characteristic of the system is not functioning, and the oxygen sensor is not controlling the amount of fuel being metered into the system. Open-loop operation commonly occurs during two types of vehicle operation. The first type occurs when a vehicle is cold started and requires a richer than normal fuel/air ratio in order to operate. This continues until the engine is warmed-up. The second type is wide-open throttle (WOT) operation (or nearly wide-open throttle operation), where a very rich fuel/air ratio is required to increase engine power. This technique is called power enrichment. In both cases, the enrichment at high altitude will be greater than at low altitude, and CO and HC emissions will increase. Therefore, additional altitude compensation must be provided for these particular modes of operation of the vehicle to assure maximum emission control.

Two basic types of electronic fuel metering devices that may be used in the future are carburetor systems or fuel injection systems. Both of these feedback systems may function much like the system on a nonfeedback controlled vehicle during open-loop operation where the fuel metering setting is fixed. Under these conditions the fuel/air mixture is significantly richer at high altitude than at low altitude. Unless some altitude compensation is added during these open-loop periods, HC and CO emissions will increase substantially.

Some electronic fuel injection systems (e.g., General Motors' throttle body injection (TBI)) are currently more sophisticated than their carbureted counterparts during open-loop operation. Such fuel injection systems may continue to monitor a variety of engine sensors (other than the oxygen sensor) to maintain the correct fuel/air mixture entering the engine.[5] More specifically, the electronic microprocessor of these systems in effect "senses" the atmospheric pressure to determine the engine's fuel requirement. This automatically compensates for the effects of high altitude, since the fuel metering system will account for the lower atmospheric pressures at higher elevations.

It is possible, however, that even TBI systems may not be fully compensating during open-loop operation. For example, the microprocessor may be incapable of fully using the range of sensor outputs that would accompany not only the normal engine operating regime, but also the added pressure variation because of changes in elevation. Also, the pressure sensors themselves may lack an adequate response range to account for the pressure variations. Finally, it is possible that all future TBI systems may not include such sophisticated fuel management because of cost considerations. Any of these circumstances would make these systems behave more like the less sophisticated carbureted feedback systems during open-loop operations. The fuel/air mixture would likely become richer with increasing altitude. As a result, hydrocarbons and CO will increase during these open-loop periods without some type of additional compensation.

The second limitation of these feedback control systems to compensate for changes in altitude pertains predominately to closed-loop operation and is related to the basic design of the fuel-metering system itself (i.e., the carburetor or fuel injection). Feedback carburetors typically incorporate two circuits to meter fuel. One circuit, the lean authority limit, meters fuel at a set air/fuel ratio through a fixed orifice, while the other circuit, the controllable portion, meters an increased level of fuel. The amount of additional fuel metered through this controllable circuit is varied to maintain the air/fuel ratio at the proper level as dictated by the oxygen sensor. As the density of air decreases at higher elevation, the controllable portion of the fuel flow is cut back to maintain the proper air/fuel ratio.

This compensation is limited by the absolute amount of fuel metered through the lean authority limit, which is fixed. Once this limit is reached, the ability to compensate for altitude disappears, and HC and CO emissions will increase with further increases in altitude. The degree to which the lean authority remains rich at high altitude will determine the degree to which emissions increase. Therefore, to compensate for higher elevations, the lean authority limit must not be reached before the maximum altitude of control.

For some fuel injection systems, an analogous situation exists. The fuel injectors used in these systems also have mechanical limitations regarding the minimum amount of fuel that can be metered into the engine.[5] As previously discussed for carburetors, this could affect the ability of the system to adequately lean the fuel/air mixture and control HC and CO emissions at high altitude.

The effects of increasing elevation on the emissions from vehicles equipped with various feedback control systems are shown in Table III-2. The inherent ability of these systems to compensate for the effects of altitude at least partially is readily apparent when the data in Table III-2 are compared to the data listed in Table III-1 for nonfeedback systems. The low- and high-altitude results for feedback systems show changes of about -11 to 110 percent for HC, -5 to 376 percent for CO, and -8 to 31 percent for NOx. These low-to-high altitude differences are significantly less than those previously cited for nonfeedback systems. In addition, the throttle body fuel injection systems shown in this table clearly demonstrate the ability to control emissions at higher elevations, although some increase still occurs.

It is unclear, however, if these systems, which are currently produced in limited numbers, characterize those which will be used on many future vehicles. If future throttle body systems are less sophisticated than the few for which data are available (Table III-2), the emissions increase with altitude may be significantly greater and could even be as poor as that for the Nissan electronic fuel injected vehicle.

The absolute emission levels shown in Table III-2 at high altitude are also important to note. Many feedback control systems already meet the proportional standards of 0.57 g/mi HC, 7.8 g/mi CO, and 1.0 g/mi NOx. Some systems also meet the statutory standards of 0.41 g/mi HC, 3.4 g/mi CO, and 1.0 g/mi NOx at high altitude.

As previously mentioned, the greater emissions from feedback systems at high altitude result from inadequate fuel metering compensation when the fuel-metering system is operating in the "closed-loop" mode, or from an increasingly rich fuel/air mixture when the system is operating in "open-loop" modes (e.g., wide-open throttle and cold-start operation). For the feedback systems that will be used in the 1984 and later model years, the rich fuel/air mixtures during "open-loop" operation will be the biggest roadblock to compliance with the various scenarios. As with nonfeedback systems, there are various ways to reduce emissions from feedback systems. These procedures and the requisite hardware for each scenario will be outlined in the next section. Generally, however, the open-loop fuel settings will have to be recalibrated either by changing the electronic module of the microprocessor of high-altitude vehicles, by expanding the capability of the existing electronics to adjust the open-loop

Table III-2

Summary of Unmodified Feedback Systems for the 1981 Model Year

Manufacturer	Car	Low Altitude (g/mi) HC	Low Altitude (g/mi) CO	Low Altitude (g/mi) NOx	High Altitude (g/mi) HC	High Altitude (g/mi) CO	High Altitude (g/mi) NOx	Comment
Nissan[2]	280ZX	0.31	2.1	0.47	0.65	10.0	0.46	[a]
Ford[6]	2.3 L				0.53	5.7	0.8	[b]
	5.8 L				0.30	2.3	1.6	[b]
					0.24	2.4	1.6	[b]
	5.0 L				0.35	3.6	0.5	[b]
					0.37	4.4	0.5	[b]
GM[6]	2.5 L				0.57	6.6	0.8	[b]
					0.60	7.5	0.9	[b]
	3.8 L				0.41	4.4	0.8	[b]
					0.46	4.6	0.8	[b]
	4.3 L				0.52	4.7	0.7	[b]
					0.53	4.5	0.8	[b]
	4.9 L				0.35	3.5	0.8	[b]
					0.46	4.2	0.7	[b]
	4.4 L				0.52	9.4	0.6	[b]
					0.55	8.8	0.6	[b]
	5.5 L				0.29	2.7	0.7	[b]
					0.40	3.8	0.8	[b]
	5.7 L				0.24	1.9	0.5	[b]
					0.34	2.8	0.6	[b]
Chrysler[2]	1.7 L	0.17	1.62	0.88	0.26	4.10	0.88	[b,c]
	2.2 L	0.13	0.78	1.38	0.73	6.65	1.58	[b,c]
	225CID	0.29	1.94	0.85	0.74	4.34	0.90	[b,c]
GM[7]	2.5 L	0.36	0.44	0.74	0.32	0.80	0.97	[c,d]
	2.5 L	0.36	2.00	0.72	0.42	3.19	0.92	[c,d]
	2.5 L	0.17	1.58	0.52	0.25	2.15	0.48	[c,d]
	4.9 L	0.48	2.14	0.85	0.49	4.78	0.80	[c,d]
	4.9 L	0.34	2.38	0.60	0.38	2.26	0.77	[c,d]
Volvo[6]		0.16	2.15	0.39	0.31	2.86	0.32	[d]

[a] Electronic fuel injection system.
[b] Carburetor system.
[c] Values include assigned deterioration factors of 1.3 for HC, 1.2 for CO, and 1.1 for NOx (Reference 4).
[d] Throttle body injection system.

fuel/air mixture, or by adding a pressure sensing device which will automatically allow the microprocessor to adjust the open-loop calibration for changes in altitude.

III. EFFECTS OF INCREASING ALTITUDE ON EVAPORATIVE EMISSIONS

Evaporative emissions consist of hydrocarbon (HC) vapors that escape (evaporate) primarily from the fuel tank and the carburetor bowl of a gasoline-fueled vehicle. They are, therefore, relatively independent of the type of exhaust emission control system (feedback or nonfeedback) used on the vehicle. Evaporative emissions are affected by the distillation temperature curve of the fuel. At higher elevations where atmospheric pressure is less, the curve is lowered so that the fuel becomes relatively more volatile and evaporation increases.

Evaporative emissions are currently controlled by routing the fuel vapors from the carburetor and fuel tank into the intake manifold of the engine when the vehicle is in operation. In this way, the vapors are burned in the combustion chamber along with the main fuel/air mixture. When the vehicle is not operating, the fuel vapors are routed to a charcoal-filled canister where they are stored until the engine is restarted. At that time, the vapors are transferred to the intake manifold and are burned in the combustion chamber. Unless the capacity and purge rate of the canister are properly designed, excess evaporative emissions may result at high altitude.

IV. TECHNOLOGIES NECESSARY FOR COMPLYING WITH THE SCENARIOS

The emission control devices and techniques necessary to comply with the various scenarios will be outlined in this section. The first step in this task will be to explain the methodology used to determine the techniques required for compliance. The second step will be to actually estimate the requisite emission control hardware which may be necessary to comply with the control scenarios that provide exemptions for low-power-to-weight vehicles (the base scenario and scenarios 1b, 2, and 3). The third step will be to estimate the requisite hardware which may be necessary for vehicles to meet the control scenarios not providing such exemptions (scenarios 1a, 1c, and 3b).

A. Methodology

The feasibility of meeting high-altitude standards involves several significant issues. One of the most important is that whatever the solution, it must be acceptable in terms of its social, environmental and economic impacts. Some ways of achieving the high-altitude standards may be environmentally and technically sound, but unacceptable because of their social or economic impacts. Therefore, some judgment has been applied at an early stage in an effort to restrict the alternative technologies to only those with the potential to be environmentally, technically, socially, and economically acceptable.

The technical analysis was limited to the use of conventional power-plant systems. No exotic technology was considered, since such applications would be unavailable in the immediate future. Some conventional means of meeting high-altitude standards also were excluded because of their potential for significant adverse energy and economic impacts on the national automotive fleet. While no guarantees can be made that some vehicles sold at low altitude will not be adversely affected by the high-altitude requirements, there are ways to mitigate this prospect, and the control hardware for each scenario has been chosen with this in mind. For instance, with respect to the standards that are continuous with altitude, any significant increase in the noble metal loading of catalysts beyond that required to meet the standards at low altitude was rejected. Among other things, the high cost of such metals (platinum, palladium, and rhodium) would easily preclude high-altitude standards from being cost effective. (This is not to imply that the high-altitude requirements could be met in every case simply by increased catalyst loading.)

Other more conventional means of complying with high-altitude standards were also rejected if they would need to be implemented on all vehicles (continuous strategies). Increases in engine size or drive axle ratio that could be used to effectively increase the power-to-weight ratio of low-power vehicles are among these techniques. Although these techniques would reduce the time spent at or near wide-open throttle, thereby reducing the overly-rich mixtures associated with power enrichment operation, they could also increase fuel consumption throughout the nation by eliminating the more fuel economic, smaller displacement engines or lower numerical axle ratios at low altitudes. Of course, manufacturers might be able to recover that lost fuel efficiency through such other, unrelated means as weight reduction, but such programs would be very costly and their cost would have to be considered a consequence of high-altitude control. By assuming that these options would be unacceptable, this analysis focused on only the more likely and, therefore, reasonable emission control technologies.

The preferred approach in conducting a technological assessment of any emission requirement is to use actual test data. However, since Congress enacted the Clean Air Act Amendments of 1977, the automotive industry has reported very little development data that demonstrate the capability of current or future emission control systems to abate gaseous pollutants significantly at higher elevations. This limited amount of testing information prevents identifying the requisite exhaust emission control hardware for each scenario based only on empirical data. In addition, no development data have been submitted regarding the statutory evaporative emission standards. When such data are lacking, the types of systems required must be chosen based on engineering judgment.

In addition, all of the information that is available was obtained from tests conducted at Denver, Colorado's altitude of approximately 5,300 feet. While tests at this altitude are useful in characterizing emission performance at 6,000 feet because of the relatively small difference in elevation, the data cannot be extrapolated to characterize emission performance at 10,200 feet. In these cases, technical judgment must be used to estimate emission control requirements. Also, no emission tests have been conducted to demonstrate a control technology's ability to compensate continuously for changes in altitude and still meet the appropriate standards. This should not be a serious fault, however, since the data collected at 5,300 feet can easily be extrapolated to characterize the continuously applicable standards. The same parameters that must be recalibrated to comply with a fixed-point standard can be made to vary continuously with altitude by changing the electronics, adding an aneroid, and using a servo motor.

Rather than attempt to specify the requisite control hardware for each individual manufacturer, a task that would be impossible given the limitations of the data base, vehicle types will be grouped according to the design of their control system and general control techniques will be selected which have a high probability of achieving the desired emission levels. Of course, implicit in this approach is that some individual systems will cost more or less than the generic system used in the analysis. Also, the hardware estimates are based on EPA's projections of the 1984 and later fleet mix of fuel-metering devices.[8] These estimates are, in turn, based on statements from various manufacturers regarding their future product plans. Because of the current state of the automotive industry, however, considerable uncertainties exist with these projections.

B. Technology Required for the Scenarios with Exemptions

The scenarios providing low-performance exemptions are 1b, 2, 3a, and the base scenario. The existing exhaust emission control systems fall into three basic categories: 1) those that will not require modification to meet high-altitude requirements, 2) feedback systems that will require modification, and 3) nonfeedback systems that will require modification. Each of these three basic types will be discussed separately in relation to their ability to meet the increasingly stringent proportional and statutory exhaust emission standards. This discussion will be followed by a brief analysis of the control hardware required to meet the proportional and statutory evaporative emission standards. Evaporative systems can be estimated independently from the required exhaust emission systems.

1. Systems Requiring No Modification

As previously stated, some emission control systems that were originally designed for compliance with low-altitude standards also have the ability to meet the proportional and statutory high-altitude standards. For example, with respect to current (1981) nonfeedback systems, the Ford vehicle in Table III-3 met the proportional standards with no known modifications. However, since nonfeedback systems do not have the inherent ability to compensate for changes in altitude, the resulting excessively rich mixture at high altitude should prevent all but a very few vehicles from meeting the high-altitude standards. Thus, the Ford vehicle's compliance is considered the exception rather than the rule. The opposite is true for unmodified feedback vehicles. Table III-2 shows that many of these systems met the proportional standards and that a few of the GM and Volvo systems even complied with the statutory standards at high altitude.

Feedback systems have the inherent ability to compensate for changes in altitude by automatically adjusting the fuel/air mixture. In the 1982 and 1983 high-altitude standards rulemaking action,[1] EPA determined that about 78 percent of the feedback systems should be capable of meeting the proportional standards without modification, since they already appear to possess an adequate range of adjustability. No better estimate regarding the number of future feedback systems which may comply with proportional standards without modification is available. Therefore, this percentage is assumed in this study to characterize both fuel injected (i.e., throttle body injection) feedback systems and carbureted feedback systems. These systems are expected to account for 59 percent and 10 percent, respectively, of the total motor vehicle fleet. As shown in Table III-4, the resulting market shares are used in the base scenario and also in scenario 3a since these feedback systems compensate continuously for altitude as well as at a fixed point of 5,300 feet.

Even though a few of the vehicles in Table III-2 with unmodified feedback systems were able to meet the statutory standards at high altitude, EPA has estimated that no unmodified feedback systems will be certified to these emission levels in scenarios 1b and 2. The rationale for this estimate is included in the following discussion of modified feedback systems.

Table III-3

Summary of Unmodified Nonfeedback Systems for the 1981 Model Year

Manufacturer	Car	Low Altitude (g/mi) HC	CO	NOx	High Altitude (g/mi) HC	CO	NOx	Comment
Nissan[2]	510	0.34	4.1	0.51	0.94	31.5	0.13	[a]
	210	0.34	2.4	0.98	0.51	12.9	0.94	[a]
Ford[2]	4.2L	0.39	1.9	0.87	0.51	5.6	0.57	[a,b]

[a] Carburetor system.
[b] Values include assigned deterioration factors of 1.3 for HC, 1.2 for CO, and 1.1 for NOx (Reference 4).

Table III-4

Estimated Exhaust Emission Control Requirements for Scenarios with Exemptions

Control Hardware	Scenario 1b: Continuous Statutory, 6,000 Feet W/Exemptions	Scenario 2: Fixed-Point Statutory, 5,200 Feet W/Exemptions	Scenario 3a: Continuous Proportional, 6,000 Feet W/Exemptions	Base Scenario: Fixed-Point Proportional, 5,200 Feet W/Exemptions
Nonfeedback Vehicles				
Fixed-Step Aneroid: A. Carburetor B. Power Enrichment C. EGR or air injection rate	N/A[a]	31% A,B,C	N/A	31% A
Continuous Aneroid: A. Carburetor B. Spark	N/A	N/A	31% A,B	N/A
Feedback Vehicles[b]				
Feedback Control w/Map (Three-Way Ford and Foreign Market Share)	31%	N/A	N/A	N/A
Expand Function of Existing Electronic A. Expand Capability B. Add MAP Sensor	59% (TBI) A 10% (FBC) A,B	59% (TBI) A N/A	13% (TBI) A 2% (FBC) A	13% (TBI) A

Table III-4 (cont'd)

Estimated Exhaust Emission Control Requirements for Scenarios with Exemptions

Control Hardware	Scenario 1b: Continuous Statutory, 6,000 Feet W/Exemptions	Scenario 2: Fixed-Point Statutory, 5,200 Feet W/Exemptions	Scenario 3a: Continuous Proportional, 6,000 Feet W/Exemptions	Base Scenario: Fixed-Point Proportional, 5,200 Feet W/Exemptions
Feedback Vehicles				
Change Electronic Modules (FBC Only) A. Recalibrate fuel metering B. Recalibrate fuel metering, spark, and EGR plus add MAP for fuel	N/A	10% (FBC) B	N/A	2% (FBC) A
No Change FBC	N/A	N/A	8%	8%
No Change TBI	N/A	N/A	46%	46%
Type of Strategy	One-Car	Two-Car	One-Car	Two-Car

[a] Not Applicable.
[b] FBC means nonfeedback carburetor systems.
TBI means throttle body injection feedback systems.

2. Feedback Systems Requiring Modification

Some feedback systems will require modification to meet either the proportional or statutory standards. Table III-5 and Figure III-1 present data on systems with varing degrees of modification. The emission levels in Table III-5 are representative of recalibrating (leaning) the fuel/air mixture during the cold-start portion of the test cycle when the systems are operating in the open-loop mode (i.e., the oxygen sensor is not functioning to control the fuel/air ratio entering the combustion chamber).

Figure III-1 presents the available data on vehicles that have had more significant modifications to their feedback emission control systems than the vehicles listed in Table III-5. These tests were conducted in an attempt to achieve sea level emission performance at high altitude. Before discussing the results shown in Figure III-1 further, an explanation of the GM test program which generated the results is necessary. The test results were obtained using three-way catalyst vehicles and, therefore, are not representative of the three-way-plus-oxidation catalyst vehicles that were certified by GM for the 1981 model year. For this reason, it is not surprising that test vehicles in Figure III-1 failed to meet even the statutory low-altitude standards. Also, modifications were apparently made to the vehicles after the low-altitude tests had been conducted. This prevents a direct comparison between emissions performance at sea level and high altitude. The high-altitude modifications included adding EGR at wide-open throttle for all vehicles, disconnection of the power enrichment circuit for all vehicles and recalibration of the open-loop, cold-start operating mode for some vehicles.[7]

Generally, comparing the low- and high-altitude results presented in Table III-5 shows that the vehicles with only recalibrated cold start fuel/air mixtures experience rather small emission increases of up to 0.2 g/mi HC, 3 g/mi CO, and 0.4 g/mi NOx. These increases should be able to be reduced or eliminated by compensating other engine operating parameters for the effects of altitude (e.g., fuel/air ratio wide-open throttle (WOT), spark timing, and exhaust gas recirculation (EGR)).

The vehicles depicted in Figure V-1 show mixed results, but some vehicles are definitely below the corresponding low-altitude levels. This shows that such extremes as disconnecting the power enrichment circuit can be very effective. Both Table III-5 and Figure III-1 indicate that controlling HC and CO emissions at high altitude may increase NOx to unacceptable levels, even when EGR is used at WOT.

Looking specifically at only the high-altitude data, the effectiveness of controlling emissions to the proportional

Table III-5

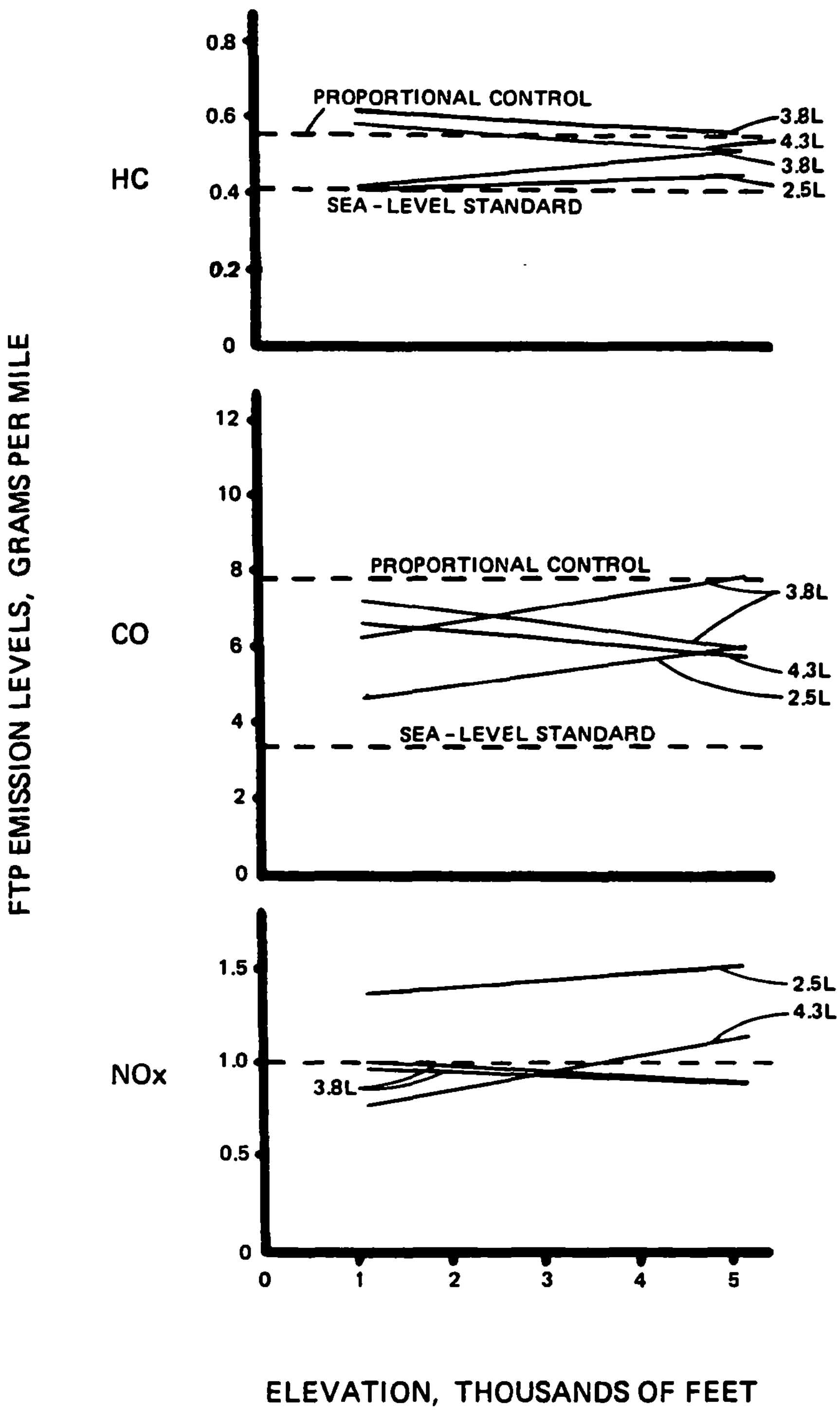
Modified Feedback Systems

Manufacturer	Car	Low Altitude (g/mi) HC	CO	NOx	High Altitude (g/mi) HC	CO	NOx	Comments
JRT[6]	122 CID				0.40	7.34	0.45	[a,b]
					0.55	7.34	0.45	[a,b]
Chrysler[2]	1.7 L	0.17	1.62	0.88	0.21	2.65	1.25	[a,b,c]
	2.2 L	0.13	0.78	1.38	0.25	3.76	1.41	[a,b,c]
	225 CID	0.29	1.94	0.85	0.52	2.74	0.98	[a,b,c]
Toyota[6]	168 CID				0.47	6.94	0.31	[a,b]
Nissan	2.0 L[5]				0.42	4.3	0.5	[a,b]
	280ZX[2]	0.31	2.1	0.47	0.52	5.4	0.35	[b,d]

[a] Carburetor system.
[b] Recalibrated open-loop mode.
[c] Values include assigned deterioration rates of 1.3 for HC, 1.2 for CO, and 1.1 for NOx (reference 4).
[d] Electronic fuel injection system.

FIGURE III-1

Emissions Performance Of Modified C-4 Systems



NOTE: ALL TESTS AT LOW MILEAGE.
ADJUSTED TO 50,000 - MILE LEVELS
USING DETERIORATION FACTORS FROM
1981 C - 4 CERTIFICATION DATA.

standards with a relatively easy recalibration of the cold-start fuel/air mixture is apparent (Table III-5). The HC and CO emissions are below the proportional standards for every vehicle. NOx is exceeded by two vehicles but one of these also violated the standard at low altitude. The other had such low HC and CO levels that these emissions could be allowed to increase by increasing the fuel/air ratio somewhat so that NOx would be reduced. (Richer mixtures increase HC and CO, but reduce NOx.) Therefore, a recalibration of the cold start, fuel/air mixture should bring even these problem vehicles into compliance with the proportional standards.

An estimate can now be made regarding the vehicles that will require modification to their feedback systems in order to meet the proportional standards in the base scenario and scenario 3a. In the interim (1982-83) high-altitude rulemaking[9] (the base scenario), EPA estimated that all manufacturers using carbureted feedback systems that could not comply with the regulations in their unmodified configuration would use differently calibrated electronic modules on the vehicles sold above 4,000 feet than on vehicles sold below that elevation. As previously shown in Table III-4, carbureted feedback systems are expected to be used on about 10 percent of the total fleet and that 78 percent of these feedback vehicles will not require changes to their systems. This leaves 2 percent that will require a module change in the base scenario.

The above emission control technology estimates from the interim rulemaking pertained predominately to carbureted systems which are expected to dominate the motor vehicle fleet during the early 1980's. In later model years, TBI systems are expected to dominate with 59 percent of the fleet utilizing such systems. In this analysis it is assumed that, although TBI may compensate fuel/air mixtures during open-loop operations, some of these vehicles may not be adequately designed to account for the effects of high altitude in the absence of high-altitude standards. Since TBI systems are still being refined, there is a serious dearth of information regarding the possible modifications which may be needed to ensure compliance in every case. To estimate the potential modifications, an analogy using carbureted systems is useful.

Previously it was stated that carbureted systems would be modified by providing new open-loop calibrations on only high-altitude vehicles. Since TBI systems are already assumed to recalibrate open-loop calibrations to some degree, the modifications to these systems should be less rigorous. It may only be necessary to ensure that the system's microprocessor (or perhaps sensors) has sufficient capability to account for the changes in various engine operating parameters as a result of higher elevations. For TBI systems it would be far less expensive to build this capability into every vehicle sold in the nation rather than change electronic hardware only on high-altitude vehicles. (The cost implications of such a change are discussed further in Chapter V.) Basically, the carbureted systems requiring modification have no existing capability to recalibrate their open-loop fuel/air mixtures automatically and would require additional hardware to be able to do so. Such automatic systems would be expensive to add to every vehicle when the modules on only high-altitude vehicles would be changed instead. TBI systems are assumed to already possess the inherent ability to compensate, hence, changes to the existing electronics would be much easier than for carbureted systems.

As previously described, TBI feedback systems are expected to comprise about 59 percent of the total fleet and 78 percent of these vehicles will not require modifications to comply with proportional standards. This leaves 13 percent that will require expansion of existing electronics in the base scenario. The requisite control hardware for this scenario is summarized in Table III-4.

Scenario 3a has the same standards at high altitude as the base scenario, but, in addition, a vehicle must automatically meet a proportional standard at all altitudes up to 6,000 feet. This one-car strategy will prevent the affected vehicles from being modified for high altitude use by requiring that all such vehicles incorporate appropriate modifications regardless of where they are sold. The continuous requirements of this scenario present no problems for either the feedback systems which already comply with the proportional standards in the base scenario or the TBI systems that would be modified in the base scenario since these systems compensate automatically with changes in elevation. This scenario does affect the carbureted systems that would have had new electronic control modules installed on only high-altitude vehicles in the base scenario, however.

The necessary changes for this scenario can readily be accomplished by expanding the memory capacity of the electronic control unit in either of two ways. First, control of the fuel/air mixtures can be enhanced by enlarging the microprocessor's memory to include a greater number of engine operating values (i.e., combinations of engine load and speed). Increasing the number of values with which to set the carburetor will result in more precise control of fuel metering and, ultimately, better emissions performances.[10]

Second, a "continuously-powered memory" may be used to compensate the fuel-metering system during open-loop operations. This is accomplished by utilizing the computer's existing capability to memorize the carburetor settings which are required to maintain the proper fuel/air ratio during "closed-loop" operation before the ignition is switched off. When the engine is restarted, the last closed-loop operating conditions can be used to modify the open-loop carburetor settings. Open-loop compensation for the effects of altitude is, therefore, automatic since as previously stated, feedback systems inherently compensate for variations in the fuel/air ratio during closed-loop operation. Such systems are readily available with current technology. In scenario 3a, 2 percent of the fleet will require an expanded memory in the electronic control unit rather than simply changing the module on high-altitude vehicles (Table III-4).

The statutory levels at high altitude represent a more stringent standard than at low altitude because of the effect of decreasing air density at higher elevations on engine performance. This fact is reflected in the data. Table III-2 shows that even systems with the best ability to control emissions at higher elevations (i.e., TBI) did not meet statutory standards at high altitude in every case when compliance at low-altitude was also demonstrated. Furthermore, Table III-5 indicates that the relatively simple readjustment of the fuel/air mixture that is sufficient to meet the proportional levels will not be enough to bring "problem" vehicles into compliance with the statutory standards at high altitude. No vehicle simultaneously met these more stringent standards for all three pollutants. Furthermore, while HC and CO are usually considered the "problem" emissions at high altitude, the data in Table III-5 and Figure III-1 suggest that as these pollutants are controlled to lower levels, NOx may increase to marginal or unacceptable levels. Therefore, additional emission reductions beyond those required by the proportional standards appear be relatively easy for most vehicles, but as the statutory levels are approached many engines will require more significant modifications to their feedback systems, including some that are represented in Figure III-1. The available techniques include further leaning of the cold start fuel/air mixture, disconnecting the power enrichment circuit of the carburetor, modifying the choke setting, changing spark timing, changing the automatic transmission shift points, modifying the air injection rates, recalibrating EGR at part-throttle operation, and adding EGR at WOT.

Specifically, to meet the statutory standards at 5,300 feet in scenario 2, the vast majority of feedback systems would require more significant changes than were needed to comply with the proportional levels. Of course, Table III-2 shows that some unmodified systems currently comply with the statutory standards of 0.41 g/mi HC, 3.4 g/mi CO, and 1.0 g/mi NOx. Conversely, some vehicles may require such extreme fixes as disconnecting the power enrichment circuit and adding EGR at WOT. It is expected that such vehicles would be relatively few in number because exemptions would be available. Therefore, the generic emission control system would be somewhere in between these two extremes and would affect 100 percent of the feedback systems or 69 percent of the total fleet.

Since scenario 2 is a two-car strategy, the necessary modifications need only be made to high-altitude vehicles where it is practical by changing the electronic module as in the base scenario. In scenario 2, however, the modifications would be more extensive. The cold start fuel/air mixtures of carbureted systems would be recalibrated as in the base scenario but would be more refined to provide the precise fuel metering that would be required. This recalibration would probably include a revised choke setting to prevent excessively rich mixtures when the engine is first started. The high-altitude electronic control module would probably include special calibrations for spark timing and EGR to provide further emission reductions. Another major change would likely include the addition of a manifold absolute pressure (MAP) sensor to the high-altitude electronic module. This sensor would be used to ensure acceptable driveability if the vehicle is driven at sea level. During the open-loop portion of the feedback carburetor system's operating regime, the fuel/air ratio is not properly compensated for changes in altitude. As a result, the mixture becomes leaner at lower elevations since the air is more dense and has more oxygen per unit volume, but the amount of fuel metered remains the same. A very lean mixture will cause hard starting under certain conditions and lean misfiring. The MAP sensor will prevent unacceptable driving characteristics by signaling the microprocessor to provide a richer fuel/air mixture at a predetermined altitude below 4,000 feet. This device was not needed in the base scenario, because the special high-altitude calibration is not significant enough to cause unacceptable performance if the car was used at sea level.

In scenario 2, TBI systems probably would have the capability of their existing electronics expanded as previously described for the base scenario. Such expansion may be more significant than for proportional standards, as it would be for carbureted systems. Throttle body systems would not require the addition of a MAP sensor because this device is already present.[5] The emission control technology for scenario 2 is shown in Table III-4.

To meet the statutory standards at all altitudes up to 6,000 feet (scenario 1b) would require essentially the same emission control hardware as in scenario 2. However, the one-car strategy of scenario 1b would mean installing the MAP sensor on all feedback-carbureted vehicles regardless of the altitude at which they are sold. The memory of the electronic control unit would have to be expanded beyond that required in scenario 3a to include additional open-loop calibrations for various altitudes. As before, TBI systems would not require further modifications to meet the statutory requirements of scenario 1b beyond that needed for scenario 2. Table III-4 shows that in this scenario (1b) all feedback carbureted systems (10 percent of the fleet) are expected to require expansion of their electronic capability and the addition of MAP sensor, while all TBI systems (59 percent of the fleet) are expected to require only the expansion of their existing electronics.

In addition to modifying current feedback systems, meeting the statutory standards at all altitudes is expected to be difficult for nonfeedback systems even with significant modifications. While it is possible to design continuously compensating nonfeedback systems, as will be discussed in the next section, controlling these systems to the precise levels needed to attain the statutory standards may be of such complexity as to preclude that approach in most instances. This difficulty could precipitate a change from nonfeedback to feedback carburetor systems which are capable of much more precise control and, therefore, can meet the requirements. This is not to say that nonfeedback systems cannot be made to do an adequate job for some vehicles, but even in these instances the amount of development effort may be so costly, in terms of time and money, that feedback systems will probably be used in the vast majority of cases. For scenario 1b, then, EPA estimates that the 31 percent market share held primarily by Ford and the foreign manufacturers would be converted to feedback carburetor systems using the same modifications as previously described. (Table III-4).

3. Nonfeedback Systems Requiring Modification

As previously stated, it is expected that all nonfeedback systems will require some type of modification in order to comply with the high-altitude standards. Table III-6 presents data on modified nonfeedback systems. These data were compiled in response to the rulemaking that implemented the 1982 and 1983 high altitude standards.[1] The goal of the test programs which generated these values was to demonstrate compliance with proportional standards, and was not to develop a system that would achieve the statutory standards at high altitude. For this reason, the vehicle modifications depicted in the table are relatively simple. The two Nissan vehicles utilized an aneroid to lean the fuel/air mixture of the carburetor during all operating modes other than wide-open throttle (WOT) (i.e., no compensation for power enrichment compensation). The remaining vehicles had aneroids installed to control spark timing and automatic transmission shift points.

The effectiveness of installing aneroids to contol certain engine parameters is best shown by comparing the high-altitude emission levels in Tables III-3 and III-6 for unmodified and modified nonfeedback vehicles, respectively. The Nissan and Ford vehicles in both tables are identical except for the installation of aneroids. The aneroid compensated carburetor on the Nissan vehicles in Table III-6 reduced HC up to 64 percent, CO up to 82 percent, and increased NOx from 70 to 900

Table III-6

Modified Nonfeedback Systems

Manufacturer	Car	Low Altitude (g/mi) HC	CO	NOx	High Altitude (g/mi) HC	CO	NOx	Comments
Nissan[2]	510	0.34	4.1	0.51	0.34	5.7	1.3	[a,b]
(Datsun)	210	0.30	2.4	0.98	0.36	5.1	1.6	[a,b]
Toyota[6]	78 CID				0.51	4.73	1.0	[a,c]
Chrysler[6]	2.6 L				0.44	5.6	1.0	[a,c]
					0.37	6.8	1.0	[a,c]
Ford[2]	4.2 L	0.30	1.3	0.96	0.49	2.3	0.99	[a,c]

[a] Carburetor system.
[b] Aneroid on carburetor.
[c] Aneroids on transmission and ignition timing.

percent. The ignition and transmission aneroids on the Ford vehicle in Table III-6 reduced HC by 4 percent, CO by 59 percent and increased NOx by 74 percent. As expected, compensating the carburetor (i.e., controlling the fuel/air ratio) is the most effective way to control HC and CO emissions at high altitude, although compensating the ignition and transmission are also quite effective. The data also shows that NOx emissions may be greater at high altitude for vehicles with some forms of altitude compensation. Generally, however, the information in Table III-6 shows the above modifications can be effective in reducing high-altitude emissions.

It is clear that the HC and CO proportional standards can readily be met with relatively simple recalibrations of key engine operating parameters (Table III-6). The results also show that leaning the fuel/air mixture to reduce HC and CO emissions may increase NOx emissions beyond allowable levels (1.0 g/mi). However, the NOx emissions in Table III-6 should not be a significant problem with regard to the proportional standards, because the values were achieved during early development testing. The Nissan vehicles which exceed the NOx standard are sufficiently below the HC and CO requirements of 0.57 g/mi HC and 7.8 g/mi CO so that enriching the fuel/air mixture should reduce NOx to acceptable levels while still meeting the HC and CO standards. Also, other NOx counter-measures may be employed, such as recalibrating the EGR system.

The specific emission control requirements for the base scenario are shown in Table III-4. As explained earlier, the estimates of the generic systems for the base scenario are taken from the interim high-altitude rulemaking. In that action, EPA estimated that all nonfeedback vehicles, 31 percent of the future fleet sold above 4,000 feet, would be equipped with aneroid-controlled carburetors even though special high-altitude hardware with fixed calibrations could be used at a lower price. Aneroids are the preferred solution for compensating fuel/air mixtures so that if a vehicle is driven at sea level, the otherwise accompanying lean mixture would be avoided. Therefore, using an aneroid to slightly richen the mixture at a predetermined altitude below 4,000 feet will ensure acceptable driveability at lower elevations. This approach is followed in this study, as shown in Table III-4.

To meet the proportional standards at all altitudes up to 6,000 feet in scenario 3a, nonfeedback vehicles will have to switch from aneroids that engage at a predetermined altitude to aneroids that operate in a continuous manner. The perfection of a continuous aneroid that will properly meter the precise degree of fuel needed over a wide range altitudes (i.e., 1,800 to 6,000 feet is a more difficult task than developing a fixed-step aneroid). While one fixed-step aneroid was estimated for the base scenario, the complexity of adopting a single aneroid which must precisely meter an air bleed to lean the fuel/air mixture may result in a less than perfect device. Therefore, an additional aneroid may be needed to control a second engine operating parameter, such as ignition timing, to assure compliance with the standards at all elevations up to 6,000 feet. Thus, two aneroids of this type have been estimated for the generic emission control system required under scenario 3a.

The choice of two aneroids for scenario 3a is a compromise. It is possible for one aneroid to operate more than one engine parameter. However, since it is also reasonable to expect that more than one aneroid may be required to meet the emission requirements for some vehicles, it has been conservatively estimated that two aneroids are needed in the average case.

In order to comply with the statutory standards at high altitude (scenarios 2 and 1b), nonfeedback systems will require additional compensation. Table III-6 shows that no vehicle simultaneously met the statutory levels of 0.41 g/mi HC, 3.4 g/mi CO, and 1.0 g/mi NOx. To reduce HC and CO emissions further, these vehicles may employ a variety of techniques. The Nissan vehicles may require a greater degree of aneroid control of the fuel-metering system. This could be accomplished by further refinement of the existing aneroid control mechanism or by adding additional aneroid control to the power enrichment or accelerator pump circuits of the carburetor. Also, aneroids could be added to control spark timing or the shift points of automatic transmissions. The addition of an air pump or a change from a pulse air pump to a continuous air pump could also be used to reduce the CO emissions to the required levels. The Toyota, Chrysler, and Ford vehicles already have the equivalent of aneroid-controlled spark timing and transmission shift points but the remaining emission control techniques mentioned above could also be used. This includes the adoption of the very effective aneroid-controlled carburetor which the Nissan vehicles already have.

Regarding NOx emissions, the Nissan vehicles already exceed the allowable level and further leaning of the fuel/air mixture entering the combustion chamber may increase the amount of this pollutant to unacceptable levels for the Toyota, Chrysler, and Ford vehicles also. Added EGR control should help remedy this problem. Generally, this requirement is most likely for low-power vehicles which spend a significant amount of time during the Federal Test Procedure (FTP) at or near WOT when tested under high-altitude conditions. Many conventional EGR systems are inoperative under these circumstances in order to maximize engine power. Alternatively, additional air injection rates from an existing system might be sufficient for some vehicles to reduce the HC and CO levels without significantly increasing NOx. These aneroids may be used to control various engine parameters. The first aneroid can provide the most effective control by compensating the fuel/air ratio of the fuel-metering device. The second and third aneroids would probably be most effective if used to regulate spark timing and air injection rates. One of these aneroids may be needed to control the rate of exhaust gas recirculation (EGR) for reduced NOx emissions.

From this, EPA estimates that the typical emission control system used under scenario 2 will include three fixed-step aneroids (Table III-4). Again, some vehicles may require more significant emission control countermeasures and some less, but three aneroids should adequately characterize the average vehicle. As an example, one of the more expensive options for reducing emissions is the addition of an air injection system. Air injection systems are used to oxidize HC and CO emissions to water and carbon dioxide by introducing additional air into the exhaust manifold after combustion has occurred. NOx emissions are relatively unaffected since they are produced during the high temperature and pressure of the combustion process.

The addition of an air injection system, or a shift from a less expensive pulse air system to a more costly air pump system, was not specifically included in the generic emission control system for two reasons. First, this course of action is primarily restricted to the nonfeedback systems of smaller displacement engines since the vast majority of other engines currently employ air pump systems. Such smaller displacement, nonfeedback engines are estimated to be less than about 10 percent of the LDV market. Also, many of these low-power vehicles may qualify for exemption under this scenario. Second, the significant increase in cost will limit its application to those vehicles that simply cannot comply with the standards by using aneroids or other less costly techniques.

The exhaust emission control requirements for scenario 1b already have been described in the section regarding modified feedback systems but will be summarized here for convenience. Meeting the statutory standards at all altitudes up to 6,000 feet may be possible by using continuous aneroids such as those estimated for scenario 3a. However, the precise control of several engine operating parameters which would be necessary to attain the statutory standards is expected to be so difficult as to preclude that approach in most instances. Therefore, EPA estimates that the 31 percent market share which is currently held by nonfeedback systems will be converted to feedback carbureted systems (Table III-4).

4. Evaporative Emission Systems

Evaporative HC emissions are greater from uncontrolled vehicles at higher elevations because of the reduced barometric pressure at these locations. The increase in evaporative emissions is proportional to the change in barometric pressure and, therefore, altitude.

In the interim (1982-83) high-altitude rulemaking (the base scenario in this analysis), EPA found that existing evaporative emission control systems should have adequate capacity to comply with the proportional standard of 2.6 g/test HC at 5,300 feet.[1] Any system capable of meeting the standard at this altitude should be able to comply with a proportional standard at any elevation, since both the level of the standard and evaporative emissions increase linearly with the change in barometric pressure. Therefore, no additional evaporative emission control hardware should be necessary for scenario 3a and the base scenario (Table III-7).

The statutory evaporative emission standard (2.0 g/test) is about 25 percent more stringent at 6,000 feet than the proportional standard. EPA estimates that compliance with this standard will generally require an increase of approximately 25 percent in the capacity of the carbon storage canister. Additional capacity can be acquired in two ways. First, the quantity of activated charcoal, upon which the fuel vapors are adsorbed, can be increased. Second, a more efficient adsorber can be used, usually a better grade of activated charcoal. A properly designed system that complies with the statutory standard at the highest elevation where control is required, should comply with the standard at any altitude. Therefore, the required evaporative emission control hardware for scenarios 1b and 2 are essentially the same (Table III-7). The difference is, of course, that in scenario 1b higher capacity canisters would be required on all vehicles sold in the nation, where scenario 2 would require these canisters on only vehicles sold above 4,000 feet.

C. Required Technology for the Scenarios Without Exemptions

Scenarios 1a, 1c, and 3a have no provision for exempting certain vehicles from the regulatory requirements. Without granting exemptions, these scenarios will certainly limit model availability at both high and low altitudes to varying degrees. Such limitations are of concern at both altitudes, of course, but they become more onerous at low altitude where 95 to 97 percent of the sales occur. This is because many of the vehicles which may require exemptions are low-power, high fuel economy vehicles principally designed for low-altitude operation. Many of these vehicles would not be sold at high altitude, or would be sold in very small numbers, since the reduced air density at higher elevations reduces their

Table III-7

Estimated Evaporative Emission Control Technology Requirements for All Scenarios

Scenario	No Change to Carbon Canister	25% Increase Carbon Canister	50% Increase Carbon Canister
1a	N/A[a]	N/A	100%
1b	N/A	N/A	N/A
1c	N/A	N/A	N/A
2	N/A	100%	N/A
3a	100%	N/A	N/A
3b	100%	N/A	N/A
Base	100%	N/A	N/A

[a] Not applicable.

performance below acceptable levels. In the future, this situation can be expected to become more common as engines become even smaller to further improve fuel economy.

The lack of exemptions in scenarios 1a, 1c, and 3b would probably result in one of two possible courses by the manufacturer. Either some low-power, high fuel economy vehicles would be discontinued with an attendant increase in national energy consumption, or more costly emission control hardware would be added to the vehicles so that they may be certified and sold. This analysis assumes that the obvious disadvantages of dropping these vehicles from the national sales offering would be avoided by using the more costly emission control hardware. Nevertheless, at this time it is impossible to state that simply adding more costly emission control systems would, in every instance, allow these low-power vehicles to meet the applicable standards, while retaining acceptable performance.

1. Feedback and Nonfeedback Systems

The national vehicular fleet can be separated into two categories for the purposes of estimating the emission control hardware required in scenarios 1a, 1c, and 3b: vehicles that would not qualify for exemptions and vehicles that would qualify for exemptions. The requisite hardware for the vehicles that would not qualify for exemption is the same as was estimated in the previous section for scenarios with the same standards and control ceiling but differing in that they allow exemptions. For these vehicles, scenario 1c corresponds to 1b and scenario 3b corresponds to 3a. In scenario 1c and 3b the technology mix which has been assumed in the analysis up to this point (10 percent feedback carbureted, 59 percent TBI, and 31 percent nonfeedback systems), would change somewhat if the previously exempted vehicles were included in the fleet. Since such a change would be well within the uncertainty of the analysis, the original fleet composition is assumed to remain the same as previously described for consistency. Scenario 1a has no corresponding scenario that allows for exemption. Therefore, it is necessary to discuss the requisite control technology for the nonexempt vehicles in this scenario before describing the hardware that may be needed to bring exempt vehicles into compliance.

In scenario 1a, all vehicles must meet statutory standards without modifications up to 10,200 feet. As previously described for scenario 1b, the continuous statutory requirements will likely force all nonfeedback-equipped vehicles to use feedback systems of some kind. The added requirement to meet these stringent standards to an elevation of 10,200 feet will require the manufacturers of many if not all feedback carburetor equipped vehicles to seek exemptions. Since this scenario does not include the possibility of exemptions, these vehicles would be forced to use the control technology discussed in the succeeding paragraphs. This same predicament would be faced by manufacturers of TBI systems. In this case, however, the sophistication of these systems with their ability to control fuel/air mixtures more precisely during both open- and closed-loop operation makes it more likely that many of these systems could comply with the requirements of scenario 1a. These systems may require additional refinement of the open-loop fuel/air mixtures than was estimated to occur in scenario 1b. It is also possible that additional changes to the power enrichment and EGR algorithms contained in the microprocessor unit will be needed.

The requisite exhaust emission control hardware for vehicles that would qualify for exemptions is, in reality, likely to be quite varied and would be difficult to establish at this time. To simplify the analysis, therefore, two emission control systems have been chosen as representative. These two systems will be applied to various percentages of the fleet under the scenarios of interest. The number of vehicles that would otherwise qualify for exemption increases with the stringency of the standards (proportional or statutory), and the altitude at which the standards must be met (6,000 feet or 10,200 feet). As shown in Table III-8, the fraction of the fleet that is expected to have significant difficulty meeting the standards is approximately 60 percent for scenario 1a, 25 percent for scenario 1c, and 10 percent for scenario 3b. The derivation of these percentages was previously presented in Chapter II, Identification of the High-Altitude Control Scenarios, and represents a "worst case" assumption.

The first system for vehicles which might otherwise be eligible for exemption is the electronic load control system (ELCS). GM devised this system as a way to achieve sea level emissions at higher elevations. Basically, the ELCS is an existing GM feedback carburetor system which includes the addition of a manifold absolute pressure (MAP) sensor. This device was used in conjunction with engine speed to calculate the engine load. The load experienced by the vehicle's engine determines the amount of fuel or quantity of fuel/air mixture which is required. Since road load is also nearly independent of altitude, the MAP sensor input can be used to meter the correct amount of fuel, EGR rate, and spark advance for a given operating condition regardless of the altitude. GM has stated that this engine-load control system (ELCS) should result in emissions performance that is independent of any change in elevation. Indeed, Figure III-2 shows that this is generally the case. HC and CO emissions are below the statutory standards and are basically equivalent at both low and high altitude. However, NOx emissions are greater at high altitude than at low altitude. This problem may require further refinements in the EGR calibration at high altitude. The ability of the ELCS to control emissions, albeit at a higher cost, makes it suitable for some "problem" vehicles which are equipped with carburetors. This system is estimated to be

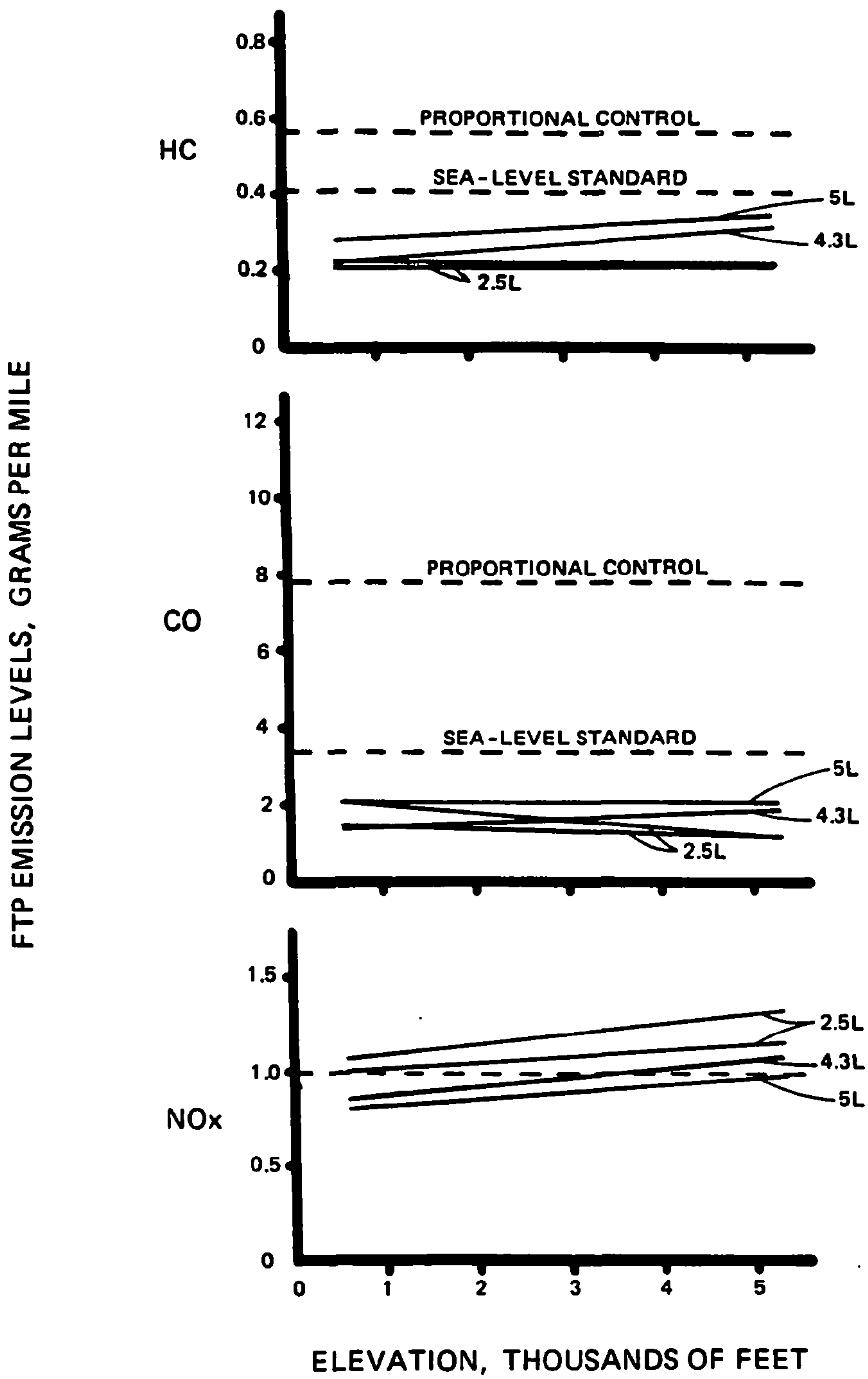
Table III-8

Estimated Exhaust Emission Control Requirements
for Vehicles Requiring Exemption
(based on the total fleet)

Control Hardware	Scenario 1a: Continuous Statutory, 10,200 Feet W/O Exemptions	Scenario 1c: Continuous Statutory, 6,000 Feet W/O Exemptions	Scenario 3b: Continuous Proportional, 6,000 Feet W/O Exemptions
Electronic Load Control System (ELCS)	20%	20%	10%
Turbocharger	40%	5%	0%

FIGURE III-2

Emissions Performance Of Engine Load Control Systems



NOTE: ALL TESTS AT LOW MILEAGE.
ADJUSTED TO 50,000-MILE LEVELS
USING DETERIORATION FACTORS FROM
1981 C-4 CERTIFICATION DATA.

representative of the emission control hardware that may be used by 10 percent of the vehicles in scenario 3b, 20 percent in scenario 1c, and 20 percent in scenario 1a (Table III-8).

It should be noted that vehicle performance may be very bad if the high-altitude emission control system, regardless of whether it is carbureted or TBI, includes eliminating power enrichment at WOT and very heavy EGR. In these cases, maintaining vehicle performance may force the use of the second control system which is more expensive. Turbocharging can be used to overcome the difficult task of meeting the emission standards at altitude when such situations as increased use of the power enrichment circuit of the fuel metering device may preclude such compliance or when total disconnection of this circuit as well as heavy EGR lead to unacceptable vehicle performance. Such drastically degraded performance could possibly force some vehicles off the market because of safety considerations or adverse consumer reaction.

A turbocharger is essentially an intake air compressor which is propelled by an exhaust gas turbine. The compressor is used to increase the charge of intake air by increasing its pressure (and density). In most light-duty vehicle applications, the reason for the use of a turbocharger has been to improve performance. With increased inlet charge density, more fuel and air can be processed through a given engine displacement and, therefore, more power can be generated. In the future, however, this increased performance may be traded for higher fuel economy since the same amount of power can be generated by a lighter, smaller displacement turbocharged engine as can be generated by a larger, naturally aspirated engine.

Use of a turbocharger at high altitude would definitely prevent the loss of power and the attendant performance and emission control problems that plague naturally aspirated engines. The turbocharger simply maintains the density of intake air independent of altitude and the engine cannot tell the difference. The use of a turbocharger as part of a system that maintains low-altitude performance at high altitude is not new. Turbochargers were first widely used for heavy-duty truck application in the western states in order to maintain performance when crossing the mountains. The concept of turbocharging light-duty vehicles in order to maintain low-altitude performance at high altitude, therefore, has some precedence. While some performance gains at low altitude still may be possible, the prime function of the turbocharger in the high-altitude case is to maintain low-altitude performance. The application of turbocharging as a high-altitude concept would enable manufacturers to retain low-performance packages which may be important for meeting the corporate average fuel economy (CAFE) standards or advertising considerations.

While turbochargers should theoretically solve the high-altitude exhaust emission problem for some spark-ignition engine vehicles, there appear to be some practical problems which must be resolved before their use becomes widespread. Ford, Chrysler, and GM have all reported some durability and emission control difficulties with current turbocharged spark-ignition engines. Also, the current production of these units is very low. Significant expansion of manufacturing capacity would have to take place if turbochargers were used to the degree required by scenario 1a. Although these problems can be overcome, it would take time. The required leadtime would very likely extend beyond the 1984 implementation date for high-altitude standards. Nevertheless, this is the type of exhaust emission control hardware which may be required to keep some models in production. Turbocharging is estimated to be used by all vehicles unable to meet the standards with modifications to their TBI systems or with ELCS. This accounts for approximately 5 percent of the vehicles in scenario 1c and 40 percent of the vehicles in scenario 1a (Tables III-8 and III-9).

The exhaust emission control technology requirements for the entire fleet under each scenario (1a, 1c, and 3b) are summarized in Table III-9.

2. Evaporative Emission Systems

As previously stated, the evaporative emission control systems are generally independent of the type of exhaust emission control system used on the vehicle. Therefore, the evaporative systems for vehicles that would qualify for exemption are the same as previously estimated nonexempted vehicles in scenarios with similar control ceilings. For scenario 3b, complying with the proportional standard up to 6,000 feet would be accomplished with existing hardware. For scenario 1c, complying with the statutory standard at every elevation up to 6,000 feet would generally require that affected vehicles be equipped with charcoal storage canisters with 25 percent larger capacity.

EPA expects that meeting the statutory evaporative emission standard up to 10,200 feet in scenario 1a would be difficult. Additional countermeasures other than the relatively easy task of increasing the canister capacity may be required. A lack of data, however, prevents making any estimate of these added requirements at this time. If increasing the working capacity of the canister is sufficient to meet the requirements of scenario 1a, EPA estimates that such an increase would be about 50 percent greater than the capacity of current systems (Table III-7). This estimate is based on the fact that the statutory standard at 10,200 feet is approximately twice as stringent as the proportional standard at 6,000 feet.

Table III-9

Estimated Exhaust Emission Control Requirements for Scenarios Without Exemptions

Contol Hardware Before Modification[a]	Control Hardware After Modification[a]	Scenario 1a: Continuous Statutory, 10,200 Feet W/O Exemptions	Scenario 1c: Continuous Statutory, 6,000 Feet W/O Exemptions	Scenario 3b: Continuous Proportional, 6,000 Feet W/O Exemptions
OL	OL w/aneroid	0%	0%	23%
OL	Turbocharged	18%	5%	0%
OL	FBC	13%	26%	8%
FBC	ELCS [b]	21%	20%	10%
FBC	Turbocharged	2%	0%	0%
FBC	No Change	0%	0%	8%
TBI	Expansion	39%	59%	13%
TBI	Turbocharged	20%	0%	0%
TBI	No Change	0%	0%	46%

[a] OL means nonfeedback or open-loop system.
FBC means feedback carburetor system.
ELCS means electronic load control system.
TBI means throttle body injection system.
Expansion means the capability of the existing electronic components is upgraded.

[b] The feedback carbureted systems that change to electronic load control systems include a portion of open-loop systems from the previous category that have switched to feedback systems. Therefore the percentages listed for each scenario do not total 100.

V. EFFECTS OF HIGH-ALTITUDE STANDARDS ON LOW-ALTITUDE CONTROL TECHNOLOGY

The generic systems presented in Tables III-4, III-7 and III-8 were chosen to reduce the economic impact on the low-altitude fleet. However, the regulatory strategies in some scenarios will have, by definition, some unavoidable effects. These effects may be positive or negative.

High-altitude standards will significantly affect low-altitude vehicles in scenarios 1 and 3 that require compliance with proportional or statutory standards at all altitudes by all vehicles. Since all vehicles must be capable of meeting the applicable standards without modification, these one-car strategies will require high-altitude emission controls on any low-altitude vehicles that could not otherwise comply with the applicable high-altitude standards. Many of these vehicles will never be operated at high altitudes, hence, it is logical to expect that the cost of these one-car strategies generally will be significantly higher than the two-car strategies without a corresponding reduction in high-altitude emissions.

The fuel efficiency of low-altitude vehicles may also change. For instance, if turbochargers are used as a result of these standards, the fuel economy of the low-altitude fleet will increase. (This topic is discussed further in the next section.)

High-altitude regulations could also have a significant environmental impact throughout the nation (i.e., even at low altitude). Tables III-4, III-8 and III-9 show the dramatic change from nonfeedback systems to feedback in scenarios 1a, 1b, and 1c where all vehicles must be certified in compliance with the statutory standards regardless of altitude. Since individual control technologies exhibit different in-use emission characteristics, fleet composite emissions will change under these scenarios.

The available evidence suggests that the electronic components of current feedback systems may have a significant failure rate, and that such failures could lead to emission increases as a result of excessively rich operating conditions.[12] Nonfeedback systems, therefore, may have lower in-use emissions because they do not exhibit such catastrophic failures. Any projection that the catastrophic failures of feedback systems will continue is very speculative, however, because of the preliminary nature of the evidence, and the uncertain ameliorative affect of inspection/maintenance programs. Therefore, increasing the number of feedback systems at all altitudes may have a significant adverse impact on air quality throughout the nation, but the effect cannot be confirmed at this time. This will be discussed further in the Chapter IV.

VI. EFFECT OF HIGH-ALTITUDE CONTROL TECHNOLOGY ON FUEL ECONOMY

The fuel economy of vehicles affected by a 1984 high-altitude standard could increase or decrease due to the requisit emission control hardware. Because these fuel economy changes could significantly affect the overall net cost of 1984 high-altitude standards and they need to be determined as accurately as possible. Although limited data are available concerning the fuel economy of vehicles equipped with altitude compensating control hardware, enough information was available to estimate the effect of a turbocharger, a closed-loop feedback control system, and one or more aneroids on fuel economy.

A. Turbochargers

When comparing a turbocharged vehicle with a naturally aspirated vehicle of similar driving performance, the engine of the turbocharged vehicle will most likely have fewer cylinders, less total engine displacement, and therefore less weight than the naturally aspirated engine. This will usually result in a fuel economy difference. Data examined by EPA showed both an increase and decrease in fuel economy. In particular, GM and Ford turbocharged gasoline vehicles were analyzed from data presented in technical reports or from emission certification test results.[13,14,15]

First, GM's turbocharged 6-cylinder Buicks were examined: a 1978 Lesabre and a 1978 Regal. GM studies showed that a 3.8-liter turbocharged 6-cylinder engine gave very similar driving performance to that of a 5.7-liter, 8-cylinder engine.[13] The urban fuel economy of the turbocharged vehicle was 19 miles per gallon (mpg), while the urban fuel economy of the naturally aspirated engine was 18 mpg.[13] Thus, turbocharging enhanced fuel economy by roughly 5 percent in this case. The turbocharged Regal had an urban fuel economy of 21 mpg. The Regal with the naturally aspirated, 8-cylinder engine exhibited an urban fuel economy of 20 mpg. Again, roughly a 5 percent increase in fuel economy occurred.

Second, Ford's turbocharged 4-cyclinder, 2.3-liter engine was examined. According to Ford, the turbocharged 4-cylinder, 2.3-liter engine had slightly better driving performance than the naturally aspirated 5.0-liter, 8-cylinder engine.[14] The fuel economy for the turbocharged 2.3-liter engine was 22.0 mpg, while that for the naturally aspirated engine was 19.0 mpg, a 15 percent improvement.

Recent certification data on the Ford 2.3-liter turbocharged engine, however, conflict somewhat with Ford's data.[15] The certification data reveal a fuel economy of 18-19 mpg for the 2.3-liter turbocharged Ford engine and lists a fuel economy of 19, 20, and 21 mpg for Ford's 6-cylinder, 2.3-liter engines and 18 mpg for an 8-cylinder, 4.2-liter engine. The 2.2-liter and the 4.2-liter engines were naturally aspirated. These engines were all installed in the same type of vehicle as the turbocharged 2.3-liter engine and it can be assumed that these vehicles had similar driving performance. Therefore, based on Ford's data, turbocharging the engine of a vehicle may either reduce fuel economy by about 15 percent or increase fuel economy by about 5 percent.

The above certification data may not be a true comparison between vehicles with similar driving performance. Ford has also indicated in its SAE paper that a 2.3-liter turbocharged engine has a driving performance rating similar to that of a much larger 5.0-liter engine, while the certification data compared the 2.3-liter turbocharged engine with either 2.3-liter engines or a 4.2-liter engines.[15] Thus, the previous comparisons of fuel economy and performance by GM and Ford may be more reliable than that constructed from certification data. It is likely, then, that turbocharged vehicles will show some fuel economy improvement when compared with a vehicle of similar driving performance.

In this analysis, a fuel economy increase of 5 percent will be used as a single best estimate. This estimate is very conversative considering that both Ford and GM show improvements of up to 15 percent. In the sensitivity analysis of Chapter V, a larger fuel economy range of 0-5 percent will be examined to evaluate the effect on the overall net cost of these regulations of an even more conservative fuel economy estimate.

B. Closed-Loop Feedback Control

The fuel economy change associated with converting an engine from nonfeedback to feedback control will be examined for the Ford Granada, Ford Thunderbird, and other Ford vehicles equipped with the 2.3-liter engine. EPA records show that Ford certified each of these vehicles with both nonfeedback and feedback emission control systems within the same model years.[16,17]

First, for the Ford Granada, which had an engine displacement of 4.2 liters and a weight of 3,625 pounds, the nonfeedback version had a fuel economy of 20 mpg while the feedback version had a fuel economy of 21 mpg 5 percent improvement.[16] Second, the Ford Thunderbird with a weight of 3,750 pounds and an engine size of 5.0 liters had a fuel economy of 20 mpg is shown for both nonfeedback and feedback systems. Thus no fuel economy improvement is observed. Finally, the certification results for the Ford 2.3-liter engine showed the feedback version obtaining 22 mpg, while the nonfeedback version had fuel economies of 20.0, 20.2, and 20.7 mpg.[17] The fuel economy improvement in this case is 6 to 20 percent. Thus, based on fuel economy data from the Ford Granada, Ford Thunderbird, and other Ford vehicles, converting an engine from a nonfeedback system to a feedback system may improve fuel economy from 0 to 20 percent.

Admittedly, the data presented here are very limited and show a very wide range of fuel economy improvement. Thus, it is difficult to make this range smaller, but EPA believes a conservative best estimate would range from 0 to 5 percent. For purpose of estimating fuel savings in this report, a 3 percent improvement will be used as a best estimate. The 0 to 5 percent range and its effect on the net cost of a 1984 high-altitude standard will be analyzed further in the sensitivity of Chapter IV, Economic Impact.

C. Aneroids

Vehicles equipped with aneroids generally show better fuel economy than the same vehicle without an aneroid. The fuel economy improvements of adding one, two, or three aneroids on Ford vehicles are shown in Table III-10.[18] A straight average of the numbers shown in this table yields an urban fuel economy benefit of 3 percent and a highway fuel economy benefit of 7 percent for vehicles with one or two aneroids, and an urban fuel economy of 9 percent and a highway fuel economy of 10 percent for vehicles with three aneroids. The composite fuel economies (based on a 55/45 urban/highway weighting) yields the following improvements: 1 aneroid, 5 percent; 2 aneroids, 5 percent; and 3 aneroids, 9 percent.

To be conservative, it will be assumed that the average fuel economy gains that were estimated above will be the maximum fuel economy improvements that would occur by utilizing aneroids. Thus, 1, 2, and 3 aneroids give improvements of 0-5, 0-5, and 0-9 percent, respectively, over vehicles with no aneroids. Of course, the fuel economy benefit will take place at high-altitude areas, as this is where an aneroid allows a leaner air/fuel mixture.

At the time 1984 high-altitude standards become effective, vehicles will have already had to comply with the 1982-83 interim standards. As a result, most high-altitude vehicles with nonfeedback emission control systems will already be equipped with an aneroid on the carburetor. The incremental benefits of fuel economy from one aneroid in addition to the one already in place should not bring about any fuel economy improvement (or an improvement of 0 percent). However, two aneroids in addition to the existing one could provide a fuel economy improvement of 0-4 percent. Based on this very limited amount of data, a single best estimate would be the midpoint of this range (0-4 percent), or 2 percent. This incremental savings will be carried through as EPA's best estimate of fuel economy savings for the addition of two aneroids. However, a

Table III-10

Percent Fuel Economy Improvement Due to Aneroids

Engine Size (liter)	Fuel Economy Improvement of 1 Aneroid		Fuel Economy Improvement of 2 Aneroids		Fuel Economy Improvement of 3 Aneroids	
	Urban	HW	Urban	HW	Urban	HW
5.0	+4	NA	+5	NA	+8	NA
5.8	+1	+2	0	+2	+9	+7
5.8	+6	+10	+7	+13	+11	+14
6.6	-1	+13	+1	+11	+5	+13
6.6	4	+4	+4	0	+11	+5

range of fuel economy increments will be evaluated in the sensitivity analysis of Chapter VI, Economic Impact, because of the large variability in the Ford data and because of the limited amount of information that was available with which to formulate a "best estimate." This range will be 0-2 percent for the addition of one aneroid and 0-4 percent for the addition of two aneroids.

D. Expansion of Adaptive Memory

Expanding the range of authority for feedback control systems could lead to fuel economy improvements at high altitude. Discussions with a few manufacturers indicate that this improvement could be 1 percent. However, no data has been encountered concerning fuel economy on this modification, and thus to be conservative, the benefit will not be considered in this report.

E. Summary

The following best estimates for fuel economy improvement were determined: turbocharger, 5 percent; closed-loop feedback control (compared to open-loop of same vehicle), 3 percent; one additional aneroid (to a vehicle with an existing aneroid), 0 percent; and 2 additional aneroids (to a vehicle with an existing aneroid), 2 percent. These fuel economy benefits are summarized in Table III-11. The effect of these fuel economy improvements on the overall net cost of potential high-altitude regulations will be analyzed in Chapter V of this document.

Table III-11

Percent Fuel Economy Improvement Due to Altitude Compensating Emission Control Hardware

Control Hardware	"Best Estimate" Fuel Economy Improvement
Turbocharger	5
Feedback control	3
Aneroids:	
1 additional	0
2 additional	2

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Chapter IV

Environmental Impact for Light-Duty Vehicles

I. INTRODUCTION

A. Scenarios Being Studied

The four basic control scenarios being evaluated were described earlier. However, to facilitate the analysis in this chapter, they are restated briefly below:

1. Base Scenario: Fixed-Point Proportional

This scenario is essentially a continuation of the 1982-83 interim high-altitude emission standards.[1] These standards apply to areas above 4,000 feet and were determined by increasing the low-altitude emission standards in proportion to the effect of altitude on uncontrolled emissions. Certification in high-altitude areas would be at a specific altitude (e.g., 5,300 feet).

2. Scenario 1: Continuous Statutory

All light-duty vehicles (LDVs) sold in this country must certify to the same emission standards, independent of where they are sold. These standards would be the same as those in low-altitude areas (below 1,800 feet) and would apply to every vehicle sold up to a maximum elevation of 6,000 feet.

3. Senario 2: Fixed-Point Statutory

The same emission standards would apply to vehicles sold in low-altitude areas (below 1,800 feet) and in high-altitude areas (above 4,000 feet) areas between 1,800 and 4,000 feet would not be subject to special control.

4. Scenario 3: Continuous Proportional

All light-duty vehicles would be subject to control but the degree of control would vary in direct proportion to altitude for areas between 1,800 and 6,000 feet. The standards at 5,300 feet would be the same as in the base scenario.

B. General Approach

As in the previous chapter, the fixed-point proportional standards of the base scenarios are assumed to be in effect for 1984 and later. Therefore, all alternative control strategies (scenarios 1 through 3) will be analyzed to determine their incremental environmental impacts.

Two basic measures will be used to evaluate the impact of the various alternative scenarios. The first is simply the overall emission reduction of hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx). These reductions will be used primarily to determine the cost effectiveness of each scenario.

The second method goes further and evaluates the relative impacts of the three scenarios on air quality. Here, computer models will be employed to examine the consequences of each scenario on the abilities of four specific high-altitude cities to comply with the National Ambient Air Quality Standards (NAAQS) for CO, NOx, and ozone. These models also project yearly emission reductions relative to pre-control base years.

This chapter concludes with a sensitivity analysis of certain critical assumptions.

II. TOTAL EMISSIONS

Although this report focuses on high-altitude areas, as described earlier, scenarios 1 and 3 have standards that apply to intermediate altitudes as well. Therefore, any determination of the emission reductions under these scenarios should include the impact in these regions in addition to high-altitude areas.

Lifetime emissions were determined from LDVs sold during 1984 through 1988 in the areas affected by the different scenarios. This particular 5-year period was chosen to correspond with the time increment used to determine the aggregate economic costs of the four scenarios. The cost effectiveness of the various options being studied can then be determined since both cost and emissions data cover the same periods of time.

A. Basic Methodology

In order to determine total lifetime emissions from the vehicles being studied, three basic factors were multiplied together: 1) the number of miles the average vehicle is expected to cover in its lifetime, 2) emission factors (the amount of pollutant emitted per vehicle per mile of travel), and 3) the number of vehicles sold in the affected areas.

1. Average Miles Traveled

For light-duty vehicles, the average lifetime mileage used in this study is 100,000 miles.[1] For light-duty trucks (LDTs) (addressed in Chapter VIII), the lifetime is 120,000 miles.[2] In both cases it is assumed that the lifetimes are independent of altitude, that is, a light-duty truck or vehicle is expected to travel the same number of miles during its lifetime whether it operates at low- or high-altitude regions.

2. Emission Factors

EPA has done considerable work in an attempt to determine accurate emission factors for mobile sources. To determine how well vehicles perform in actual use, EPA administered a series of exhaust emission surveillance programs. Test fleets of consumer-owned vehicles in various major cities were selected by model year, make, engine size, transmission, and carburetor in such proportion as to be representative of both the normal production of each model year and the contribution of that model year to total vehicle miles traveled. These programs have focused principally on light-duty vehicles and light-duty trucks. As a result of EPA's test programs, emission factors for past model years are known with the greatest degree of accuracy, while projected emission factors for vehicles with recently introduced control technologies are subject to considerable uncertainty.

The surveillance program data were used to determine mean emissions by model year in each calander year, the change in emissions with the accumulation of mileage and age, the percentage of vehicles complying with standards, and the effect of vehicle parameters on emissions (engine displacement, vehicle weight, etc.). These surveillance data, along with prototype vehicle test data, assembly line test data, and technical judgment, formed the basis for the MOBILE2 emission factor model which was then used to determine fleetwide composite emission factors for the specified study years (used as inputs to EKMA and Rollback models discussed later in this chapter).[3]

Table IV-1 lists the low-altitude (1,800 feet) emission factors in grams per mile for the gasoline-fueled and diesel-powered light-duty vehicles that were used as the basis for determining emission factors at other altitudes in this study. These emission rates were determined from tests conducted using the Federal Test Procedure (FTP) and are further discussed in Appendix II.[4] The control technology expected to be required for each scenario has already been discussed in Chapter III.

When determining the high-altitude emission rates for areas above 4,000 feet, two pertinent factors must be considered which are unique to this study. The first is the exact altitude for which emission rates are desired and the second is vehicle age in terms of miles traveled. The high-altitude emission data available were based on tests conducted at Denver (elevation 5,300 feet). Thus, the emission factors developed to study the high-altitude impact of the various scenarios, listed in Table IV-2, were based on this elevation. Implicit in this procedure is the assumption that the average high-altitude place of residence is 5,300 feet. Since Denver, the largest high-altitude city, lies at this approximate elevation and since 5,300 feet is roughly the average altitude above 4,000 feet that these scenarios apply, this assumption does not significantly affect the results of

Table IV-1

Emission Rates for 1984-88 Light-Duty Vehicles at 1,800 Feet[a]

Pollutant		LDGV[b] Scenario 1	LDGV[b] Scenarios 1, 2, 3, & Base	LDDV[b] All Scenarios
HC	Zero-Mile Emission Level (g/mi)	0.37	0.33	0.39
	Deterioration Rate (g/mi/10,000 miles)	0.17	0.18	0.03
	Average Lifetime Emission level (g/mi)[c]	1.22	1.23	0.54
CO	Zero-Mile Emission Level (g/mi)	4.27	3.21	1.27
	Deterioration Rate (g/mi/10,000 miles)	2.13	1.88	0.05
	Average Lifetime Emission Level (g/mi)	14.92	12.61	1.52
NOx	Zero-Mile Emission Level (g/mi)	0.56	0.63	0.75
	Deterioration Rate (g/mi/10,000 miles)	0.10	0.11	0.05
	Average Lifetime Emission Level (g/mi)	1.06	1.18	1.0
Evap. HC	Zero-Mile Emission Level (g/mi)[d]	0.10	0.10	-
	Deterioration Rate (g/mi/10,000 miles)	0.0	0.0	-
	Average Lifetime Emission Level (g/mi)	0.10	0.10	-

[a] Emission Rate = Zero Mile Level + (Cummulative Mileage/10,000)(Deterioration Rate)
Values on this table are further discussed in the Appendix.
[b] Light-duty gasoline-powered vehicle
Light-duty diesel-fueled vehicle
[c] Based on average lifetimes of 100,000 miles for light-duty vehicles.
[d] See Table IV-7 for derivation of these figures.

Table IV-2

Emission Rates for 1984-88 Light-Duty Vehicles at 5,300 Feet[a]

Pollutant		Scenario: Base and #3 LDGV	Base and #3 LDDV	#1 LDGV	#1 LDDV	#2 LDGV	#2 LDDV
HC	Zero Mile Emission Level (g/mi)	0.44	0.54	0.38	0.39	0.34	0.39
	Deterioration Rate (g/mi/10,000 miles)	0.19	0.03	0.18	0.03	0.19	0.03
	Average Lifetime Emission level (g/mi)[b]	1.39	0.69	1.28	0.54	1.29	0.54
CO	Zero-Mile Emission Level (g/mi)	6.25	2.22	5.22	1.27	3.75	1.27
	Deterioration Rate (g/mi/10,000 miles)	2.22	0.05	2.76	0.05	2.24	0.05
	Average Lifetime Emission Level (g/mi)	17.35	2.47	19.02	1.52	14.95	1.52
NOx	Zero-Mile Emission Level (g/mi)	0.58	0.75	0.54	0.75	0.58	0.75
	Deterioration Rate (g/mi/10,000 miles)	0.10	0.05	0.10	0.05	0.10	0.05
	Average Lifetime Emission Level (g/mi)	1.08	1.0	1.04	1.0	1.08	1.0
Evap. HC	Zero-Mile Emission Level (g/mi)[c]	0.13	-	0.10	-	0.10	-
	Deterioration Rate (g/mi/10,000 miles)	0	-	0	-	0	-
	Average Lifetime Emission Level (g/mi)	0.13	-	0.10	-	0.10	-

[a] Emission Rate = ZML + (M)(DR)
Where: ZML = Zero-Mile Level
M = Cumulative Mileage/10,000 (cumulative mileage = 50,000 miles, half the lifetime mileage)
DR = Deterioration Rate
Values in this table are further discussed in Appendix II.

[b] Based on average lifetimes of 100,000 miles for light-duty vehicles.

[c] See Table IV-7 for the derivation of these numbers.

this analysis. The procedure used to determine emissions in intermediate altitudes (1,800-4,000 feet) is discussed below.

Light-duty vehicles sold at intermediate altitudes are subject to special standards under scenarios 1 and 3 (as opposed to scenario 2 and the base scenario where only those vehicles sold above 4,000 feet are subject to control). Thus, to determine the emissions from vehicles in these intermediate altitudes another set of emission factors needs to be developed. Ideally, a different set of emission factors would be derived for each altitude above 1,800 feet at which vehicles are driven. These values would then be used to examine scenarios 1 and 3. Such a methodology would involve literally thousands of emission factors, however, and is thus beyond the scope of this report. Instead, EPA has determined the average altitude where the population above 1,800 feet (the altitude at which these scenarios first apply) resides and calculated an average set of emission factors based on that altitude to approximate the emission levels from vehicles above 1,800 feet. By examining the population and altitude distributions of the 20 largest U.S. cities, (excluding those in California, which has its own motor vehicle emission program) this elevation was determined to be 4,100 feet. For the purpose of this study it is assumed that the per capita ownership of light-duty vehicles does not significantly vary with altitude. Thus, population distribution is an appropriate surrogate for light-duty vehicle usage.

The 5,300 feet emission factors can be used to estimate emissions in areas above 4,000 feet. By using the 4,100 feet emission factors, emissions in areas above 1,800 feet can be determined. The difference between the total emissions calculated by these two sets of emission factors is equal to the emissions in the intermediate altitudes of 1,800 to 4,000 feet.

The second important factor used in determining high-altitude emission rates is vehicle age. This is important since emissions tend to increase with vehicle usage. To estimate lifetime emissions, emission factors were determined for vehicles that were halfway through their average lifetimes (i.e., 50,000 miles). The actual equations used in this procedure can be found in Tables IV-1 and IV-2.

Table IV-3 contains emission factors for the 4,100 feet elevation; these factors were obtained by interpolating values from Tables IV-1 and IV-2. The emission factors developed to determine total emissions do not include the potential benefits of inspection/maintenance programs. This was done because most areas affected by the various scenarios are not expected to have such programs. A further discussion of the derivation of the emission factors in Tables IV-1 and IV-2 can be found in Appendix II.

Table IV-3

Average Lifetime Emission Rates for 1984-88
Light-Duty Vehicles at 4,100 Feet (g/mi)[a]

Scenario	Pollutant	Vehicle Class LDGV	LDDV
1	HC	1.26	0.54
	CO	17.61	1.52
	NOx	1.05	1.0
	Evap. HC	0.10	-
3	HC	1.34	0.64
	CO	15.72	2.14
	NOx	1.09	1.0
	Evap. HC	0.12	-
Uncontrolled	HC	1.41	0.88
	CO	16.47	2.14
	NOx	1.04	1.0
	Evap. HC	0.12	-

[a] The exhaust emission rates in this table were derived by interpolating those found in the previous 2 tables for 1,800 and 5,300 feet. Derivation of the evaporative hydrocarbon emission factors is discussed in the text and presented in Table IV-6. The uncontrolled high-altitude emission factors used to derive the above intermediate uncontrolled emission factors are given in Appendix II.

From Table IV-1, it is apparent that under scenario 1 the LDGV lifetime emission levels for CO are significantly greater than those for the other control scenarios at 1,800 feet. This is the result of one of the most uncertain assumptions used in developing the emission factors for this analysis (i.e., the expected failure rate for feedback emission control systems).

In Chapter III, it was estimated that manufacturers would need to replace existing nonfeedback emission control systems with feedback systems to meet the stringent all-altitude requirements of scenario 1. Current information indicates that some in-use feedback systems are subject to catastrophic failures which cause CO emissions to increase well beyond allowable levels. Since nonfeedback systems do not exhibit such gross failures, emissions in both low- and high-altitude areas of the country could increase with a switch to feedback systems. However, the data base with which these emission factors were developed is very limited and extrapolating these results to characterize the behavior of feedback systems in the future is speculative. Indeed, it is possible that additional information will show markedly lower failure rates than are assumed in this analysis. If this occurs, the potential adverse impact could be moderated or eliminated at low altitude and emission reductions like those found under scenario 2 may be possible at high altitude. The sensitivity of the analysis to such a reduction in the expected catastrophic failure rates for feedback vehicles in scenario 1 is discussed further at the end of this chapter.

3. Number of Vehicles

Nationwide sales projections of new light-duty vehicles for each year are presented in Table IV-4. These projections, published by Data Resources Corporation,[5] take into account such factors as the driving-age distribution of U.S. citizens, changes in real disposable income, and unemployment estimates. The percentage of diesel-powered vehicles in the total fleet was taken from previous EPA estimates made to support the recently promulgated particulate emission standards from LDDVs and LDDTs.[6]

As discussed earlier, the scenarios being evaluated do not always affect the emissions performance of each car sold in this country. Scenario 2 and the base scenario only apply to vehicles sold above 4,000 feet and scenarios 1 and 3 have intermediate altitude control in addition to that at high altitude. Thus, sales projections need to be determined for areas affected by each of the scenarios. Based on cities whose population is over 10,000 (excluding those in California), EPA found that approximately 5.25 percent of the U.S. population resides above 1,800 feet and 3.1 percent above 4,000 feet.

For the purposes of this study, it will be assumed that all cars sold above 4,000 feet will comply with high-altitude standards as depicted by the various scenarios. (The fraction

Table IV-4

Nationwide Sales Projections of Light-Duty Vehicles[5,6] (millions of vehicles)

Year	Gasoline-Fueled	Diesel-Powered
1984	10.5	1.1
1985	10.3	1.3
1986	9.9	1.6
1987	9.5	1.9
1988	9.4	2.0
5-Year Total	49.6	7.9

of cars above the ceilings for which the standards apply is too small to significantly affect the outcome of this analysis.) Scenarios 1 and 3, therefore, affect the emissions of 5.25 percent of the non-California, light-duty motor vehicle fleets, while scenario 2 and the base scenario will apply to 3.1 percent of these vehicles. As previously stated, it is assumed that population distribution is an appropriate surrogate for light-duty vehicle sales.

Since the scenarios being analyzed do not apply to California for reasons discussed earlier, the above-mentioned intermediate- and high-altitude sales fractions should apply to the nationwide sales estimates in Table IV-4 minus those in California. Population estimates indicate that roughly 10 percent of the nation resides in California.[7] Therefore, assuming this percentage remains fairly constant for the years being studied and that light-duty vehicle sales are proportional to the population distribution, the numbers of vehicles subject to emission control under the various scenarios can be readily calculated and are shown in Table IV-5.

4. Evaporative Hydrocarbon Emissions

The 1982-83 interim high-altitude emission regulations call for an evaporative hydrocarbon emission standard of 2.6 grams per test for light-duty gasoline-fueled vehicles and trucks; the low-altitude standard is 2.0 grams per test.[1] Each test consists of a diurnal and a hot-start portion in order to simulate actual evaporative conditions.[8] To determine the amount of evaporative hydrocarbons emitted per mile, results from the hot-start test are first multiplied by the expected number of trips per day. Next, results from the diurnal test are added to this product and the sum is divided by the number of miles traveled per day. Based on in-use data and the above-mentioned standards, evaporative hydrocarbon emissions up to 1,800 feet are 0.10 grams per mile (Table IV-6). Similarly, 0.13 grams of evaporative hydrocarbons are emitted per mile at 5,300 feet. By interpolating the inputs used to derive these emission rates, it was determined that 0.12 grams of evaporative hydrocarbons are emitted per mile at 4,100 feet. Evaporative emissions under the various scenarios were then determined by using these emission factors together with the same vehicle miles traveled used to determine total exhaust emissions.

B. Presentation and Discussion of Results

Following the procedures outlined in the previous section, total hydrocarbon (HC), carbon monoxide (CO) and oxides of nitrogen (NOx) emissions from 1984-88 LDVs were determined for each scenario. These are given in Tables IV-7 and IV-8. In any evaluation of pollution control options, a comparison of the relative amounts of emission reduction is beneficial. Such a presentation can be found in Tables IV-9 and IV-10.

Table IV-5

Number of New Vehicle Sales in Selected Areas for Indicated 5-Year Periods (millions of vehicles)

	LDGV[a]	LDDV
Scenarios 1 and 3 (above 1,800 feet)	2.34	0.37
Scenarios 2 and the Baseline (above 4,000 feet)	1.38	0.22

[a] The 5-year period for LDVs is 1984-88.

Table IV-6

Determination of Evaporative Hydrocarbon Emission Levels[a]

Altitude (feet)	Hot Start (grams/test)	Trips/Day	Diurnal (grams/test)	Miles/Day	Emission Rate (grams/mile)[b]
1,800	0.63	3.05	1.07	31.1	0.10
4,100	0.75	3.05	1.28	31.1	0.12
5,300	0.82	3.05	1.39	31.1	0.13

[a] Values reported for 1,800 and 5,300 feet were based on in-use data. The 4,100 values were obtained by interpolation.

[b] Evaporative Emission Rate = $\frac{(HS)(TPD) + D}{MPD}$

Where:

HS = Hot Start
TPD = Trips Per Day
D = Diurnal
MPD = Miles Per Day

Table IV-7

Total Lifetime Emissions of 1984-88
LDVs Above 4,000 Feet (1,000 metric tons)

Scenario	Pollutant	Vehicle Class LDGV	LDDV
Base and #3	HC	191.8	15.18
	CO	2394	54.34
	NOx	149.0	22.0
	Evap. HC	17.94	-
1	HC	176.7	11.88
	CO	2625	33.44
	NOx	143.5	22.0
	Evap. HC	13.8	-
2	HC	178.0	1.88
	CO	2063	33.44
	NOx	149.0	22.0
	Evap. HC	13.8	-

Table IV-8

Total Lifetime Emissions of 1984-88 LDVs from 1,800-4,000 Feet for Affected Scenarios (1,000 metric tons)

Scenario	Pollutant	Vehicle Class	
		LDGV	LDDV
Base [a]	HC	122.9	9.5
	CO	1302	24.86
	NOx	109.5	15.0
	Evap. HC	10.2	-
1	HC	118.2	8.12
	CO	1496	22.76
	NOx	102.2	15.0
	Evap. HC	9.6	-
3	HC	121.8	8.52
	CO	1284	24.86
	NOx	106.1	15.0
	Evap. HC	10.2	-

[a] Note that the base scenario calls for no special standards for these altitudes. The emission factors used here come from Table IV-3 and Appendix II, adjusted to the desired altitude by the same procedures discussed previously. Evaporative emissions are the same as those in scenario 3. These base scenario emission levels are used to determine emission reductions from scenarios 1 and 3 in intermediate altitudes.

Table IV-9

Lifetime Emission Reductions for 1984-88 High-Altitude Vehicles Relative to Base Case for Regions Above 4,000 Feet (metric tons)

Scenario	Pollutant	Vehicle Class LDGV	LDDV
1	HC	15,200	3,300
	CO	-231,000	20,900
	NOx	-5,500	0
	Evap. HC	4,140	-
	Total HC	19,340	3,300
2	HC	13,800	3,300
	CO	331,000	20,900
	NOx	0	0
	Evap. HC	4,140	-
	Total HC	17,940	3,300
3	HC	0	0
	CO	0	0
	NOx	0	0
	Evap. HC	0	0
	Total HC	0	0

Table IV-10

Lifetime Emission Reductions for 1984-88
High-Altitude Vehicle Relative to Base Case
for Regions Between 1,800 and 4,000 Feet (metric tons)

Scenario	Pollutant	Vehicle Class LDGV	Vehicle Class LDDV
1	HC	4,700	1,380
	CO	-194,000	2,100
	NOx	-7,300	0
	Evap. HC	600	-
	Total HC	5,300	1,380
3	HC	1,100	980
	CO	18,000	0
	NOx	3,400	0
	Evap. HC	0	-
	Total HC	1,100	980

As shown in Tables IV-9 and IV-10, implementing scenario 1 would reduce exhaust HC emissions from 1984-88 LDGVs by 15,200 metric tons in areas which lie above 4,000 feet. In areas between 1,800 and 4,000 feet, an additional reduction of 4,700 metric tons beyond those provided by the base case could be realized.

Looking at the results for CO emissions in these areas, it is obvious that scenario 1 may have significant detrimental effects. Above 4,000 feet, 231,000 more metric tons of CO could be emitted under scenario 1 than under the base scenario. From 1,800 to 4,000 feet, an additional 194,000 metric tons could be emitted. These emission penalties, as discussed earlier, are due to the projected higher emission rates of feedback vehicles when they undergo catastrophic failure. (Scenario 1 would require that essentially all light-duty gasoline-fueled vehicles be equipped with feedback systems, as opposed to only 69 percent under the other scenarios.) However, the predicted increase in CO is particularly sensitive to the failure rate that has been assumed in developing the emission rates used in this analysis. The failure rate may, in reality, be far less. The effect of such a decrease in the failure rate is further discussed at the end of this chapter.

NOx emissions would decrease under scenario 1 by 5,500 metric tons in regions above 4,000 feet and by 7,300 metric tons between 1,800 and 4,000 feet. Similarly, evaporative HC emissions would decrease under scenario 1 by approximately 4,740 metric tons above 1,800 feet. This is due to the application of larger canisters (as described in the Technology section). These evaporative HC reductions plus reductions in exhaust HC emissions yield a total HC reduction of approximately 26,640 metric tons for scenario 1.

Again, if the assumed catastrophic failure rates for feedback vehicles in this analysis are valid, scenario 1 will also affect emissions in areas below 1,800 feet since vehicles sold at lower elevations would also adopt feedback systems. The effects this might have on emissions in these areas is indicated by Table IV-1. HC emissions from 1984 and later model year LDGVs would decrease by 0.8 percent but CO emissions would rise by 18.3 percent. NOx emissions would decrease by 8.3 percent. While the increases in CO emissions do not appear to be significant, it is important to remember that these increases would occur over approximately 95 percent of the nationwide non-California fleet. Table IV-4 shows that roughly 47 million vehicles would be so affected in the years being studied. Thus, the implementation of scenario 1 would cause CO emissions from 1984-88 light-duty, gasoline-fueled vehicles to increase by approximately 10,900,000 metric tons in areas below 1,800 feet. However, as mentioned before, the estimated rate of catastrophic failure is tenuous at best and could easily change in the future. The effect of lowering the failure rate will be examined at the end of this chapter.

Comparisons of scenario 2 to the base scenario in terms of total emissions can be found in Table IV-9. This option, if implemented, would decrease exhaust HC emissions from 1984-88 LDGVs by 13,800 metric tons and lower CO emissions by 331,000 metric tons in regions above 4,000 feet. No further NOx reductions would result under scenario 2 but an additional 4,140 metric tons of evaporative HC emissions would be removed from the atmosphere in these high-altitude areas. This would yield a total HC reduction of roughly 17,900 metric tons. In other areas of the country, scenario 2 and the base scenario have the same emission characteristics.

To examine the benefits of requiring LDGVs sold in intermediate regions to comply with proportional standards similar to those for high-altitude areas under the 1982 and 1983 interim standards, scenario 3 was devised. As mentioned earlier, scenario 3 and the base scenario would offer the same emission reduction potential in areas above 4,000 feet. From Table IV-10, it can be seen that 1,100 metric tons of HC and 18,000 metric tons of CO would be removed per year under this scenario in intermediate altitudes relative to the base scenario, NOx emissions would not change in this scenario over the base.

In conclusion, even though scenario 1 would reduce HC emissions nationwide, the potential negative effect of catastrophic failures in feedback-equipped vehicles could cause CO emissions to increase throughout the country. If the assumed failure rate for feedback systems is valid, scenario 1 does not appear to be a viable alternative to the base scenario. Scenario 2 would apparently reduce emissions from light-duty gasoline-powered vehicles in high-altitude areas more than any other option. While scenario 3 would not further reduce emissions over the base scenario above 4,000 feet, it would reduce HC, CO, and NOx emissions in regions of the country lying between 1,800 and 4,000 feet, scenario 2 would not. However, high-altitude areas are in greater need of improved emission control than the intermediate areas, and the CO emission reduction offered by scenario 2 is much greater than that of the other scenarios. Also, relatively little difference lies in the reduction potential for the other pollutants among the scenarios. Thus, scenario 2 appears to offer the greatest emission reductions of all the scenarios which were analyzed as alternatives in this report to continuing the current proportional standards.

When considering the impact of the various options on emissions from diesel-powered light-duty vehicles (LDDVs), comparisons are simplified. Returning to Tables IV-9 and IV-10, scenarios 1 and 2 offer the same reduction potentials in regions above 4,000 feet. (This is because both scenarios require essentially the same type of control technology.) The emissions reductions for these scenarios are approximately 3,300 metric tons of HC and 20,900 metric tons of CO from

1984-88 vehicles. As was the case with LDGV emissions, scenario 3 and the base scenario produce the same benefits in areas above 4,000 feet. No NOx reductions are expected from the control technology which is applied to these vehicles. Since diesels are not a significant source of evaporative HC emissions (due to inherent diesel fuel characteristics), diesel evaporative emissions are not evaluated in this report.

In areas between 1,800 and 4,000 feet, scenario 1 would reduce LDDV HC emissions by roughly 1,380 metric tons and CO emissions by 2,100 metric tons. Scenario 3, the only other control option which controls emissions in this range, would reduce HC emissions by 980 metric tons. No benefit is seen with regard to CO reductions since diesels emit relatively small amounts of CO compared to gasoline-powered vehicles and can comply with either the statutory or proportional standards without significant modifications.

In order to gain further insight into the environmental consequences of the four scenarios being examined, an analysis of the air quality impact was performed. This is discussed in the following section. After the results of that analysis are presented and discussed, the effect of critical assumptions made in this environmental impact study will be assessed.

III. AIR QUALITY

A. Basic Methodology

In order to evaluate the relative air quality impacts of the control scenarios, two computer models were used which attempt to represent the relationship between pollutant emissions and the resulting ambient pollutant concentration. These are the Rollback and Emperical Kinetic Modeling Approach (EKMA) models. Rollback was used to study CO and NOx while the more complex EKMA model was utilized for ozone. Detailed discussions of these models can be found in the literature.[9,10]

In preparing the air quality projections, future control strategies and growth rates were applied to baseline emission rates for various non-motor vehicle source categories taken from the National Emissions Data System (NEDS).[11] These data, in combination with similar projections made for motor vehicle sources of air pollution (discussed below), allow an evaluation of the effects on air quality of the various scenarios. Due to the large number of composite emission factors used in this analysis, they are not included in this chapter but are listed in Reference 11.

With both the Rollback and EKMA models, the relative changes from scenario-to-scenario are more reliable than the absolute predictions of pollutant concentration. Following this guide, results are compared to the baseline emission inventories in two ways: 1) changes in the percent reductions from the base year, 1979, and 2) changes in the number of NAAQS violations expected. This was done for 1986 through 1990 and in 1993 and 1995.

The air quality analysis in this chapter focuses on those high-altitude cities which are projected to maintain or develop air quality problems in the future. For CO, these are: Denver, Colorado Springs, Ft. Collins, Greeley, Albuquerque, and Salt Lake City. For ozone, Denver and Salt Lake City were modeled. For NOx, only Denver is expected to have difficulties meeting the NAAQS.

B. Growth Rates and Stationary Source Control Assumptions

To project base year inventories and air quality concentration levels, it is necessary to estimate the future activity levels of both mobile and stationary pollution sources. In general, two sets of growth rates were used in this analysis to provide a range of air quality estimates for each pollutant. A special zero-growth rate case was also run for CO and NOx to indicate the air quality impact of a significant error in estimated growth rates. However, since high-altitude areas currently experience relatively high-growth rates, the results of this analysis are not discussed here and are instead presented in Appendix II.

As shown in Table IV-11, LDV and LDT vehicle miles traveled (VMT) were projected to grow by 0.4 to 2.4 percent per year, compounded. This range was arbitrarily established as being ±1 percentage point of the historical growth rate for these vehicle classes.[9] Similarly, HDG and HDD VMT were projected to change at the rate of -3 to -1 and 4 to 6 percent, respectively. These heavy-duty growth rates are based on sales figures indicating that diesel trucks are replacing gasoline-powered trucks in the heavy-duty fleet.[12]

The stationary and off-highway mobile source growth rates which were used in this analysis are consistent with EPA's most recent guidelines for conducting air quality modeling analyses. The various growth rates for each pollutant are presented in Appendix II. The additional assumptions regarding stationary source emission controls are described in References 9 and 13.

C. Presentation and Discussion of Results

As mentioned earlier, Rollback and EKMA results from scenarios 1, 2, and 3 will be compared to those from the base scenario in two ways: changes in projected numbers of NAAQS violations and relative percentage reductions in pollutant concentrations. The results in the first half of Tables IV-12

Table IV-11

Growth Rates for Light-Duty Vehicles, Light-Duty Trucks, and Heavy-Duty Vehicles

	Annual Compound Growth Rate (percent) Low	High
Light-Duty Gasoline Vehicles	+0.4	+2.4
Light-Duty Gasoline Trucks	+0.4	+2.4
Heavy-Duty Gasoline Vehicles	-3.0	-1.0
Light-Duty Diesel Vehicles	+0.4	+2.4
Heavy-Duty Diesel Vehicles	+4.0	+6.0

Table IV-12

Average Percent Reduction in Expected Maximum 1-Hour Ozone Concentrations from 1979 Base Year in Denver and Salt Lake City (low and high growth)[a]

With Inspection/Maintenance

Scenario	1986 Low	1986 High	1987 Low	1987 High	1988 Low	1988 High	1989 Low	1989 High	1990 Low	1990 High	1993 Low	1993 High	1995 Low	1995 High
Base	24-32	22-28	26-34	23-30	27-35	24-32	28-36	25-32	29-37	25-33	29-38	25-32	28-36	24-31
1	24-32	22-29	26-34	23-30	28-36	24-32	28-37	25-33	29-38	25-34	29-39	25-33	29-38	25-32
2	24-32	22-29	26-34	23-30	27-35	24-32	28-36	25-33	29-37	25-33	29-38	25-32	28-36	24-31
3	24-32	22-28	26-34	23-30	28-36	24-32	28-37	25-32	29-37	25-33	29-38	25-32	28-36	24-31

Without Inspection/Maintenance

Scenario	1986 Low	1986 High	1987 Low	1987 High	1988 Low	1988 High	1989 Low	1989 High	1990 Low	1990 High	1993 Low	1993 High	1995 Low	1995 High
Base	21-27	18-24	22-29	19-25	24-31	20-27	24-32	21-28	25-33	22-28	26-34	22-29	26-34	21-28
1	21-27	18-24	22-29	20-26	24-31	20-27	25-32	21-28	25-34	22-29	27-35	23-29	26-35	22-29
2	21-27	18-24	22-29	19-25	24-31	20-27	25-32	21-28	25-34	22-29	26-35	22-29	26-35	21-28
3	21-27	18-24	22-29	19-25	24-31	20-27	25-32	21-28	25-34	22-29	26-35	22-29	26-35	21-28

[a] Note that a range of values are reported. These reflect two different ratios of HC/NOx ambient concentrations, as discussed in the text. Values from the higher HC/NOx ratio are listed first.

through IV-15 are based on controls placed on light-duty vehicles and assume the presence of inspection/maintenance (I/M) programs in these areas. Similar results without I/M are found in the lower half of these tables. Light-duty trucks will be discussed separately in Chapter X.

Tables IV-12 and IV-13 contain the air quality impacts of ozone. It should be pointed out that the hydrocarbon emission factors used as input to these and other ozone projections in the air quality analysis contain contributions made by evaporative emission losses. As can be seen, there is a range of values reported in these tables. This was done in order to reflect two different possible ratios of nonmethane hydrocarbon to oxides of nitrogen ambient concentrations (i.e., 7 to 1 and 9.5 to 1). (The EKMA model relies upon such a technique to yield ozone projections.) The future ozone air quality should, therefore, fall within the range of the estimates.

Table IV-12, shows that only scenarios 1 and 2 are predicted to yield reductions in the expected maximum ozone concentrations in Denver and Salt Lake City below that already provided by the base scenario. Table IV-13 shows that in 1989 and 1990 without I/M, one less violation of the ozone NAAQS could occur under the high-growth case of both scenarios 1 and 2, compared to the base scenario. In 1993, only scenario 1 appears to provide fewer violations than the base scenario, one less under high growth. All scenarios lead to the same number of violations in 1995.

The results with I/M indicate that the number of exceedances is projected to be the same for each scenario in all years except 1989. In that year, scenario 1 could lead to one less violation under low growth.

Tables IV-14 and IV-15 contain similar results for CO levels as only scenarios 1 and 2 offer different projections from the base scenario. Looking just at scenario 1, one more violation is projected for 1993 for the high-growth, no-I/M case compared to the base scenario (Table IV-15). In other years, there appear to be no high-growth differences in the number of exceedances under these two scenarios. With I/M, Table IV-14 shows that scenario 1 should result in a slightly greater reduction in the expected second highest 8-hour CO concentrations in several of the years studied compared to the base scenario. However, this benefit is quite small since scenario 1 and the base scenario do not differ in the number of projected violations under the I/M case (see Table IV-15).

Scenario 2 appears to be the only alternative to the base scenario which can offer fewer CO NAAQS violations. Without I/M, the expected benefits of scenario 2 begin in 1986, the first year investigated, when one less violation is projected under the low-growth case. In each year after that until 1993,

Table IV-13

Number of Violations of Ozone NAAQS
in Denver and Salt Lake City (Low and High Growth)[a]

With Inspection/Maintenance

Scenario	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Base	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-0	0-1	0-0	0-1	0-1	0-1
1	0-1	0-1	0-1	0-1	0-1	0-1	0-0	0-1	0-0	0-1	0-0	0-1	0-1	0-1
2	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-0	0-1	0-0	0-1	0-1	0-1
3	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-0	0-1	0-0	0-1	0-1	0-1

Without Inspection/Maintenance

Scenario	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Base	0-2	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	0-2	0-1	0-2	0-1	1-2
1	0-2	1-2	0-1	1-2	0-1	1-2	0-1	0-2	0-1	0-1	0-1	0-1	0-1	1-2
2	0-2	1-2	0-1	1-2	0-1	1-2	0-1	0-2	0-1	0-1	0-1	0-2	0-1	1-2
3	0-2	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	0-2	0-1	0-2	0-1	1-2

[a] Note that a range of values are reported. These reflect two different ratios of HC/NOx ambient concentrations, as discussed in the text. Values from the low HC/NOx ratio are listed first.

Table IV-14

Average Percent Change in Expected Second Highest 8-Hour CO Concentrations from 1979 Base Year in 6 High-Altitude Cities (low and high growth)[a]

With Inspection/Maintenance

Scenario	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Base	55	48	60	54	64	58	68	61	71	65	76	69	78	70
1	55	48	60	54	65	58	69	62	71	65	77	70	78	71
2	55	49	61	55	66	59	69	63	72	65	77	71	80	73
3	55	48	60	55	64	58	68	61	71	65	76	69	78	70

Without Inspection/Maintenance

Scenario	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Base	45	37	51	42	55	47	60	51	63	54	70	61	72	62
1	45	37	51	42	55	47	60	51	63	54	68	59	71	60
2	46	38	51	43	57	48	61	53	64	56	71	62	74	65
3	45	37	51	42	55	47	60	51	63	54	70	61	72	62

[a] The cities modeled are Denver, Colorado Springs, Ft. Collins, Greeley, Albuquerque, and Salt Lake City.

Table IV-15

Number of Violations of CO NAAQS
in 17 High-Altitude Counties (low and high growth)[a]

With Inspection/Maintenance

Scenario	1986 Low	1986 High	1987 Low	1987 High	1988 Low	1988 High	1989 Low	1989 High	1990 Low	1990 High	1993 Low	1993 High	1995 Low	1995 High
Base	7	18	2	8	0	3	0	1	0	0	0	0	0	0
1	7	18	2	8	0	3	0	1	0	0	0	0	0	0
2	7	16	2	7	0	3	0	1	0	0	0	0	0	0
3	7	18	2	8	0	3	0	1	0	0	0	0	0	0

Without Inspection/Maintenance

Scenario	1986 Low	1986 High	1987 Low	1987 High	1988 Low	1988 High	1989 Low	1989 High	1990 Low	1990 High	1993 Low	1993 High	1995 Low	1995 High
Base	21	43	10	28	3	17	1	9	0	4	0	0	0	0
1	21	43	10	28	3	17	1	9	0	4	0	1	0	0
2	20	43	10	26	3	14	0	8	0	3	0	0	0	0
3	21	43	10	28	3	17	1	9	0	4	0	0	0	0

[a] *The cities modeled are Denver, Colorado Springs, Ft. Collins, Greeley, Albuquerque, and Salt Lake City.*

scenario 2 may yield from one to three fewer violations than the base scenario, with benefits appearing under both low- and high-growth rates. In 1993 and 1995, no violations are projected under either the base case or scenario 2. Table IV-14 indicates, however, that lower CO concentrations could be expected in these two years under scenario 2.

With I/M, the advantages of scenario 2 over the base scenario still appear to be present, although they are not as pronounced. Table IV-14 indicates a general trend of lower CO concentrations under scenario 2 as compared to the base scenario. However, from Table IV-15, the number of CO NAAQS violations under these two scenarios are projected to differ only in 1986 and 1987 when scenario 2 has 1-2 less violations.

As was mentioned earlier, none of the potential alternative control scenarios nor the base scenario have high-altitude NOx standards that are numerically different from those at low altitudes. This is because NOx emissions generally decrease with altitude. The rollback analysis was nonetheless performed for Denver, the only high-altitude city which is projected to have a NOx problem, to examine the possible situation whereby some control strategies for HC or CO could detrimentally affect NOx emissions. The results of this analysis indicate that there are no significant air quality differences among the scenarios. For this reason, the results of the NOx air quality analysis are not presented in this chapter. (The actual NOx air quality data are included in Chapter XI.)

In conclusion, without I/M, scenarios 1 and 2 could reduce ozone concentrations slightly more than the base scenario in Denver and Salt Lake City. With I/M, only scenario 1 appears to reduce ozone concentrations. In terms of violation of the ozone NAAQS standard, scenarios 1 and 2 could yield one less violation in 1989 and 1990 under the high-growth, no-I/M case. Scenario 1 alone could yield one less violation in 1993 under the high-growth, no-I/M case. With I/M, scenario 1 is projected to provide one less violation in 1989 under low growth. Thus, scenario 1 appears to have a slight overall advantage with regard to ozone NAAQS violations. Scenario 2, however, seems to offer by far the most benefit with regard to CO air quality. It is projected to reduce the second highest 8-hour concentrations by as much as 3 percent and provide the fewest NAAQS exceedances. No significant NOx air quality differences are expected among the scenarios.

These air quality projections must be used with a considerable degree of caution, however. The errors associated with air quality models can be considerable. One source of potential error involves the emission factors projected for future model years which are based on limited data. Also, due to time and resource constraints many of the input parameters used in the model, such as growth rates, were national averages and not site-specific values. While ranges of values were used in many cases to ensure the inclusion of varying local values, it is still possible that the use of site-specific input data would result in more optimistic or pessimistic projections. This is especially true when these improved input data are coupled with more sophisticated air quality models optimized for a specific locale. Thus, the air quality projections made here can serve as a general indicator of when most high-altitude areas will comply with the NAAQS for CO and ozone. However, they cannot be used to predict with confidence when any one, or all, of the areas will comply with the NAAQS.

Unfortunately, the absolute air quality need for further control beyond that provided by the base scenario depends on the number of violations of the NAAQS occurring under the base scenario. For ozone, only one or two violations are projected in 1986 or beyond under any scenario. At the same time, these violations persist to beyond 1995. While additional control would appear to be needed to bring these one or two areas into compliance, more detailed analyses are necessary to ensure that this is the case. At the same time, those areas just complying with the NAAQS should also be examined in greater detail to ensure that they will indeed comply in the future. The same qualifications hold for any conclusions concerning attainment of the NAAQS for CO. Thus, while further control appears to be merited at this time, a firm decision cannot be made. Further air quality analysis will be necessary before this decision can be made with confidence.

IV. SENSITIVITY ANALYSIS

Of the assumptions made in this analysis, two appear to have the possibility of changing the conclusions drawn as to which of the alternative scenarios is most beneficial: 1) the catastrophic failure rate of feedback systems, and 2) the impact of low-altitude LDVs at high altitude.

A. Catastrophic Failure Rate

The environmental impact of scenario 1 is greatly influenced by the assumed catastrophic failure rate for feedback systems. This failure rate is important in scenario 1 because EPA expects the stringent requirements of meeting the statutory standards at all altitudes to force manufacturers to replace nonfeedback systems, currently 31 percent of the market, with feedback systems. Nonfeedback systems do not require electronic controls; therefore, they do not exhibit catastrophic failures that can lead to excessive in-use vehicle emissions. Because of this, any increase in the use of feedback systems throughout the nation has the potential to affect air quality adversely in both low- and high-altitude areas.

The effect of a substantial reduction in the catastrophic failure rate assumed in this analysis needs to be considered because the currently projected failure rate was derived from a very limited data base. Only a small number of feedback systems have currently been tested in the Agency's in-use surveillance programs and many of the test vehicles in these programs were equipped with "early" feedback systems which may be less reliable than future designs. Thus, EPA expects that as more information becomes available the observed rate of catastrophic failures will change. The direction of this change is, of course, unknown at this time, but it is most likely that the rate would decrease. If this does occur, the effect of scenario 1 on emissions in areas above 4,000 feet may be much like the benefits of scenario 2, since both strategies control emissions at high-altitude to statutory levels. Benefits may also occur at intermediate altitudes (1,800 feet to 4,000 feet) that are greater than scenario 3 which controls emissions to only proportional levels. Therefore, depending on the assumed catastrophic failure rate of feedback systems, scenario 1 could have a positive environmental impact instead of the negative effect that was projected in the air quality analysis. For example, the CO benefit may be a total reduction of approximately 350,000 metric tons as opposed to an increase of approximately 425,000 metric tons.

B. Low-Altitude Vehicles at High Altitude

The recreation popularity of high-altitude areas and the relatively high population growth rate of high-altitude states could significantly affect the outcome of this analysis. People who visit and migrate to these areas from low-altitude sections of the country often bring low-altitude vehicles with them. Under fixed-point high-altitude emission standards, these low-altitude vehicles would pollute more than their counterparts sold in high-altitude areas since many of them would not be able to compensate for the lower air density at higher elevations. (As mentioned in Chapter III, approximately 69 percent of the future low-altitude LDGV fleet under the fixed-point scenarios, number 2 and the base scenario, are expected to be equipped with closed-loop emission control systems which will be able to compensate to some extent for altitude effects.) This implies that the estimates in this chapter of future pollution levels under the fixed-point scenarios are somewhat lower than will actually occur.

Estimates made of future pollution levels under the continuous scenarios, numbers 1 and 3, would not be affected by bringing low-altitude vehicles to high-altitude regions since they require all vehicles to be able to compensate for changes in altitude automatically. Thus, if enough cars in high-altitude areas (above 4,000 feet) were in fact from lower altitudes, the benefits of scenarios 1 and 3 could increase relative to the base scenario to such an extent that scenario 2 would no longer offer the most emissions reduction potential.

One way to examine the impact of low-altitude vehicles at high-altitude in the context of this analysis is to replace a certain fraction of the high-altitude vehicles expected to be sold there with low-altitude vehicles. Unfortunately, there are no studies available which indicate what this percentage should be. A relatively high estimate would be to assume that one out of every ten vehicles operated at high altitude is a low-altitude vehicle. This conservative approach was followed below.

To compare the effectiveness of scenarios 1, 2, and 3 to the base scenario in this condition, emission factors must be determined for low-altitude vehicles in high-altitude areas. Table IV-16 contains these emission factors which were derived based on the in-use surveillance program mentioned earlier. As can be seen by comparison to Table IV-1, vehicles not equipped for high-altitude conditions would be expected to emit approximately 22 percent more HC and 47 percent more CO than they would at low-altitude. Since NOx emission rates naturally decrease with increasing altitude, they are not included in this sensitivity analysis.

By weighting the emission factors in Tables IV-2 and IV-16 for a fleet comprised of nine high-altitude vehicles to every one low-altitude vehicle, the average lifetime HC and CO emission factors for 1984-88 model year LDGVs become 1.40 g/mi and 17.46 g/mi, respectively, for the base scenario. For scenario 2, this same procedure yields adjusted emission factors of 1.31 g/mi for HC and 15.30 g/mi for CO. It should be pointed out that evaporative HC emissions would also rise under scenario 2 from low-altitude cars brought to high-altitude regions since the canisters used at low-altitude would not be able to control evaporative emissions to the level specified by scenario 2. However, this emission increase is negligible and will not be considered further.

The two sets of adjusted emission factors described in the previous paragraph, can be multiplied by the same sales and mileage data discussed earlier in this chapter, to determine the revised total lifetime emissions from 1984-88 model year LDGVs above 4,000 feet. According to this methodology, approximately 1,400 more metric tons of HC (113,200 versus 111,800) and 15,000 more metric tons of CO (2,409,000 versus 2,394,000) would be emitted over the lifetime of 1984-88 model year LDGVs sold above 4,000 feet under the base scenario if one out of every ten was a low-altitude vehicle. For scenario 2, 2,800 more metric tons of HC (180,800 versus 178,000) and 48,000 more metric tons of CO (2,111,000 versus 2,063,000) would be emitted by factoring in the impact of low-altitude vehicles.

The revised emission reductions, relative to the new base scenario, for scenarios 1, 2, and 3 are listed in Table IV-17

Table IV-16

Emission Rates of 1984-88 Model Year Low-Altitude Vehicles at 5,300 Feet Under the Base Scenario and Scenario 2[a]

	Pollutant	
	HC	CO
Zero-Mile Emission Level (g/mi)	0.55	7.44
Deterioration Rate (g/mi/10,000 miles)	0.19	2.21
Average Lifetime Emission Level (g/mi)	1.50	18.49

[a] Emission rate = ZML + (M)(DR)

Where:

ZML = Zero-Mile Level
M = Cumulative Mileage/10,000 (cumulative mileage = 50 miles, half the lifetime mileage).
DR = Deterioration Rate

Table IV-17

Lifetime Emission Reductions for 1984-88 LDGVs Relative to Base Scenario for Regions Above 4,000 Feet (metric tons)

Scenario	Pollutant	With Low-Altitude Vehicles	Without Low-Altitude Vehicles
1	HC	16,600	15,200
	CO	-216,000	-231,000
	NOx	-1,300	-5,500
	Evap HC	4,140	4,140
	Total HC	20,740	19,340
2	HC	12,400	13,800
	CO	298,000	331,000
	NOx	0	0
	Evap HC	4,140	4,140
	Total HC	16,540	17,940
3	HC	1,400	0
	CO	15,000	0
	NOx	0	0
	Evap HC	0	0
	Total HC	1,400	0

for areas above 4,000 feet. For comparison, this table also includes the emission reductions from Table IV-9 which were generated without accounting for low-altitude vehicles at high-altitude. As can be seen, the overall merits of scenario 2 still appear to outweigh those of scenarios 1 and 3 since the potential CO penalty associated with scenario 1 remains sizeable. The consequences of adding low-altitude vehicles to high-altitude areas with regard to cost effectiveness will be addressed in Chapter VI.

V. SUMMARY

In this chapter, the emissions and air quality characteristics of the three basic control options were compared to the base scenario (a continuation of the 1982 and 1983 interim high-altitude standards). The analysis found that scenario 1 would reduce HC and NOx emissions in areas above 1,800 feet. Unfortunately, this scenario also appears to have the potential for increasing CO emissions in all parts of the country due to the predicted catastrophic failures of the requisite emission control systems. Neither scenario 2 nor 3 exhibited such potential problems as both yielded reductions in HC and CO emissions. Under scenario 2, the projected HC emission reductions at high-altitude were slightly less than that of scenario 1 but substantially greater than under scenario 3. The projected CO benefit of scenario 2, over both scenarios 1 and 3, is significant however. Because of this effect on CO, scenario 2 appears to be preferable to the other options. The air quality analysis of selected high-altitude cities verifies this finding as scenario 2 also appears to be the course of action which could provide benefits to both CO and ozone air quality beyond that provided by the base scenario. The slight HC emissions benefit of scenario 1 over scenario 2 mentioned above was large enough to yield only one less violation of the ozone NAAQS for that scenario relative to scenario 2 both with and without I/M.

Scenario 1 could still be a viable control alternative, however, in spite of its potential adverse environmental impact. The adverse impact is totally dependent on the single assumption regarding the catastrophic failure rate of the requisite technology. This assumed failure rate is based on preliminary information and may change as additional data becomes available. In fact, it is possible that the air quality impact of scenario 1 may be greater than the combined benefits of scenario 2 and 3. Therefore, the viability of scenario 1 remains to be decided in subsequent chapters.

It would appear that additional control beyond that provided by the base scenario (e.g., scenario 2) is merited, since violations of the NAAQS for ozone could persist to at least 1995. Violations of the NAAQS for CO could persist as far in the future as 1993-95 or may disappear as early as 1988, depending on external factors such as VMT growth and the presence or absence of local I/M programs. However, as discussed earlier, these projections must be used with caution because of the many known sources of potential error. Before any firm conclusions can be drawn concerning the absolute need for additional high-altitude control beyond that provided by the base scenario, more detailed air quality analysis of those areas just in and out of compliance with the NAAQS will be necessary.

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Chapter V

Economic Impact for Gasoline-Fueled Light-Duty Vehicles

I. INTRODUCTION

This chapter will examine the incremental costs of complying with each of the alternative high-altitude regulatory scenarios outlined in Chapter II relative to complying with the base scenario. This will be done by evaluating the cost to manufacturers and the cost to consumers. Manufacturers' primary expenses will involve the variable costs of adding emission control hardware to their vehicles, the fixed costs of new vehicle certification, and the development of special high-altitude calibrations. The consumer will pay for the expenses incurred by the manufacturer and, in addition, pay for a profit that the manufacturer must make on his investment. Consumers will also bear the cost or savings of any changes in vehicle maintenance or fuel economy.

Following these two sections, the aggregate cost to the nation for the first five years that high-altitude standards are in effect will be determined. After this, the socioeconomic impact on high-altitude areas and the nation of each alternative control scenario will be discussed.

II. COSTS TO MANUFACTURERS

The costs of high-altitude standards to manufacturers can be conveniently separated into two types: variable and fixed. The variable costs, which are essentially the costs of emission control hardware, will be analyzed first. This cost will be determined on a per vehicle basis in terms of the retail price equivalent (i.e., the change in the purchase price of the vehicle). The fixed costs will be analyzed next. These costs will be determined for the entire vehicle fleet and then converted to a per vehicle basis. The fixed costs are examined separately because they represent the capital investment manufacturers must make prior to the actual implementation of the standards. These fixed costs will include research and development (R&D), equipment for manufacturing control hardware, development of high-altitude calibrations, certification, and test facility additions or modifications.

A. Emission Control System Costs

In this section, the retail price equivalent (RPE) of the emission control hardware required by each control scenario will be determined. First, the methodology used in the analysis will be presented and discussed. Second, the cost of each emission control component will be estimated using this methodology. Finally, the total control hardware cost for each scenario will be summarized. The control technology upon which these cost estimates are based was identified in Chapter III.

1. Cost Methodology

In general, the RPE of emission control hardware includes the direct material, direct labor, fixed and variable overhead and profit at the vendor level, tooling expense, land and building expense, and overhead and profit at the corporate and dealer level. In this analysis, R&D is not included in the emission control hardware costs because it is not considered to be a variable cost. R&D costs will be estimated separately under "Fixed Costs." With this one exception, the RPE and estimates used in this chapter will follow the methodology used in recent regulatory analyses,[1,2] and will not be discussed in detail here. These regulatory analyses consider corporate overhead and profit, in addition to dealer overhead and profit (29 percent of the vendor level costs) since the manufacturers must receive a return on their investment. For the most part, estimates of vendor-level costs will be taken from Lindgren.[3,4]

In addition, the cost of each component depends on its production volume. For the continuous statutory or continuous proportional scenarios (numbers 1 and 3), all vehicles must be certified for use at high altitude unless they are exempted from sale at high altitude. Thus, control hardware will be installed on nearly all vehicles nationwide unless the standards can be met without additional altitude-compensating equipment. For fixed-point scenarios (the base scenario and number 2), only those vehicles sold at high altitude will require control devices (unless the vehicle can meet high-altitude standards with its normal low-altitude configuration). This amounts to only about 3 percent of all vehicles certified as was discussed in Chapter IV. Thus, the production volumes vary markedly between scenarios and hardware costs will have to reflect this variation.

In the estimates which follow, the range of costs determined for scenarios 1 and 3 is large enough to account for variations in production volumes. For scenario 2 and the base scenario, approximately 3.1 percent of vehicles are affected by a high-altitude standard. As discussed in Chapter IV, approximately 1.38 million non-California light-duty gasoline-fueled vehicles will be sold between 1984-88, and 3.1 percent of this total is approximately 280,000 vehicles annually. This will affect the costs of fixed-step aneroids. The cost for this device has been estimated by Lindgren based on a production volume of 1 million units per year. In scenario 2 and the base scenario, it is estimated that 31 percent of all high-altitude vehicles will require aneroids, corresponding to a volume of 87,000 units per year. It is assumed that these aneroids will be produced by, at most, two outside suppliers with an annual production of 38,000 units for each supplier. Therefore, the aneroid cost estimate from Lindgren must be adjusted to reflect the lower production volumes. If a 12 percent learning curve is used, as in past regulatory analyses,[2,3] an economy-of-scale factor is calculated to be 1.8. This economy-of-scale factor should be a conservatively high estimate, when considering that at most two suppliers would manufacture these aneroids. In scenario 2 only, it is estimated that 10 percent of all high-altitude vehicles will require the addition of a MAP sensor. Unlike aneroids, however, no adjustment to Lindgren's cost estimate is necessary for the MAP sensor in this scenario. These sensors already will have attained the proper economy-of-scale since they are assumed to be used in throttle body injection (TBI) systems on 59 percent of the fleet even in the absence of high-altitude standards (this is further discussed in Chapter III). Thus, only the costs of aneroids will be adjusted to the lower production volumes associated with scenario 2 and the base case.

In this analysis, the number of suppliers for emission control development is also of particular concern for estimating the total R&D cost for expanding the capability of existing electronic control units. The total number of suppliers is estimated to range from two to four, depending on the number of vehicles affected. In this case, these suppliers may be the larger vehicle manufacturers or outside suppliers, and for purposes of this analysis, it is assumed that half of the total suppliers are the vehicle manufacturers themselves. This information will be used for estimating the capital costs to manufacturers in a later section.

All costs in this analysis will be estimated in 1981 dollars. Nearly all cost estimates are taken from Lindgren[4,5] where costs are quoted in 1977 dollars. As in past regulatory analyses,[1,2,3] an 8 percent per annum inflation rate will be used to convert control hardware costs from 1977 dollars to 1981 dollars. This inflation rate can be supported by the fact that the new car price index (NCPI) for the years 1977, 1978, 1979, and 1980 was 7.2, 6.2, 7.4, and 7.5 percent, respectively. While the NCPI is much lower than the Consumer Price Index for the past 3-4 years, it is a better indicator of the specific inflation rate for vehicle manufacturing. The NCPI may reflect some lowering of profits to sell cars in the last few years. However, the 8 percent inflation rate provides some degree of compensation for the effect of such practices.

2. <u>Estimated Cost for Each Component</u>

This section analyzes the cost of each emission control component that is expected to be used to meet high-altitude standards under the various scenarios. The cost estimates are presented as RPE, and in most cases a cost range is given due to variations in the production volume, material, and design that could occur with each scenario.

The following emission control items or engine modifications will be examined in this section: electronic load control system (ELCS), fixed-step aneroid, continuous aneroid, turbocharger, feedback control system, expansion of existing electronic functions, modification of the electronic control module, and enlargement of the charcoal canister for the storage of evaporative emissions. A summary of these costs are shown in Table V-1.

a. Electronic Load Control System (ELCS). The ELCS was developed by GM and a complete description of the exact hardware included has never been given. However, from the preliminary description that is available, EPA estimates the primary components should include a manifold absolute pressure (MAP) sensor, an air temperature sensor, and an expanded capability of the microprocessor memory. The MAP sensor is currently used by GM in some of its computer command control systems and is expected to be used on over half of the vehicles produced in the future. It is estimated that the sensor's production cost is about $15 based on data in an unpublished report by DOT.[6] The air temperature sensor will also be used in over half of the vehicles. The production cost of this device is about $1.[5] Assuming about $5 to install both the MAP and temperature sensors, and $6 for corporate overhead and profit, the total hardware cost for these two sensors is about $27. Expanding the adaptive memory involves additional development of the electronic control unit (microprocessor). This cost is due mostly to research and development and is discussed separately under "Fixed Costs" later in this chapter. Thus, without the cost of expanding the adaptive memory, the RPE for the ELCS is about $27.

In conjunction with the ELCS, it may be necessary to incorporate idle speed adjustment for acceptable vehicle operation, especially for vehicles expected to meet the same standard at high altitude as well as low altitude. In Chapter III it was estimated that only those vehicles under the continuous statutory scenario applicable to 10,200 feet (scenario 1a) would require idle speed control. Little data are available on the cost of this item but one manufacturer has indicated that this cost is similar to that of an aneroid. As discussed below, an aneroid costs between $7-9; therefore, this cost applies to the idle speed control also.

b. Fixed-step aneroid. In Chapter IV, Technology Assessment, it was projected that a fixed-step aneroid would be used under fixed-point scenarios requiring that compliance be demonstrated at a single high-altitude location (2 and the base scenario). Under these scenarios, only vehicles sold at high altitude will require modification. Thus, fixed-step aneroids

Table V-1

Vehicle Hardware Costs (RPE, $1981)

Control Technique	Cost
Electronic Load Control System	$27
Idle Speed Control	7-9
Fixed-Step Aneroid	7-9
Continuous Aneroid	7-9
Turbocharger	253
Feedback Control	190-243
Expand Function of Existing Electronics	
A) Expand Microprocessor Capability	0
B) Add MAP Sensor	26
Change Electronic Modules	
A) Recalibrate	0
B) Add MAP for Fuel, Spark, and EGR	26
Enlarged Charcoal Canister	2-3
A) Statutory 10,200 feet scenarios	6
B) Statutory 6,000 feet scenarios	2-3

will be manufactured at a low production volume which will result in a relatively higher unit cost.

Fixed-step aneroids are currently used on some car and truck models to control carburetion, and most other models could easily be similarly modified. In addition, for some scenarios aneroids may be used to improve the functions of power enrichment and EGR. A fixed-step aneroid has been estimated to cost $4-5 for a production volume of about 1 million per year.[5] At most, about 3 percent of the national fleet could potentially use fixed-step aneroids (to be developed by, at most, two suppliers). As discussed earlier, an economy of scale factor of 1.8 should be a conservatively high estimate for these low production volumes. At this production volume an aneroid would cost $7-9.

c. Continuous aneroid. The continuous aneroid is more likely to be used for scenarios with continuous standards (numbers 1 and 3) and thus would be incorporated into vehicles certified and sold at all altitudes. There is currently no cost estimate available for continuous aneroids, but the major differences between this type of aneroid and that of the fixed-step aneroid is the added cost of a calibration needle able to make continuous adjustments and the decrease in cost due to larger anticipated production volumes. These effects would bring the cost of a continuous aneroid close to that of a fixed-step aneroid, which was estimated with a conservatively high economy-of-scale factor. Thus, a cost of $7-9 is used here also.

d. Turbochargers. The cost of turbocharging has been estimated by EPA for diesel-fueled light-duty vehicles,[7] and these costs should apply to gasoline-fueled vehicles as well. From these previous EPA estimates, the cost of turbocharging a 4- and 6-cylinder engine (in 1979 dollars) was $207 and $226. In 1981 dollars these costs are $241 and $264, respectively. Included in the estimate is the turbocharger itself, oil lines and other plumbing, and manifold and exhaust transition hardware. The cost of turbocharging an 8-cylinder engine is not estimated because very few, if any of these engines are expected to be produced after 1984. Since the future market shares of 4- and 6-cylinder engines is unknown, they are assumed to be produced in equal numbers. Therefore, the average cost of a turbocharger is $253.

e. Feedback control. The cost of an electronic feedback control system is difficult to estimate and EPA is not aware of any documented cost analysis. However, an attempt has been made by DOT in an unpublished report to determine the cost of a feedback control system,[6] and these estimates will be used in this analysis. For 1980 production levels, these costs come to $190-210 (1981 dollars). This cost estimate includes the following components: electronic control unit (ECU), ECU mounting bracket and screws, closed-loop wiring harness and straps, ZrO_3 oxygen sensor, MAP sensor, throttle position sensor, electromechanical carburetor solenoid, high energy ignition with electronic spark control, advance and retard solenoid for spark control revisions, tubing, valves and mounting brackets, detonation sensor, vacuum switch and idle deceleration unit, cold start switch, maintenance indicator lights, closed-loop carburetor, vortex mixer, a proportional EGR system, intake manifold revisions, and exhaust manifold revisions. The cost of the feedback control system also includes credits for the standard carburetor and backpressure EGR system.

Only vehicle manufacturers who presently produce vehicles with nonfeedback systems may need to convert their vehicles to feedback control. These manufacturers include Ford (assumed to have a 20 percent market share) and some foreign manufacturers (assumed to have an 11 percent market share). While certification data show that all of Ford's open-loop vehicles are equipped with three-way catalysts,[8] some foreign manufacturers do not currently use them. These latter vehicles will probably use three-way catalysts when converting to feedback control. The cost increment of a three-way catalyst is about $95,[4] so the total cost of feedback control for foreign manufacturers is $190-305 per vehicle. Based on the assumed market shares for the manufacturers, the average cost of converting from nonfeedback to feedback is $190-243.

f. <u>Expanding functions of existing electronics</u>. Expanding the functions of existing electronics consists of primarily augmenting the electronic memory (microprocessor) capability. For some feedback carburetor equipped vehicles, a MAP sensor will also be added. Expanding the microprocessor capability is primarily an R&D cost, and this will be discussed in detail later in the section on fixed costs. As was estimated for the ELCS above, the MAP sensor costs about $15. If $5 for installation is assumed along with $6 for corporate profit and overhead, the total hardware cost of the MAP sensor is $26.

g. <u>Changing electronic control modules</u>. Modifying the electronic module involves either: 1) replacing an existing module with a differently calibrated module to control fuel metering, spark timing and EGR, or 2) the addition of a MAP sensor to automatically adjust the fuel metering, spark timing, and EGR control. There is essentially no variable cost associated with replacing the existing control module since no additional hardware is required beyond that already present in vehicles. An R&D cost will be involved, and this is discussed below under "Fixed Costs" for engine recalibration. The cost of the MAP sensor has already been estimated above at $26.

h. Charcoal canister for evaporative emissions. A charcoal canister is necessary for the storage of evaporative emissions. Due to the decrease in air density at high altitude, a larger canister is expected to be required. Thus, a larger plastic container and an increased amount of charcoal are necessary for high-altitude evaporative emission control. The cost increase is then basically an increase in the cost of additional charcoal. One estimate shows that a 50 percent increase in carbon bed costs about $6.[9]

For the continuous statutory standard applicable to 10,200 feet, or scenario 1a, it is estimated that approximately 50 percent more carbon will be necessary for storage of evaporative emissions. The cost in this case is $6. For the continuous statutory standards applicable to 6,000 feet, or scenarios 1b and 1c, or scenario 2 and for the fixed-point statutory standard at 5,200 feet, approximately 25 percent additional charcoal will be required to meet evaporative emission standards. This will cost roughly $2-3. For proportional standards, or scenarios 3a, 3b, and the base scenario, no additional evaporative emission control should be necessary, and thus no costs would be incurred.

3. Control Hardware Cost for Each Scenario

In the technology section of this report, EPA projected the fraction of gasoline-fueled light-duty vehicles expected to require each of the above-mentioned control hardware components or modifications. For convenience, this information is duplicated in Tables V-2 through V-4 for the seven scenarios being analyzed. With this information, the average hardware cost for the vehicles affected by high-altitude standards in each scenario is readily calculated by multiplying the appropriate market shares (Tables V-2 through Table V-4), together with the cost of the respective emission control components as detailed in the preceding section of this chapter (section (B)(b)(1-9)), and then adding these results. Rather than present a detailed description of the calculations for each scenario, an example will be provided below for the base scenario which is a continuation of the 1982 and 1983 interim high-altitude standards.

In the base case, only vehicles sold at high altitude need to comply with high-altitude standards. The effect of this two-car strategy is that only about 3 percent of all vehicles sold nationwide (excluding California vehicles) will be required to be equipped with high-altitude emission control hardware.

Table V-2 shows that 31 percent of the vehicles sold at high-altitude dealerships should require a fixed-step aneroid for the carburetor. Also, 2 percent are estimated to require a recalibrated electronic control module and 13 percent should

Table V-2

Estimated Exhaust Emission Control Requirements
for Scenarios with Exemptions

Control Hardware	Scenario 1b: Continuous Statutory, 6,000 Feet W/Exemptions	Scenario 2: Fixed-Point Statutory, 5,200 Feet W/Exemptions	Scenario 3a: Continuous Proportional, 6,000 Feet W/Exemptions	Base Scenario: Fixed-Point Proportional, 5,200 Feet W/Exemptions
Nonfeedback Vehicles				
Fixed-Step Aneroid: A. Carburetor B. Power Enrichment C. EGR or air injection rate	N/A[a]	31% A,B,C	N/A	31% A
Continuous Aneroid: A. Carburetor B. Spark	N/A	N/A	31% A,B	N/A
Feedback Vehicles [b]				
Feedback Control w/MAP (Three-Way Ford and Foreign Market Share)	31%	N/A	N/A	N/A
Expand Function of Existing Electronic	59% A (TBI)	59% A (TBI)	13% A (TBI)	13% A (TBI)
A. Expand Capability	10% A,B (FBC)		2% A (FBC)	
B. Add MAP Sensor				

Table V-2 (cont'd)

Estimated Exhaust Emission Control Requirements for Scenarios with Exemptions

Control Hardware	Scenario 1b: Continuous Statutory, 6,000 Feet W/Exemptions	Scenario 2: Fixed-Point Statutory, 5,200 Feet W/Exemptions	Scenario 3a: Continuous Proportional, 6,000 Feet W/Exemptions	Base Scenario: Fixed-Point Proportional, 5,200 Feet W/Exemptions
Change Electronic Modules for FBC A. Recalibrate Fuel Metering B. Recalibrate Fuel Metering, Spark, and EGR Plus Add MAP for Fuel	N/A	10% B (FBC)	N/A	2% A (FBC)
No Change FBC	N/A	N/A	8%	8%
No Change TBI			46%	46%

[a] Not applicable.
[b] FBC means feedback carburetor system.
TBI means throttle body injection system.

Table V-3

Estimated Exhaust Emission Control Requirements for Scenarios Without Exemptions

Control Hardware Before Modification[a]	Control Hardware After Modifications[a]	Scenario 1a: Continuous Statutory, 10,200 Feet W/O Exemptions	Scenario 1c: Continuous Statutory, 6,000 Feet W/O Exemptions	Scenario 3b: Continuous Proportional, 6,000 Feet W/O Exemptions
OL	OL W/Aneroid	0%	0%	23%
OL	Turbocharged	18%	5%	0%
OL	FBC	13%	26%	8%
FBC	ELCS [b]	21%	20%	10%
FBC	Turbocharged	2%	0%	0%
FBC	No Change	0%	0%	8%
TBI	Expansion	39%	59%	13%
TBI	Turbocharged	20%	0%	0%
TBI	No Change	0%	0%	46%

[a] OL means nonfeedback or open-loop system.
FBC means feedback carburetor system.
ELCS means electronic load control system.
TBI means throttle body injection system.
Expansion means the capability of the existing electronic components is upgraded.

[b] The feedback carbureted systems which change to electronic control systems include a portion of open-loop systems that have switched to feedback systems. Therefore, the percentage listed for each scenario does not add to 100.

Table V-4

Estimated Evaporative Emission Control Technology Requirements for all Scenarios

Scenario	No Change to Carbon Canister	25% Increase in Carbon Canister	50% Increase in Carbon Canister
1a	N/A [a]	N/A	100%
1b	N/A	N/A	N/A
1c	N/A	N/A	N/A
2	N/A	100%	N/A
3a	100%	N/A	N/A
3b	100%	N/A	N/A
Base	100%	N/A	N/A

[a] Not applicable.

require an expansion of their existing electronic controls primarily for fuel metering. Since these are R&D costs, however, they are not included here but are discussed later under "Fixed Costs." The remaining 54 percent should require no new exhaust emission control hardware or modifications. Under this scenario, no high-altitude vehicle requires additional charcoal and larger canister for evaporative HC controls (Table III-4). With costs taken from Table V-1, the sales-weighted average cost is $2-3. Again, this cost applies to only the 3 percent of all nationwide vehicles certified for high-altitude sale.

The cost increase for each high-altitude vehicle can also be stated as an average for all vehicles sold in the nation by amortizing the costs over the entire fleet (i.e., both low- and high-altitude sales). Stated in this way, the average cost would be less than 10 cents per vehicle or essentially $0 per vehicle.

In this analysis the incremental cost of each <u>alternative</u> scenario is important. This cost is found by calculating the total average cost of each alternative scenario, as previously explained, and then including a credit for the costs of the control hardware associated with the interim standards (base scenario), if this hardware is no longer needed. Therefore, a credit of $2-3 is applied toward scenario 2 (two-car strategy), while no credit ($0) is applied toward the remaining scenarios (one-car strategies).

It should be noted that for scenarios with exemptions, the exempted vehicles must be included in the estimates when the incremental cost is expressed as an average for all vehicles sold in the nation. In scenario 2, as in the base scenario example, this is accomplished by amortizing the high-altitude costs over the entire national fleet (i.e., both low- and high-altitude sales). In scenarios 1b and 3a it is easily accomplished by reducing the average sales price by the respective percentage of exemptions for each scenario.

The average incremental hardware costs for the alternative scenarios are presented in Table V-5.

B. Fixed Costs

The fixed (or capital) costs of high-altitude control are examined in this section. These costs include R&D for expanding the electronic capability, developing engine calibrations, certification, selective enforcement auditing, and test facility additions or modifications.

Table V-5

Incremental Control Hardware Costs for Each Scenario ($1981)[a]

Scenario	Average Cost, High-Altitude Fleet[b]	Average Cost, National Fleet[c]
1a		140-148
1b		48-61
1c		67-81
2	8-9	1 [d]
3a		4-5
3b		21-26

[a] Reflects costs of control over the base case scenario.

[b] Applies only to vehicles sold at high altitude in fixed-point scenarios. Assumes manufacturer has amortized costs over those vehicles affected (i.e., vehicles sold at high altitude).

[c] Applies to vehicles sold nationwide. Assumes manufacturers will recover cost over entire national fleet, and not only on vehicles affected by a high-altitude standard.

[d] Although the average cost of scenario 2 on a fleet basis is less than 50 cents, a value of $1 will be assumed to be conservative.

1. Research and Development Costs for Expanding Electronic Capability

Expanding the capability of electronic functions is primarily an R&D expense. The total R&D expense will depend first on the number of suppliers and second on the expense incurred by each supplier. The total number of suppliers are estimated to be two or four, depending on whether only high-altitude vehicles or all vehicles are affected. These suppliers may be the larger vehicle manufacturers or outside suppliers. In this analysis, it will be assumed that half of the total suppliers are manufacturers while the other half are outside suppliers.

R&D costs for the expansion of the microprocessor's capability should be much less than that for similar technologies such as the electronic control unit (ECU), which Lindgren estimates to be about $2.7 million in 1981 dollars.[4] This is because much of the work on electronic capability should have been performed by 1984, so that any futher development of the microprocessoring unit should cause only a small increase in R&D expenses. A best estimate here is that a total expense of $500,000 or less will be incurred by each outside supplier. It will be assumed that this R&D cost will be recovered during the 5-year period being analyzed, or 1984-89. The total R&D cost for all suppliers is then estimated to be $1-2 million, depending on the control scenario.

Expanding the memory capability is an integral part of both the ELCS and upgrading the functional capacity of an existing electronic-feedback system. All continuous scenarios are projected to require either ELCS or increased electronic-control capacity on at least some vehicles. The percentage of vehicles expected to use either technique is presented in Tables V-2 and V-3 for each scenario.

Since continuous scenarios require that all vehicles sold nationwide must meet the applicable standards it is assumed that manufacturers will recover their R&D costs through nationwide sales. The average annual nationwide sales has been discussed in the Environmental Impact chapter of this report and these sales projections are repeated in Table V-6. Between the years 1984-88, or the first five years after the high-altitude standard would become effective for light-duty vehicles, the average annual nationwide sales of gasoline-fueled light-duty vehicles would be about 9 million. Over the 5-year period, total sales would amount to about 45 million vehicles. This estimated sales volume is used for predicting amortized costs later in section "g."

As shown in Tables V-2 and V-3, the number of vehicles requiring expanded memory capability for ELCS or for upgrading the electronic control system varies according to each

Table V-6

Year-by-Year Projections of the Sales of Gasoline-Fueled Light-Duty Vehicles (reduced by 10 percent to eliminate California vehicles)

Model Year	LDV Sales (millions)	High-Altitude LDV Sales (millions)[a]
1984	9.41	0.29
1985	9.26	0.28
1986	8.90	0.28
1987	8.56	0.26
1988	8.45	0.26

[a] Estimated to be 3.1 percent of all vehicles in each vehicle group.

scenario. In scenario 1a, approximately 60 percent of all vehicles will require an expansion of the electronic microprocessor either for the ELCS or the existing throttle body injection (TBI) system, and EPA estimates that a total of four suppliers will perform the necessary R&D at a total cost of $2 million. In scenario 1b and 1c, approximately 70-80 percent of all vehicles will require R&D for expanded electronics, and again total R&D costs is projected to be $2 million. In scenario 3a, only 15 percent of vehicles certified for high-altitude sale will require expanded electronics, and this should only require two suppliers and $1 million of R&D. In scenario 3b, approximately 23 percent of vehicles will require R&D, and EPA estimates this work will be done by three suppliers for a total cost of $1.5 million.

The R&D cost to manufacturers (which is assumed to be half of the total number of suppliers) is shown for each scenario in Table V-7. Included in this table is the cost of capital, which is assumed to be 15 percent.

2. Development Costs for Recalibrating Existing Hardware

A detailed analysis of development costs for high-altitude engine recalibration can be found in Appendix III of this report. A summary of development costs is shown in Table V-8 for families with unique high-altitude calibrations. Development costs for scenarios other than the base scenario are estimated to be $3.2-8.2 million.

3. Certification Costs

This analysis assumes that a full-certification program is in effect for motor vehicles sold at higher elevations. Such a program requires that actual vehicular emission tests be conducted under high-altitude conditions. The high-altitude certification requirements could incorporate a less rigorous procedure by allowing engineering evaluations by the manufacturers to be substituted for actual test data. Such "self-certification" requirements are now being used in conjunction with the 1982 and 1983 interim high-altitude standards in response to President Reagan's regulatory relief initiatives. This type of program would be somewhat less costly and less time consuming than the program assumed in this analysis. Nevertheless, the more rigorous certification requirements are evaluated in this document to ensure that the certification costs were not understated.

A detailed analysis of certification costs can be found in Appendix III. A summary of the certification costs, incremental to the base scenario, is shown in Table V-9. The incremental costs are $0-18,773,000 for the first year, and $0-14,000 for each year after. In addition to these costs, there would be a 15 percent cost of capital. The large costs

Table V-7

R & D Costs for Expanding Memory Capability ($1981)[a]

Scenario	R&D	R&D with Cost of Capital
1a	1,000,000	1,150,000
1b	1,000,000	1,150,000
1c	1,000,000	1,150,000
2	0	0
3a	500,000	575,000
3b	750,000	862,000

[a] It is assumed outside suppliers will incur costs equal to that shown for each scenario in this table.

Table V-8

High-Altitude Development Costs ($1981)

Scenario	Recalibrated Engine Families	Total Tests[a]	Costs[b]	With Cost of Capital[c]
1a	109	16,350	8,175,000	9,401,000
1b	82	12,300	6,150,000	7,073,000
1c	109	16,350	8,175,000	9,401,000
2	93	13,450	6,975,000	8,021,000
3a	45	6,750	3,375,000	3,881,000
3b	50	7,500	3,750,000	4,313,000

[a] 150 FTP tests for gasoline vehicles.
[b] $500 per FTP development test.
[c] Includes 15 percent cost of capital.

Table V-9

Incremental Certification Costs ($1981)[a]

Scenario	Cert. Cost First Year (1984 models)	With Cost of Capital[b]	Annual Cert. Cost Subsequent to First Year (1985-88 models)	With Cost of Capital[b]
1a	18,773,000	21,589,000	14,000	16,000
1b	6,104,000	7,020,000	0 [c]	0
1c	12,624,000	14,518,000	14,000	16,000
2	0	0	0	0
3a	0	0	0 [c]	0
3b	3,107,000	3,573,000	14,000	16,000

[a] Reflects certification costs over base scenario.
[b] Includes 15 percent cost of capital.
[c] Incremental cost is calculated to be actually less than $0, or a potential cost savings over the base scenario.

shown in Table V-9 for the first year are due to the fact that the continuous scenarios (numbers 1 and 3) will require the recertification of many or most low- and high-altitude vehicles in 1984. These incremental certification costs will be carried out through the remainder of this report.

The promulgation of a high-altitude standard in 1984 should not affect the number of Selective Enforcement Auditing (SEA) tests performed on LDVs. High-altitude vehicles count toward a manufacturer's annual quota and are merely substituted for low-altitude audits. Manufacturers may experience a slight cost increase due to transporting vehicles to SEA sites. However, these costs should be negligible and should not adversely affect manufacturers of high-altitude vehicles.

4. Test Facility Modifications

There is difficulty in forecasting a manufacturer's needs for test facilities. The possibility that new facilities are needed should not be ruled out, especially considering that it will be more difficult to comply with some scenarios than others. For scenarios 1a, 1b, and 1c it is estimated that one new facility may have to be built for each large manufacturer (assumed to be GM, Ford, Chrysler, AMC, and Toyota in this analysis). The cost of building a new high-altitude testing chamber is approximately $2-4 million (assuming that a building already exists for the testing chamber).[10] An average of $3 million will be used here. The additional equipment, which includes the dynamometer, a CVS system, analyzers, software and computer hookup, and other emission related test equipment, costs about $1 million. The total cost for a fully-equipped facility is estimated to be about $4 million. The total maximum cost for all five large manufacturers is then $20 million for scenarios 1a, 1b, and 1c.

For scenarios 2, 3a, 3b, and the base case, the promulgation of a 1984 high-altitude standard should not require manufacturers to purchase new equipment for constructing new test facilities or for modifying existing emission test cells. The existing facilities which manufacturers use to measure emissions for the interim standards should be adequate for any future standards. For scenarios 3a, and 3b, where emission standards apply continuously between low and high elevations (i.e., between 1,800 feet and 6,000 feet), it is assumed that good engineering judgment can be used to estimate emission results. Thus, a cost of $0 will be used for these scenarios.

The test facility costs are shown in Table V-10. As with the R&D costs above, a 15 percent cost of capital is used.

Table V-10

Test Facility Costs ($1981)

Scenario	Test Facility Costs	With Costs of Capital[a]
1a	20,000,000	23,000,000
1b	20,000,000	23,000,000
1c	20,000,000	23,000,000
2	0	0
3a	0	0
3b	0	0

[a] Includes 15 percent cost of capital.

5. Summary of Capital Costs to Manufacturers

The total capital costs to manufacturers consist of the development, certification, and R&D efforts required by a change in standards and any new test facilities required. Other capital investments should be incurred by outside suppliers. A summary of the manufacturer's fixed or capital costs are shown in Table V-11.

6. Amortized Cost of Capital

To estimate the development and certification, R&D for expansion of memory capability, and test facility modification costs on a per vehicle basis, first the production volume of gasoline-fueled vehicles not sold in California must be projected for the first five years after a 1984 high-altitude regulation is promulgated. These sales projections are shown in Table V-6 for the years 1984-88. Next, the development and certification, R&D, and test facility costs previously determined must be amortized over these production volumes. Certification and development should take place one year before the first year these standards would become effective, or in 1983. After that year, only certification costs will occur, again one year prior to the actual year each vehicle is sold. The final cost over the five-year period would then be calculated at the present value when the regulation first takes effect, or 1984 for LDVs, using a 10 percent discount rate for each year's fixed cost. This cost is then amortized over 1984-88 production and is weighted to result in an equal cost per vehicle over the years of production cited. Expenses are assumed to occur on January 1 of the given year and revenues are assumed to be received on December 31 of the given year.

The total development and certification costs and the costs per vehicle are shown in Table V-12. Manufacturers may choose to recover their costs over the 3 percent of total vehicles sold at high altitude (for scenario 2 only), or they may choose to recover costs over the entire national fleet. The results of these costs for the different amortization strategies are also shown in Table V-12. The fixed costs per vehicle should be about $1 for scenario 1a, 1b, and 1c, and much less than $1 for scenarios 3a and 3b. For scenario 2, fixed costs amount to $6 per vehicle if amortized over vehicles sold at high altitude only.

III. COSTS TO USERS

The total user cost of the various alternative control scenarios includes changes in purchase price, maintenance, and fuel economy.

Table V-11

Total Capital Costs to Vehicle Manufacturers ($1981)[a]

Scenario	Development	Certification	Test Facility	R&D[b]	Total
1a	9,401,000	21,653,000	23,000,000	1,150,000	55,204,000
1b	7,073,000	7,020,000	23,000,000	1,150,000	38,243,000
1c	9,401,000	14,582,000	23,000,000	1,150,000	48,133,000
2	8,021,000	0	0	0	8,021,000
3a	3,881,000	0	0	575,000	4,456,000
3b	4,313,000	3,637,000	0	862,000	8,711,000

[a] Includes a cost of capital, which is estimated to be 15 percent.

[b] This cost is for scenarios which require the use of expanded microprocessor capability, and assumes that half of total R&D is performed by manufacturers.

Table V-12

Amortized Capital Costs Per Vehicle ($1981)

Scenario	Certification, Development, Test Facility, and R&D[a] (1983)	Certification (1984-87)	Total Cost (Present Value in 1984)	Cost Per Vehicle[b] HA Fleet[c]	Cost Per Vehicle[b] Nat. Fleet
1a	56,290,000	56,000	61,968,000	--	1
1b	39,393,000	0	43,334,000	--	1
1c	49,219,000	56,000	54,190,000	--	1
2	8,021,000	0	8,823,000	6	1[d]
3a	4,456,000	0	4,902,000	--	1[d]
3b	8,748,000	56,000	9,671,000	--	1[d]

[a] The cost for R&D in this table includes that cost which is incurred by outside suppliers as well as manufacturers. As an example, the total R&D cost for scenario 1a is $2.3 million instead of the $1.15 million shown in Table V-11.

[b] Amoritization weighted to result in an equal cost per vehicle over the years of production cited. Discount rate assumed to be 10 percent. Expenses are assumed to occur in January 1 of the given year and revenues are assumed to be received on December 31 of each year.

[c] For fixed-point scenarios only. Assumes 3.1 percent of all vehicles are sold at high altitude.

[d] Although these costs are much less than $1, a cost of $1 will be carried through the remainder of this report as a conservatively high estimate.

A. Sticker Price Increase

Vehicle purchasers will have to pay for the costs of emission control hardware and engine modifications on vehicles affected by high-altitude standards. In addition, they will have to pay for the costs of the capital investment required of manufacturers. The vehicle manufacturers will pass on these costs to the purchaser by increasing the retail price or "sticker price" of the vehicle.

The average costs for control hardware has already been estimated for each scenario on a per vehicle basis and is summarized in Table V-5. To these must be added the amortization of the fixed costs of control, which are summarized in Table V-12. The average sticker price increase for vehicles affected by the high-altitude standards is approximately $141-149 in scenario 1a, $49-62 in scenario 1b, $68-82 in scenario 1c, $5-6 in scenario 3a, $22-27 in scenario 3b, and $14-15 in scenario 2.

B. Maintenance Costs

Two control hardware items that will probably result in additional maintenance costs or operating costs are the turbocharger and the feedback control system.

The turbocharger hardware itself should require no maintenance. However, the addition of a turbocharger requires that the engine oil and the filter be replaced approximately every 3,000 miles that the vehicle is driven[11] rather than every 6,000-7,500 miles for a naturally aspirated engine. Over the 100,000 mile useful life of a light-duty vehicle this would mean that a turbocharged vehicle would require roughly 15-20 more oil changes than its naturally aspirated counterpart. With the cost of an oil change around $15, this would amount to a lifetime cost of about $225-300. The average lifetime of a light-duty vehicle is 10 years, and assuming that the oil changes occur at their regular intervals and using a 10 percent discount rate, the maintenance cost is $150-185, discounted to the time of vehicle purchase. This cost should be included in the overall cost for each scenario requiring turbochargers (i.e., 40 percent in scenario 1 and 5 percent in scenario 1c).

The feedback control system may also require some maintenance even though manufacturers are currently not recommending any maintenance intervals for these systems. Recent data from EPA's I/M program implies that roughly 15 percent of all vehicles will require some maintenance of the oxygen sensor.[12] A survey of local dealerships indicate that the replacement cost of an oxygen sensor with labor is about $20. This would probably occur once during the vehicle's lifetime, and for purposes of this analysis, EPA assumes that this will occur halfway through the vehicle's life, or about five years after the vehicle was purchased. Thus, this cost discounted to the year of vehicle purchase is about $14. A sales-weighted average cost is then 15 percent of $14, or about $2 per light-duty vehicle. This cost would apply to 13 percent of the vehicles in scenario 1a, 31 percent in 1b, 26 percent in 1c, and 8 percent in 3b. These vehicles are estimated to change from nonfeedback to feedback systems to comply with the high-altitude standards.

It is also possible that the microprocessor will require some maintenance. However, by 1984, or the first year of high-altitude standards for LDVs, the development of a microprocessor should be improved so that no maintenance is necessary.

If the above costs are sales-weighted appropriately for each scenario in which they occur, then the total maintenance cost is $61-75 in scenario 1a, $1 in scenario 1b, $9-10 in scenario 1c, and essentially $0 in scenario 3b.

C. Fuel Economy

Purchasers may also benefit from fuel economy savings due to implementation of high-altitude emission control technology, as was already discussed in detail in Chapter IV. The fuel economy benefits summarized here will be incremental to those experienced by continuing the 1982 and 1983 interim rule, the continuation of which is the base scenario. These fuel economy benefits are best EPA estimates based on a wide range of data indicating the fuel economy improvements or penalties associated with the various control techniques. For turbocharged vehicles, an average fuel economy benefit of 5 percent was observed compared to naturally aspirated vehicles of similar driving performance. Vehicles with aneroids will also experience some fuel economy benefit at high altitude. In the baseline case, one aneroid is assumed to already exist on some vehicles. If an additional aneroid is installed (see scenario 3a and 3b), then a fuel economy benefit of 0 percent is expected. If two aneroids are added (scenario 2) the data indicate an improved fuel economy of 2 percent. For vehicles with feedback control, a 3 percent fuel economy benefit should be possible over those vehicles in the baseline case using open-loop (nonfeedback) control. Expanding the microprocessor's capability for some vehicles may also improve fuel economy, but data confirming this effect could not be found, so no fuel economy benefit will be projected here.

These fuel economy benefits can be expressed in terms of cost savings if the gallons of fuel saved and the price per gallon are estimated for the full lifetime of a vehicle. First, the lifetime of a light-duty vehicle is assumed to be 100,000 miles accumulated over a period of 10 years.[13] Second the corporate average fuel economy (CAFE) standard is 27 mpg in 1984 and 27.5 thereafter for LDVs. This latter CAFE standard (27.5 mpg) is used in this analysis. Based on this information, the average amount of fuel consumed by LDVs is estimated to be 3,600 gallons for vehicles affected by this regulation. A fuel economy benefit of 1, 2, 3, and 5 percent translates to a savings of 36, 72, 106, and 173 gallons, respectively, for LDVs. Finally, the price of unleaded gasoline is currently (at the time of this writing) about $1.30 per gallon.

The total fuel economy savings must be discounted back to the original year or purchase. A 5 percent discount rate is used for fuel costs, instead of a 10 percent rate which is used elsewhere in this analysis, to indicate that the expected inflation of fuel costs will be much greater relative to all other goals. This procedure has been done in a recent EPA regulatory analysis.[3] If it is assumed that fuel usage occurs equally for each year during a vehicle's lifetime, then one-tenth of the total fuel consumption is used each year for LDVs. Thus, based on the discount rate, the total fuel consumption, the price of unleaded gasoline, and the percent savings of fuel as a result of using each control hardware component, the following fuel economy benefits are observed for LDVs when compared to the baseline case: 2 additional aneroids, $80; turbocharger, $190; and feedback control, $115. A summary of these fuel economy savings is shown in Table V-13.

Of course, these cost savings will not apply to all vehicles in each scenario, since all vehicles will not be equipped with each of these control hardware components. However, a sales-weighted average savings can be calculated for each scenario, again based on the percentage of control hardware expected to be used for each scenario (Tables V-2 and V-3).

D. Net Cost to Consumer

The net cost to the consumer for each scenario is shown in Table V-14. These costs include the control hardware price increase, the R&D for expanded memory capability, the maintenance cost, the certification and development cost, test facility costs, and the fuel economy savings. The costs shown in Table V-14 apply either to those vehicles sold at high altitude only (scenario 2), or to those vehicles sold throughout the nation.

IV. AGGREGATE COSTS

The aggregate costs to the nation of complying with the 1984 high-altitude standards consist of the sum of increased costs for development, certification, emission control hardware, engine modifications, R&D for expanded memory capability, test facility modifications and additions, and

Table V-13

Fuel Economy Improvement

Control Hardware	Percent Improvement (best estimate)	Cost Savings ($1981)[a]
Two Aneroids	2%	80
Turbocharger	5%	190
Feedback Control	3%	115

[a] Estimated using a 5 percent discount rate, for a vehicle lifetime of 100,000 miles over period of 10 years.

Table V-14

Net Cost to Consumer (LDVs) ($1981 per vehicle)

Scenario	Hardware	Maintenance[a]	Certification, Development, R&D, and Test Facilities[a]	Fuel Economy[a]	Net Vehicle Cost: HA Fleet	Net Vehicle Cost: Nat. Fleet
1a	140-148	61-75	1	-91	N/A [b]	111-133
1b	48-61	1	1	-36	N/A	14-27
1c	67-81	9-10	1	-40	N/A	37-51
2 [b]	8-9	N/A	6	-25	-11 to -10[c]	N/A
3a	4-5	N/A	1	0	N/A	5-6
3b	21-26	0	1	-9	N/A	12-17

[a] Discounted to year of purchase.
[b] Not applicable.
[c] Costs for scenario 2 apply to vehicles sold at high altitude only, or about 3.1 percent of the national vehicle fleet.

changes in fuel consumption and maintenance. This cost is simply the net cost to the consumer times the number of vehicles sold. These costs will be calculated for the first five years after which the high-altitude standard becomes effective. The year 1984 will be used as the base year to compare present values of the money throughout the time period of concern. A discount rate of 10 percent is used for all costs when calculated in this manner. All costs are expressed in terms of 1981 dollars.

The aggregate cost to the nation is dependent on the number of light-duty vehicles sold during the time period. Although any sales projection of this type will be rough due to the many social and economic factors involved, the sale projections shown in Table V-6 are suitable for this analysis. Only the percentage of the national fleet to which net costs are applicable are used in calculating aggregate costs.

The aggregate cost for each alternative scenario is shown in Table V-15. As can be seen, for LDVs the scenarios range from a net savings to a net cost of $4,974 million. This large range is due to the fact that fuel economy benefits are the predominant factor in determining the net cost estimate of some scenarios relative to others. This effect is explored further in the sensitivity analysis at the end of this chapter.

V. SOCIOECONOMIC IMPACT

In this section, the socioeconomic impact on manufacturers, dealers, and users will be discussed.

A. Impact on Manufacturers

The impact on manufacturers will be analyzed in two separate categories. First, the capital expenditures which manufacturers must confront could be burdensome and will thus be investigated. Second, the additional cost of each vehicle could affect demand and, subsequently, the sales of each manufacturer.

1. Capital Expenditures

Capital expenditures consist of development costs for high-altitude engine calibration, research and development for expanded memory capability, and certification. The total capital costs have already been calculated and are shown in Table V-11. The bulk of the capital expenditures will occur in the first year of this regulation, and the real burden of a high-altitude standard can be viewed as raising the first year's fixed costs before vehicle sales begin to repay the investment. In this section, the first year cost is examined with a 15 percent cost of capital.

Table V-15

Aggregate Costs[a]

Scenario	Aggregate Costs (millions of $1981)
1a	4151-4974
1b	524-1010
1c	1384-1907
2	Net Savings [b]
3a	187-224
3b	449-636

[a] Present value in 1984.

[b] If the estimated fuel economy benefit is excluded, the aggregate cost would range up to $17 million.

It is possible that other capital expenses will result from a high-altitude standard. However, as previously stated, all capital costs associated with the control hardware, such as tooling, machinery, and building expenses, are expected to be borne by outside suppliers with the exception of expanding memory capability, where approximately half of the total R&D expense is likely to be incurred by manufacturers.

The first year capital costs are shown for each scenario in Table V-16 and are simply the sum of development, first year certification, test facility additions, and R&D for expanded memory capability, multiplied by 1.15 to account for the predicted cost of capital. Most of the costs will be incurred by manufacturers with a large number of engine families for certification and development. Of course, the impact of capital cost will vary according to each scenario. Admittedly, the largest capital expenses, which are necessary in scenarios 1a, 1b and 1c, may be significantly more burdensome to manufacturers than those capital expenses resulting from the other scenarios.

Smaller LDV manufacturers will have the most trouble raising capital than will the larger manufacturers, since they have less vehicles to spread their cost over. In particular, scenarios 1a, 1b, and 1c could significantly affect the ability for each manufacturer to finance the required investment. In contrast, scenarios 2, 3a, and 3b would be much less burdensome and should not significantly affect small manufacturers.

It is true that some of these large manufacturers will absorb a higher percentage of the total capital costs than will other manufacturers, but usually a manufacturer which pays a higher capital expense has earned a larger profit when compared to manufacturers spending less on capital. Thus, even for the scenarios requiring more capital, larger manufacturers should not be severely impacted.

2. <u>Effects on the Demand for High-Altitude Vehicles</u>

The impact of sales can be evaluated by examining the sticker price increases per vehicle for each scenario. With the exception of scenario 2, the sticker price increase will probably occur for all vehicles in the nation, even though the air quality benefit is obtained at altitudes above 1,800 feet. Scenarios 1 and 3 require all vehicles to be be equipped with special control hardware whether or not they are ever used at higher elevations. In scenario 2, cost increases will probably occur only for vehicles sold for principal use above 4,000 feet, since only high-altitude vehicles need be equipped with control hardware.

Table V-16

First Year Capital Costs to All Manufacturers of Light-Duty Vehicles ($1981)[a]

Scenario	Development	Certification	Test Facility	R&D	Total
1a	9,401,000	21,589,000	23,000,000	1,150,000	55,140,000
1b	7,073,000	7,020,000	23,000,000	1,150,000	38,243,000
1c	9,401,000	14,158,000	23,000,000	1,150,000	48,069,000
2	8,021,000	0	0	--	8,021,000
3a	3,881,000	0	0	575,000	4,456,000
3b	4,313,000	3,573,000	0	862,000	8,748,000

[a] A 15 percent cost of capital is included.

The price increase for each scenario can be applied in conjunction with the following equation to estimate the impact of sales:

% Change in Vehicle Sales = [price elasticity]
[0.5 (% change in vehicle price)]

In the above equation, the price elasticity for vehicles during 1984-88 is assumed to be the same as that for 1982-83, or 0.35.[13] Next, the total sales must be determined, and according to Table V-6, the total 5-year sales for gasoline LDVs (that are not sold in California) is 44.58 million. The average cost of a vehicle is roughly $7,000 in 1981 dollars.[13]

The maximum impact of high-altitude sales would occur for scenario 1a, where the average sticker price increase would be about $141-149 (hardware costs plus fixed costs). This impact would reduce sales by as much as 0.37 percent, or by 165,000 vehicles over a period of five years. Sales by the smaller manufacturers may decrease at a higher rate than that by the larger manufacturers, due to a smaller manufacturer's lower production volume with which to amortize fixed costs. Thus, while larger manufacturers may not be greatly affected by the increase in price under scenario 1a, the smaller manufacturers may be affected somewhat more severely under this scenario.

The next largest impact would occur under scenario 1c, where a sticker price increase of $68-82 could reduce sales by as much as 0.21 percent, or by 89,000 vehicles. Although the loss of sales here is estimated to be over 75,000 less than the 5-year loss of sales for scenario 1a, this loss of sales could still adversely affect the smaller manufacturers. Under scenario 1b, which has a sticker price increase of about $49-62, or close to that of scenario 1c, the estimated 5-year loss of sales is about 69,000, and the impact on manufacturers would be nearly the same as that projected for scenario 1c. Scenario 3b could increase the sticker price up to $27 with a potential sales reduction of about 30,000 vehicles. Such a sales loss could also have an adverse impact on some small manufacturers. Thus, scenarios 1a, 1b, 1c, and 3b could adversely affect sales, particularly for the smaller manufacturers.

For scenario 3a, the maximum sticker price increase is $6, and this could cause a decrease of about 7,000 vehicles over a 5-year period. This is small compared to the loss of sales determined for scenarios 1a, 1b, 1c, and 3b, and would probably not significantly affect any of the manufacturers. For scenario 2, the sticker price increase for vehicles sold at high altitude is about $15, and based on a 5-year high-altitude sales projection of 1.4 million, the potential sales loss is 525 vehicles. This represents about 105 lost sales per year, which is less than the amount of lost sales estimated in the regulatory analysis for the 1982 and 1983 interim standards.[13] As was concluded in the interim standards analysis, this loss of sales should not noticeably affect the sales of any manufacturer. Thus, scenarios 2 and 3a should not significantly affect a single manufacturer's sales due to the sticker price increases examined above. Also, there should be no impact on employment or productivity in the industry.

B. Impact on High-Altitude Dealers

The effects of a 1984 high-altitude standard on dealerships can be divided into two general areas: reduced model availability and higher vehicle prices. These changes arise from each scenario and affect vehicle sales, and hence, dealership profitability.

1. Model Availability

As previously stated, the 1977 high-altitude regulations resulted in the unavailability of many models and optional engine configurations in high-altitude areas. At that time, manufacturers chose to limit model availability in high-altitude areas because the small percentage of the market represented by high-altitude sales (about 3 percent) did not justify the development costs required to certify the emission control capabilities of all their vehicle configurations. Some high-altitude dealers alleged that this resulted in lost sales.

Model availability should not be a problem with each of the scenarios where exemptions from high-altitude sales are 10 percent or less (scenarios 1a, 1c, 3a, and 3b). Since almost all new vehicles in each scenario will be certified for sale at high altitude, each manufacturer will be more likely to make a substantial amount of his product line available to high-altitude purchasers. Conceivably, a manufacturer might comply with the regulations by certifying all models for high-altitude sales but choose not to offer certain models to high-altitude purchasers. However, EPA believes that due to the expense involved with certifying and developing each vehicle, manufacturers will offer almost all of the vehicle configurations for sale at high altitude. Also, vehicles that are exempted from sale at high altitude are most likely low-power vehicles that would normally not be sold at high altitude. Thus, the model availability at low altitude should remain unchanged and the model availability a high altitude should not be noticeably affected for scenarios where exemptions are 10 percent or less.

For scenarios where exemptions are estimated to be greater than 10 percent (scenarios 1b, 25 percent and 2, 15 percent), model availability may be a problem for dealers at high altitude. This greater number of exempted vehicles may curb availability of the more popular fuel efficient vehicles. If it is determined that these exemptions would affect model availability significantly, methods could be introduced to ease this problem, such as allowing waivers for particular exempted models, or specifying different criteria so that fewer vehicles would be exempted. Also it is believed that these control strategies combined with the manufacturers' increased experience with altitude-compensating emission control systems during 1982 and 1983 will keep availability to acceptable levels.

2. Higher Vehicle Prices

The cost of a high-altitude vehicle depends on whether the dealer acquires the new vehicle by ordering it as original equipment from the factory or through a "dealer trade" with a low-altitude dealer. Under scenario 2 some low-altitude vehicles acquired in dealer trades must be modified into the proper high-altitude configuration before they are sold.

The cost of factory-built high-altitude vehicles depends on the manufacturer's pricing strategy. Manufacturers may choose to amortize the cost of these standards across vehicles sold at high-altitude only (for scenario 2), or over the entire national production.

In scenarios 1a, 1b, 1c, 3a, and 3b, it is likely that manufacturers will recover these costs over nationwide sales. Although the high-altitude market represents only a small percentage of total sales, this small amount may be more significant for manufacturers during their ascent from recent economic difficulties and as the entire market shifts to more competitive smaller cars than in the 1982 and 1983 model years. Therefore, competition for high-altitude sales among manufacturers could be quite intense. Additionally, the industry's historical price leader, General Motors, will likely incur the least additional cost no matter which of these scenarios is used. Therefore, because of competition with such companies as GM, other manufacturers may indeed raise high-altitude vehicle prices less than the sticker prices indicated previously in this analysis in order to remain competitive.

In scenario 2, manufacturers may choose to recover their costs only on high-altitude sales, and the estimated average price increase is about $15. This represents approximately 105 lost sales per year. As stated in the regulatory analysis for the interim standards,[13] there are about 1,000 high-altitude dealerships. However, only those dealers representing manufacturers whose vehicles must be recalibrated to meet the high-altitude standards (41 percent of the fleet) will be affected by significantly higher vehicle prices. The manufacturers building LDVs that generally will not require recalibration are GM, AMC, Nissan, Volkswagen, Volvo, JRT, BMW, Peugeot, Porsche, and Saab. The actual number of high-altitude dealers selling recalibrated vehicles is not readily available. Nevertheless, it is possible to reasonably estimate the number of high-altitude dealerships selling vehicles with significantly higher prices based on the national fraction of dealer outlets representing manufacturers which build recalibrated LDVs. Using this analogy, EPA estimates that 50 percent of the 1,000 high-altitude dealers potentially may be affected by significant first price increases. Since only 105 lost sales should occur, most of the 500 potentially affected dealers will not experience any sales reduction. Therefore, the potential price increase for original equipment vehicles should have no significant economic impact on individual high-altitude dealerships. Of course, in scenario 2, if a manufacturer chooses to amortize his cost over the entire national fleet, then the cost increase would be so small that sales should not be affected at all.

In some cases, dealer trades may be adversely affected by each of the scenarios. The impact on sales, however, remains conjectural. Dealer trades generally involve small rural dealers who cannot stock a wide variety of vehicles and must trade with large metropolitan area dealers to satisfy customer demand. Dealer trades were estimated by the Colorado Automobile Dealers Association to involve from 10 to 15 percent of sales by small rural dealers. Therefore, the potential impact will predominantly apply to high-altitude dealerships which are isolated from high-altitude metropolitan areas. EPA is unable to estimate the number of such isolated dealerships, but believes it is reasonable to postulate that the number is relatively small since most high-altitude areas are within "trading" distance (a few hundred miles) of a high-altitude metropolitan area. Also, not all manufacturers will have special high-altitude vehicles, so some dealers should not have any problem. Nevertheless, even though the number of high-altitude dealerships which may trade with low-altitude metropolitan dealerships may be relatively small, the potential impact on these dealers needs to be explored further.

First, for the continuous proportional and the continuous statutory scenarios (scenarios 1a, 1b, 1c, 3a, and 3b), vehicles sold at high altitudes should have identical configurations as their low-altitude counterparts and, thus, dealers should have no problem obtaining a desired vehicle. This of course assumes that the desired vehicle is a non-exempt vehicle. As was discussed in the previous section, scenarios with a significant percentage of exemptions may cause model availability problems. For the fixed-point statutory scenario, or scenario 2, about 41 percent of the high-altitude vehicles will differ from their low-altitude counterparts. However, dealers should generally have access to all high-altitude models from the factory. But, if models are available from the factory, why be concerned with dealer trades at all?

In the past, for fixed-point strategies, high-altitude dealers have stated that their primary concern is being able to obtain vehicles that are in high demand. Apparently, in 1977 when most vehicles involved factory installed high-altitude modifications, there were sometimes long delays in obtaining vehicles and sales were lost. EPA has addressed this problem for the interim standards by requiring all vehicles that do not automatically comply with the standards, to be capable of being modified to do so. This will also hold true for scenario 2 of the 1984 standards. This will help ensure that the small number of isolated, rural dealerships which trade with low-altitude dealers can obtain vehicles on a timely basis and modify them into the proper configuration before sale. The only potential barrier could be that the modification might be expensive. The Colorado Automobile Dealers Association estimated that modifications costing perhaps up to $150 per vehicle would not affect sales. As discussed in the Summary and Analysis of Comments for the 1982-83 standards,[14] EPA expects many vehicles will be modifiable for less than that amount. Since dealer trades appear to be most critical for high-demand vehicles for which long ordering delays may be experienced, the real potential impact of the high-altitude standards is whether or not dealers will lose sales for those few vehicles that are in high demand and are expensive to modify.

Looking closer at scenario 2, if it is first assumed that by the time a prospective customer contacts a dealership the customer has previously decided that a specific new car is necessary and that a substitute (i.e., one that is more available) is not suitable, there are two fundamental problems in the "worst case." First, the vehicle of choice must be ordered from the factory but there will be a delay. Second, the vehicle of choice may be available sooner but must be modified at an extra cost of a few hundred dollars.

Since under scenario 2 it will be illegal for the prospective customer to purchase a low-altitude vehicle, a decision based primarily on economics must be made (i.e., is it worth the extra cost to have the specific vehicle sooner), or is it better to wait and, in the process, save money. No matter which choice is made, the sale is not lost in this example.

Of course, under scenario 2 a prospective customer may not have previously decided on a particular high-demand vehicle that is in short supply. If this is the case he may shift to another more available vehicle from the same manufacturer. In this case the sale would not be lost. The customer may also decide to purchase a comparable vehicle from another dealer. In this case the potential high-altitude sale would not be lost. Or, the customer may have only been marginally interested in the particular "problem" vehicle and decide not to buy any vehicle. In this case the potential sale would be lost.

In summary, the regulations under any of the scenarios should not significantly affect overall high-altitude sales unless a large number of vehicles are exempted, as was discussed in the previous section. The potential for adversely affecting sales is predominantly limited to relatively isolated, rural high-altitude dealerships which must "modify" low-altitude vehicles acquired in dealer trades with low-altitude dealerships and this would probably occur only under scenario 2. For these isolated dealers, the potential problem should be limited to the relatively few "high-demand" vehicles which are expensive to modify into the proper high-altitude configuration. Even in these instances, however, only a portion of such potential sales would be lost. Therefore, it is reasonable to assume that any single high-altitude dealership will not be greatly affected by high-altitude standards.

C. Impact On User

Users will be affected by higher new vehicle prices. Along with this initial price increase the purchaser will pay for additional maintenance and benefit from fuel economy savings. The average sticker price increase would be greatest for scenario 1a, which has a cost of $141-149. This represents about 2 percent of the total vehicle cost, and could affect a consumer's ability to purchase new vehicles. Also, under this scenario, maintenance costs are high, although this increase should be offset by a fuel economy benefit. Thus, some purchasers may have trouble financing their desired vehicle. For scenario 1b and 1c, the sticker price increase is approximately 1 percent of the total vehicle cost, and would have a lesser effect than scenario 1a on the ability for consumers to purchase new vehicles. In scenarios 2 and 3a, the sticker price increase is 2 percent or less of the initial vehicle price. Purchasers should have no problem paying for the desired vehicles in these scenarios. Looking at scenario 3b, the sticker price increase is about 0.4 percent. These are small percentages when compared to scenarios 1a, 1b, and 1c, and would not affect purchasers of high-altitude dealers.

Thus, scenarios 1a, 1b, and 1c could affect a purchaser's ability to buy a new vehicle, while scenarios 2, 3a, and 3b would affect very few, if any, purchasers.

VI. SENSITIVITY ANALYSIS

The net cost to consumers shown in Table V-14 was based on conservative estimates for fuel economy benefits and was also based on the assumption that the control hardware costs were accurately determined.

Earlier in this chapter, the following best estimates of fuel economy improvements were used for vehicles compared to the base-line case: 2 additional aneroids, 2 percent, turbocharging, 5 percent; and feedback control, 3 percent. These numbers are conservative estimates based on a range of data for fuel economy improvements or penalties that were observed. Based on an analysis of fuel economy data as explained in Chapter III of this report, it is not unreasonable that fuel economy changes for the above control technologies could be expanded to the following ranges: 2 additional aneroids, 0-4 percent, turbocharging, 5-10 percent, and feedback control, 0-5 percent. These fuel economy changes would lead to the following savings over the lifetime of a light-duty vehicle: 2 additional aneroids, $0-150; turbocharging, $190-380; and feedback control, $0-190. In addition, these savings could be expanded even further if other control technologies which were discussed in Chapter III were also included (i.e., expanding the microprocessor capability and adding 1 aneroid). However, the sensitivity analysis will be conducted only with the potential fuel savings for the technologies already included in the analysis since any fuel economy impacts of the remaining control hardware has already been rejected. The effect of including the range of savings can be seen in Table V-17, where the net cost due to the sensitivity analysis is compared to the net cost under the best estimate of fuel economy savings.

The sensitivity analysis on fuel economy shows that the potential fuel savings could significantly affect the net cost of each scenario with the exception of scenario 3a. Table V-17 shows that a small change in fuel economy benefit can cause a large change in the net cost. This is especially apparent in scenario 2, which is extremely sensitive to the estimated fuel economy increment. Instead of a net savings, implementing the standards in this scenario may actually result in a net cost. Interestingly, while the estimated fuel economy benefits are crucial to the outcome of the net cost under each scenario, the ranking of the scenarios in order of costs remains essentially unchanged. In conclusion, this sensitivity analysis generally shows that the net cost estimates in Table V-14 should be conservative and thus should be referred to when considering the net cost of a high-altitude standard. For scenario 2, however, this analysis shows that the potential to underestimate the actual cost of the standards is such that it would be better to consider a range for the net vehicle cost based on the best fuel economy estimate and no assumed benefit. Therefore, a net vehicle cost of $-11 to $15 will be considered for scenario 2 in the succeeding chapters of this report to retain the conservative nature of the analysis.

Next, the sensitivity of control hardware costs needs to be examined. For purposes of this analysis, a sensitivity of ±30 percent will be used for hardware costs so that the effect

Table V-17

Net Cost Per Vehicle Due to Fuel Economy
Sensitivity Analysis (LDVs)($1981)

					Net Vehicle Cost		Best Estimates Net Vehicle Cost	
Scenario	Control Hardware	Maintenance[a]	Certification, Development, R&D and Test Facility	Fuel Economy[a]	HA Fleet	Nat. Fleet	HA Fleet	Nat. Fleet
1a	$140-148	61-75	1	-177 to -76	N/A[b]	25-148	N/A	111-133
1b	$48-61	1	1	-59 to 0	N/A	-9 to 63	N/A	14-27
1c	$67-81	9-10	1	-68 to -10	N/A	9-82	N/A	37-51
2 [c]	$ 8-9	N/A	6	-47 to 0	-33 to 15	N/A	-11 to -10	N/A
3a	$4-5	N/A	1	0	N/A	5-6	N/A	5-6
3b	$21-26	N/A	1	-15 to 0	N/A	7-27	N/A	12-17

[a] Discounted to year of vehicle purchase.
[b] Not applicable.
[c] Costs for scenario 2 apply to vehicles sold at high altitude only, or about 3.1 percent of the national vehicle fleet.

of the net cost can be observed. The results of a ±30 percent control hardware cost sensitivity can be seen in Table V-18. The effect of a ±30 percent sensitivity does appear to affect net costs and widens the range of cost for each scenario considerably. However, as for fuel economy, each scenario remains the same with regard to its cost rank. In addition, scenario 2 is less sensitive to reasonable changes in the hardware cost estimates than for fuel economy.

In summary, the effect of a change on fuel economy and control hardware costs could affect significantly the net cost for each scenario. The most dramatic effect is observed for fuel economy, where a small percent change in fuel economy improvement or penalty leads to a larger percent change in the net cost of each scenario. A change in control hardware costs leads to about an equal change in net costs and this would probably not affect the determination of which scenario has the least economic impact. A change in fuel economy, on the other hand, has greater potential to affect the determination of which scenario is the most desirable economically and thus needs to be estimated accurately. Because of the extreme sensitivity of scenario 2 to the fuel economy estimates, a range of $-11 to $15 will be considered for the net vehicle cost under this scenario in subsequent chapters of the report.

Table V-18

Net Cost Per Vehicle Due to Fuel Economy
Sensitivity Analysis (LDVs)($1981)

Scenario	Control Hardware	Maintenance[a]	Certification, Development, R&D and Test Facility	Best Estimate Fuel Economy[a]	Net Vehicle Cost HA Fleet	Net Vehicle Cost Nat. Fleet	Best Estimates Net Vehicle Cost HA Fleet	Best Estimates Net Vehicle Cost Nat. Fleet
1a	$98-192	61-75	1	-91	N/A[b]	69-177	N/A	111-113
1b	$34-79	1	1	-36	N/A	0-45	N/A	14-27
1c	$47-105	9-10	1	-40	N/A	17-76	N/A	37-51
2 [c]	$ 6-12	N/A	6	-25	-13 to -7	--	-11 to 10	N/A
3a	$ 3-7	N/A	1	0	N/A	4-8	N/A	5-6
3b	$15-34	N/A	1	-9	N/A	7-27	N/A	12-17

[a] Discounted to year of vehicle purchase.
[b] Not Applicable.
[c] Costs for scenario 2 apply to vehicles sold at high altitude only, or about 3.1 percent of the national fleet.

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Chapter VI

Cost Effectiveness

I. INTRODUCTION

Cost effectiveness refers to an analytical method by which several alternative means of achieving a desired goal are evaluated based on their costs (usually in dollars) and a separate measure of effectiveness. In this report, the goal is to reduce automotive emissions of hydrocarbons and carbon monoxide.

II. METHODOLOGY

The costs of meeting this goal for each scenario were determined in Chapter V. For the purposes of determining cost effectiveness, total costs (i.e., the costs for both the manufacturer and the operator), are used on a per vehicle basis and discounted to the year of vehicle purchase. These costs are then equally allocated between the two pollutants being controlled.

In order to measure the effectiveness of each scenario, total lifetime emission reductions are used on a per vehicle basis. Since the primary purpose of this report is to determine if the described alternative approaches to continuing the 1982 and 1983 interim high-altitude standards are cost effective enough to warrant further consideration, it is the incremental cost effectiveness of each scenario over the base scenario that needs to be examined. Thus, the relative costs and emission reductions are the differences between those under the interim high-altitude standards (base scenario) and each of the other scenarios. The incremental cost effectiveness is determined, then, by dividing the added cost of control by the additional amount of pollutant removed from the atmosphere.

III. ANALYSIS

The incremental cost, emission reduction, and the resulting cost effectiveness are presented in Table VI-1 for each alternative scenario. Before discussing the overall results of the analysis, a brief explanation of the cost-effectiveness values listed for scenario 1 is necessary. As previously stated in Chapters III and IV, the stringent requirements of meeting the statutory standards at all altitudes are expected to cause nonfeedback systems to be replaced by feedback systems in scenario 1. The emission factors used in this analysis assume that a significant number of feedback systems will experience catastrophic failures. These in-use failures result in excessive CO emissions well beyond allowable limits. For this reason, the air quality analysis for scenario 1 shows a significant increase in CO

Table VI-1

Incremental Cost Effectiveness of LDGV Control Strategies

Scenario	Costs[a] (dollars per vehicle) Low	High	Reductions[b] (10^{-3} metric tons per vehicle) HC	CO	Incremental Cost Effectiveness (dollars/metric ton) HC Low	HC High	CO Low	CO High
1a	2120	2530	10.5	-181.6	101,000	121,000	[c]	[c]
1b	265	515	10.5	-181.6	12,600	24,500	[c]	[c]
1c	705	970	10.5	-181.6	33,600	46,200	[c]	[c]
2	-11[d]	15	13.0	239.9	neg.	575	neg.	30
3a	95	115	0.5	7.7	95,000	115,000	6,200	7,500
3b	230	325	0.5	7.7	230,000	325,000	14,900	21,100

[a] 1981 dollars discounted to year of vehicle purchase. Costs were allocated to the vehicles above 1,800 feet for scenarios 1 and 3 and to the vehicles above 4,000 feet for scenario 2 in order to correspond to the same vehicles used to determine emission reductions.

[b] Emission reductions were calculated by dividing fleetwide emission reductions in Tables IV-9 and IV-10 by LDGV sales in Table IV-5.

[c] The cost-effectiveness values for CO under scenario 1 were not presented in the table since emissions of this pollutant may increase under this strategy. However, it is also possible that CO emissions may decrease by about the same total amount listed for both scenarios 2 and 3. Using this assumption, the cost effectiveness would range from $535 to $5,100 per metric ton for CO.

[d] The great uncertainties associated with the expected fuel economy benefit make any conclusion that a savings may result from implementing scenario 2 very tentative.

emissions, since the nonfeedback systems that were replaced by feedback systems do not exhibit such catastrophic failures.

The data base with which the emission factors were developed, however, is quite limited and extrapolating the current trend of catastrophic failures into the future is speculative at this time. It is very likely that new information will show different failure rates and that the lifetime emissions for feedback systems may possibly be more like those for nonfeedback systems. Therefore, instead of increasing CO emissions, scenario 1 (with exclusively feedback systems) may actually reduce this pollutant by an amount similar to that calculated for scenario 2 (with a mixture of both systems) in areas above 4,000 feet. At intermediate altitudes (1,800 feet to 4,000 feet) the incremental benefits may be greater than for scenario 3 which controls vehicles to only proportional levels. The possibilities that CO emissions may increase or decrease under scenario 1 are considered in the following discussion.

Table VI-1 shows that scenario 2 is predicted to be the most cost effective of the alternative scenarios analyzed in this report. The cost-effectiveness values range up to $575 per metric ton of HC, compared to $12,600 to $121,000 per metric ton for scenario 1 and $95,000 to $325,000 per metric ton for scenario 3. Under scenario 2, the cost effectiveness for CO ranges up to $35 per metric ton. The cost effectiveness of CO emission reductions from scenario 3 ranges from $6,200 to $21,100 per metric ton. As previously stated, CO emissions under scenario 1 could either increase or decrease. The cost effectiveness was not calculated for the possibility that CO emissions might increase. The cost effectiveness of potential CO reductions under scenario 1 was determined by assuming that any benefit would be the total of those listed for scenarios 2 and 3 (0.25 metric tons per vehicle). Using this value, the cost effectiveness of reducing CO emissions under scenario 1 ranges from $535 to $5,100 per metric ton.

Scenarios 1 and 3, as analyzed in this report, are predicted not to be cost effective for the primary reason that, while emission reductions are achieved solely on vehicles above 1,800 feet (roughly 5 percent of the fleet), vehicles sold below this altitude (95 percent of the fleet) must also bear the additional cost of applying high-altitude control systems on them as well. This approach tends not to be cost effective.

In Chapter IV, the environmental consequences of a high-altitude fleet comprised of one low-altitude vehicle out of every ten vehicles in high-altitude areas was discussed as part of the sensitivity analysis. As explained in that chapter, emissions at high-altitude would be greater under the fixed-point strategies (scenario 2 and the base scenario) if a certain fraction of the vehicles were low-altitude cars, as opposed to all high-altitude vehicles, because low-altitude cars are unable to adequately compensate for the effects of less dense air under these scenarios. However, if a continuous strategy were implemented (scenarios 1 or 3), this trend would not be true since low-altitude vehicles at higher elevations would be able to adjust.

Table VI-2 presents the incremental cost effectiveness of the alternative control options based on cost estimates in Chapter V and the emission reductions determined in Chapter IV for a fleet containing one low-altitude vehicle for every nine high-altitude vehicles (refer to Table IV-17). As can be seen, even in this extreme case scenario 2 is still by far the most cost effective of the analyzed alternatives to the base scenario.

Cost-effectiveness figures for other control strategies already adopted are provided for comparison in Table VI-3. The values listed in that table and Table VI-1 show that even the high cost estimate for scenario 2 is comparable to many of the other HC control strategies. The high estimate for CO control is less than that for the LDV statutory standards or inspection/maintenance programs.

Compared to the interim (1982-83) high-altitude standards, scenario 2 may be less cost effective. This is to be expected since the benefits of each succeeding increment of pollution control is generally more costly to attain. The important point to consider is that if, after additional study, further emission reductions are necessary to assume attainment and maintenance of the NAAQS in high-altitude areas, further control of motor vehicle emissions in these areas is predicted to be cost effective.

It should be pointed out that at the time this document is being prepared, the cost-effectiveness figures reported in Table VI-3 for the HDG evaporative strategy are based on a proposal that is not yet final. Also, this strategy may not be strictly incremental because there could have been intermediate control levels chosen. Thus, the cost effectiveness was determined over a wide range of emission reductions rather than just the last increment. This approach tends to yield low cost-effectiveness values.

While scenario 2 is the most cost effective of the six alternative scenarios being studied, the final decision as to the viability of scenario 2 will be reached in the next chapter. This decision will depend on such factors as the overall costs of compliance, the overall emission reduction potential, the effect on air quality, and the effect of potential errors in estimates and assumptions used in the analysis.

Table VI-2

Cost Effectiveness Comparison
Adjusted for Low-Altitude Vehicles Above 4,000 Feet [a]

Scenario	Costs[b] (dollars per vehicle) Low	Costs[b] (dollars per vehicle) High	Reductions[c] (10^{-3} metric tons per vehicle) HC	Reductions[c] (10^{-3} metric tons per vehicle) CO	Incremental Cost Effectiveness (dollars/metric ton) HC Low	HC High	CO Low	CO High
1a	2120	2530	11.1	-175.2	95,500	114,000	[d]	[d]
1b	265	515	11.1	-175.2	11,900	23,200	[d]	[d]
1c	705	970	11.1	-175.2	31,800	43,700	[d]	[d]
2	-11	15	12.0	215.9	neg.	625	neg.	35
3a	95	115	1.1	14.1	43,200	52,300	3,400	4,100
3b	230	325	1.1	14.1	105,000	148,000	8,200	11,500

[a] Assumes that 1 out of every 10 vehicles sold above 4,000 feet emits as if it were a low-altitude vehicle.

[b] 1981 dollars discounted to year of vehicle purchase. Costs were allocated to the vehicles above 1,800 feet for scenarios 1 and 3 and to the vehicles above 4,000 feet for scenario 2 in order to correspond to the same vehicles used to determine emission reductions.

[c] Emission reductions were calculated by dividing fleetwide emission reductions in Tables IV-10 and IV-17 by LDGV sales in Table IV-5.

[d] The cost-effectiveness values for CO under scenario 1 were not presented in the table since emissions of this pollutant may increase under this strategy. However, it is also possible that CO emissions may decrease by about the same total amount listed for both scenarios 2 and 3. Using this assumption, the cost effectiveness would range from $580 to $5,500 per metric ton for CO.

Table VI-3

Cost Effectiveness Comparison With Other Emission Control Strategies

Control Program	Baseline Emissions [a]	Emissions After Control Strategy Implemented	Cost Effectiveness ($/metric ton) HC	CO
LDV Statutory[2] Standards	HC 0.9 CO 15	HC 0.41 CO 3.4	734	67
LDV I/M [3]	--	--	640	58
LDT 1984 [4] Standards	HC 1.7 CO 18	HC 0.8 CO 10	195	15
HDE 1984 Standards[5][b]				
(gasoline)	HC 1.5 CO 25	HC 1.3 CO 15.5	305	10
(diesel)	HC 1.5 CO 25	HC 1.3 CO 15.5	325	--
Motorcycle Standards [6]	HC 9 CO 34.67	HC 8-22.5 [c] CO 27.4	582	Neg.
HDG Evap. [7][d]	HC 1.8	HC 0.17	200	
Interim 1982-83 HA Standards [8]	HC 1.47(cars) 4.19(trucks) CO 16.23(cars) 73.02(trucks)	HC 1.33 (cars) 3.78 (trucks) CO 13.21 (cars) 55.65 (trucks)	393	12

[a] Emission levels are expressed as a standard in grams per mile except for the HDE 1984 levels which are in grams per brake horsepower-hour.

[b] The baseline and after control strategy emission values were based on different test procedures (see reference 5).

[c] Sliding scale based on engine displacement (cubic centimeters).

[d] The evaporative standard is in terms of grams/test and converted to g/mi here to facilitate comparison.

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Chapter VII

Comparing the Alternative Control Scenarios for Light-Duty Gasoline-Fueled Vehicles

I. INTRODUCTION

The primary purpose of this report is to determine if any of the alternatives to continuing the current fixed-point proportional standards (the base scenario), which are analyzed in this report, deserve further consideration. This chapter evaluates the seven control scenarios identified in Chapter II on the basis of the previous analyses (Chapters III-VI) for light-duty gasoline-fueled vehicles (LDGVs). It then identifies what appears to be the most desirable of the six alternative high-altitude control scenarios. Subsequent chapters will evaluate this single alternative scenario for its effects on light-duty, gasoline-fueled trucks (LDGTs) in addition to diesel-powered light-duty vehicles and light-duty trucks (LDDs).

Using LDGVs to identify a viable control strategy simplifies the analysis by eliminating the need to review LDGTs and LDDs in detail for each scenario, but does not compromise the final selection. Any alternative scenario which is predicted to be inappropriate for LDGVs will also be inappropriate for the overall motor vehicle fleet because this category forms the bulk of the total vehicle market.

A detailed description of the control scenarios analyzed in the report was originally presented in Chapter II, but is repeated here for clarity.

A. Base Scenario: Fixed-Point Proportional Standards with Exemptions

This scenario will require vehicles to comply with high-altitude standards of 0.57 g/mi HC, 7.8 g/mi CO, 1.0 g/mi NOx, and 2.6 g/test evaporative HC at only one elevation (i.e., 5,300 feet). It is essentially a continuation of the current high-altitude requirements for 1982 and 1983 model year vehicles. Exemptions may be granted for certain low-power vehicles that would perform unacceptably at high altitude and that may have technical difficulty in meeting the standards cost effectively.

B. Scenario 1: Continuous Statutory Standards

This alternative scenario will require vehicles to comply with standards of 0.41 g/mi HC, 3.4 g/mi CO, 1.0 g/mi NOx, and 2.0 g/test evaporative HC (the current low-altitude standards) is required at all elevations up to a maximum altitude. This scenario is subdivided further, depending on the maximum altitude to which compliance must be demonstrated and on whether performance-based exemptions are provided:

1. 1a - Compliance required up to 10,200 feet and no exemptions allowed;

2. 1b - Compliance required up to 6,000 feet with exemptions allowed; and

3. 1c - Compliance required up to 6,000 feet and no exemptions allowed.

C. Scenario 2: Fixed-Point Statutory Standards with Exemptions

This strategy is similar to the base scenario, except that at 5,300 feet vehicles must meet the low-altitude statutory emission standards (0.41 g/mi HC, 3.4 g/mi CO, 1.0 g/mi NOx and 2.0 g/test evaporative HC) instead of the proportional standards presented in the base scenario.

D. Scenario 3: Continuous Proportional Standards

Under this control strategy, vehicles must meet standards that increase proportionally with altitude up to 6,000 feet. At 1,800 feet, the emission standards are the low-altitude standards; at 5,300 feet, they are the high-altitude standards outlined in the base scenario. The standards vary linearly in between these two altitudes and up to 6,000 feet. Like scenario 1, this scenario has two variations:

1. 3a - Exemptions are allowed; and

2. 3b - No exemptions are allowed.

These seven scenarios differ in their approach to solving the high-altitude emissions problem. The base scenario and scenario 2 are termed "two-car" strategies since they allow vehicle modifications performed on vehicles sold for principal use above 4,000 feet. This is not the case for scenarios 1a, 1b, 1c, 3a, and 3b. Any modifications which are necessary to satisfy the high-altitude requirements in these scenarios must be performed on all affected vehicles regardless of the altitude at which they are sold. These scenarios are termed "one-car" strategies.

II. METHODOLOGY

Identifying the most desirable alternative high-altitude control strategy is done in three parts. First, the alternative control scenarios are evaluated by examining the aggregate cost, total emissions reduction, and cost effectiveness from the previous chapters. The control scenarios are then ranked according to their ability to reduce high-altitude emissions in a cost-effective manner. Second, the preliminary ranking is reviewed to determine if further consideration of the underlying assumptions would change the order and to determine if the first ranked scenario merits further consideration. Third, the most desirable alternative scenario is evaluated further based on its air quality impact in comparison to the base scenario and with regard to the need for additional pollution control in high-altitude regions.

III. REVIEW OF THE ECONOMIC IMPACT, ENVIRONMENTAL IMPACT, AND COST EFFECTIVENESS

A. Economic Impact

The economic impacts of the six alternative high-altitude control scenarios were calculated for a 5-year period (1984-89) as an increment beyond the costs of continuing the current 1982 and 1983 high-altitude standards (base scenario). The aggregate cost to the nation for each of the six alternative strategies appears in Figure VII-1. These costs are primarily based on estimates of the requisite hardware (see Chapter III), and include expenses for development, certification, emission control hardware, engine recalibration, R&D for expanded microprocessor capacity in the electronic engine control unit, and changes in fuel consumption and maintenance. A range of costs was estimated for each scenario because of uncertainties in defining the production costs.

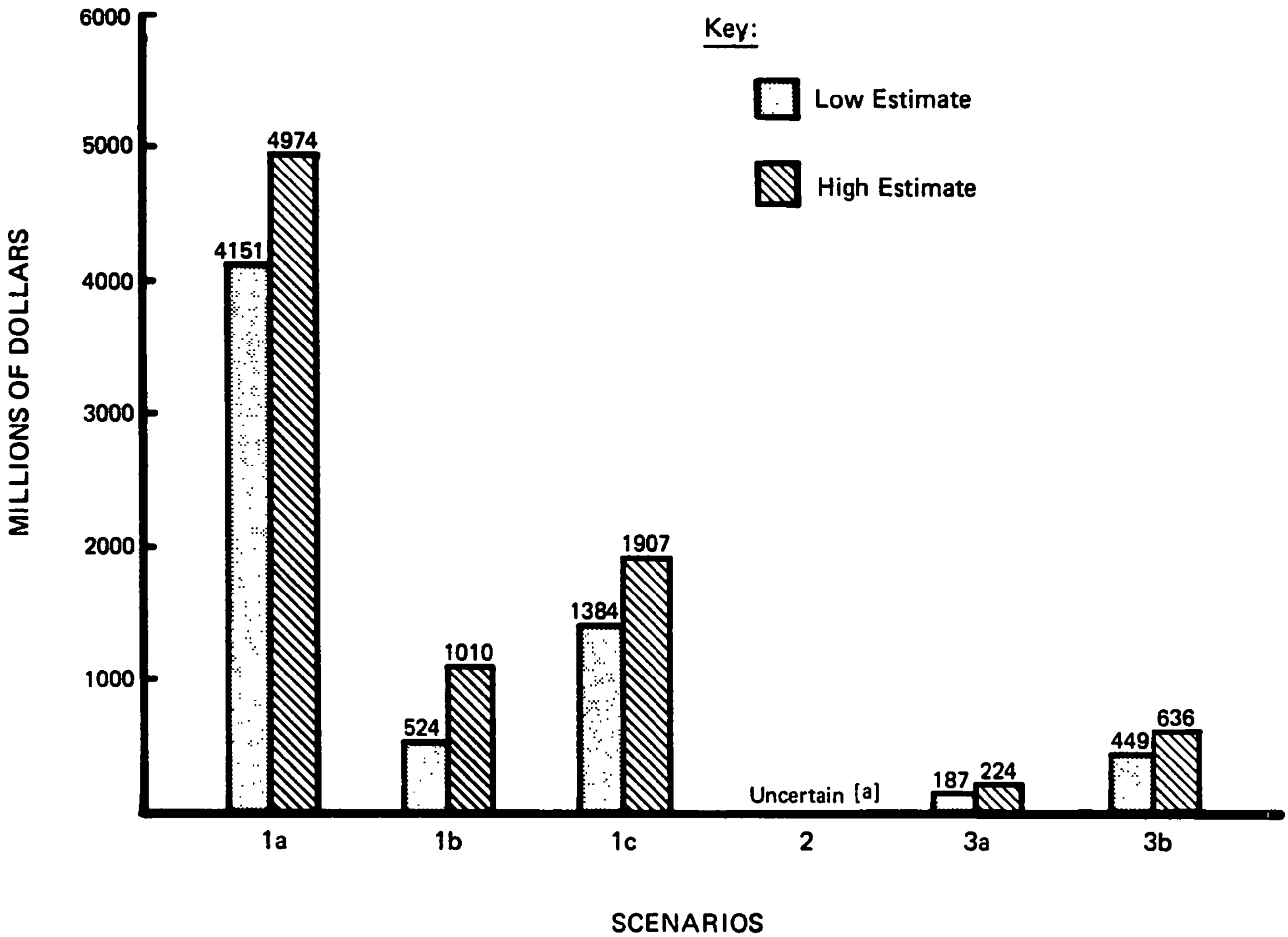
Scenario 2 is by far the least costly of the alternative scenarios (Figure VII-1). However, the exact cost of this scenario is difficult to determine. A net savings to the nation may result if the estimated fuel economy benefit, which is larger than the relatively low hardware costs, is included in the cost calculation. This estimated benefit is based on very limited information and is considered tentative at this time. Nevertheless, even without including this estimated benefit, the incremental cost of scenario 2 is only about $17 million.

The primary cause of the large price differential between this scenario and the other scenarios is that only scenario 2 is a two-car strategy. Therefore, under this scenario only vehicles sold at high altitude (above 4,000 feet) need to be equipped with additional emission controls. The other scenarios are one-car strategies and require emission control modifications on all vehicles throughout the nation regardless of where they are sold.

Scenarios 3a and 3b have the lowest net cost with a range of about $190 million to $640 million. The cost difference between allowing and not allowing exemptions is clear. Granting exemptions for low-power vehicles in scenario 3a

FIGURE VII-1

Incremental Aggregate Costs to the Nation (1981 Dollars)



[a] SCENARIO 2 MAY RESULT IN A NET SAVINGS IF THE INCREMENTAL PURCHASE PRICE INCREASE (ABOUT $15.00 PER HIGH-ALTITUDE VEHICLE) IS OFFSET BY A POTENTIAL FUEL ECONOMY BENEFIT (ABOUT $25.00 PER HIGH-ALTITUDE VEHICLE). IF THE POTENTIAL FUEL ECONOMY IMPROVEMENT IS EXCLUDED, THE COST WOULD BE ABOUT $17 MILLION. THE ESTIMATED FUEL SAVINGS IS TENTATIVE AT THIS TIME BECAUSE OF THE LIMITED DATA BASE.

reduces the cost of the continuous proportional standards by about $260-410 million.

Scenarios 1a, 1b, and 1c are the most stringent of the alternative scenarios and their higher costs reflect the difficulty in achieving them. Meeting the statutory standards at all elevations up to 10,200 feet without exemptions makes scenario 1a the most expensive at $4.15 billion to $4.97 billion. Reducing the elevation to 6,000 feet (scenario 1c) decreases the cost by about 65 percent to between $1.38 billion and $1.91 billion. Scenario 1b is the least stringent continuous statutory standard with a cost of $524 million to $1.01 billion. It differs from 1c in that exemptions for low-power vehicles are allowed. Providing exemptions reduces the cost in this scenario by about $900 million.

B. Environmental Impact

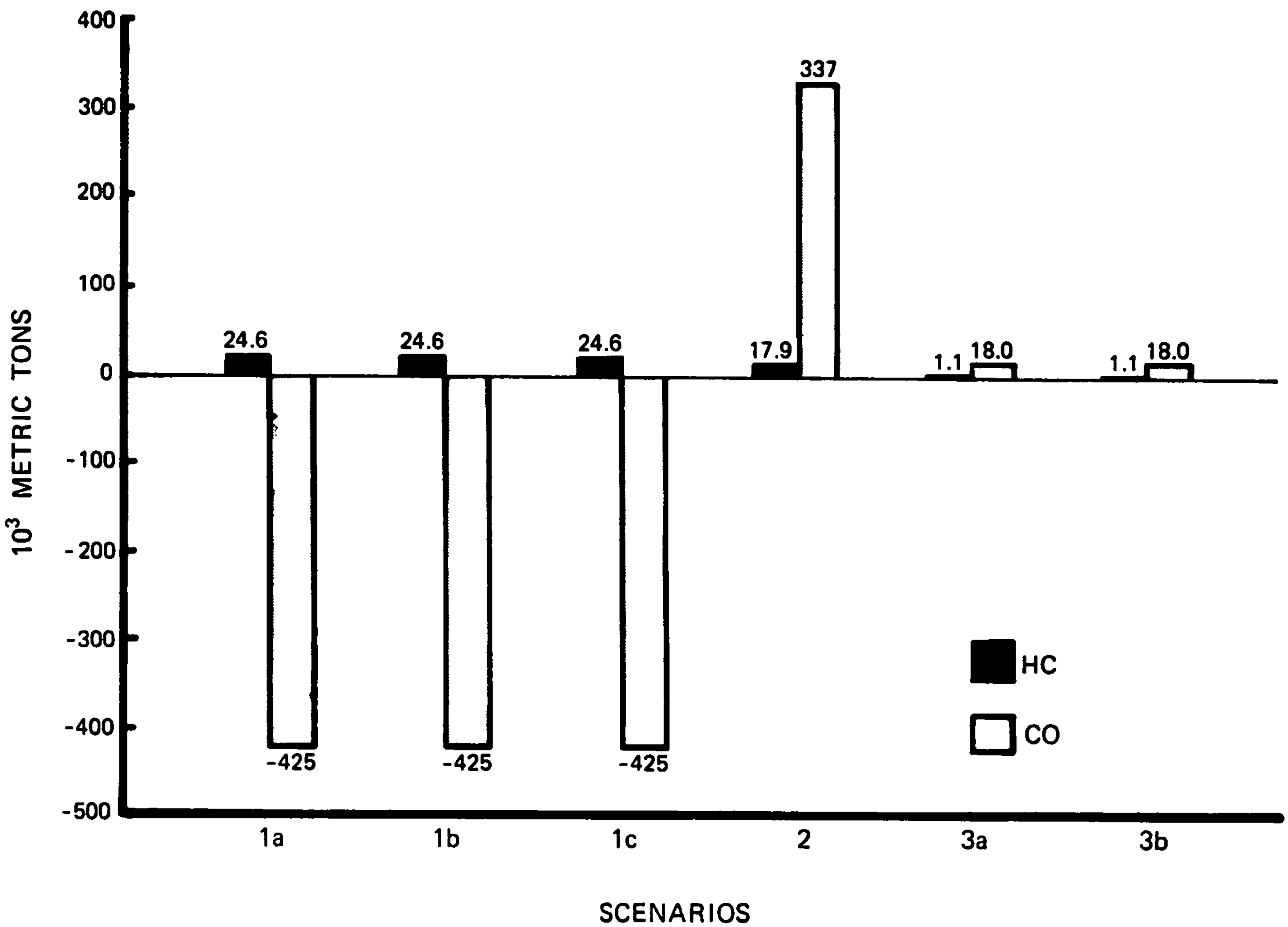
The incremental lifetime emissions from LDGVs which are affected by the 1984 high-altitude standards were calculated for a 5-year period. Three basic factors were used: 1) the number of miles traveled by a vehicle in its lifetime, 2) the emission factor for each pollutant (amount of pollution per mile), and 3) the number of vehicles affected by the standards.

The emission reductions achieved over the lifetimes of those vehicles sold in the first 5 years of regulation for each alternative control strategy are presented in Figure VII-2. Scenarios 1a, 1b, and 1c show the greatest reductions in hydrocarbon (HC) emissions. These strategies also appear to increase carbon monoxide (CO) emissions in high-altitude areas. A similar penalty would occur at low altitude (not shown) and is caused by the expected catastrophic failure of some feedback systems which are used as emission control hardware in these scenarios. However, the emission factors that generated these results for scenarios 1a, 1b, and 1c are considered to be very preliminary at this time because of the limited number of vehicle tests upon which the catastrophic failure rate is based. The vehicles in this sample were also "early" feedback systems and it is difficult to extrapolate the results from these tests to future systems. (This same general qualification also applies to the other scenarios because they also rely on estimates of emission factors for future feedback emission control systems, although to a lesser degree.)

EPA believes that because of the limitations in the original data base, the emission factors may change as further tests are conducted in the Agency's surveillance programs. The direction of this change is, of course unknown, but as stated in Chapter IV, it is most likely that future systems will exhibit fewer catastrophic failures. If this occurs, the emission factors for feedback systems may be more like those for nonfeedback systems which show a significant reduction in

FIGURE VII-2

Incremental Emission Reductions [a]



[a] ALTHOUGH CO EMISSIONS MAY INCREASE IN SCENARIO 1, IT IS ALSO POSSIBLE THAT THIS POLLUTANT MAY BE SIGNIFICANTLY REDUCED.

HC and CO emissions when controlled to the statutory levels at high altitude. Therefore, instead of producing an adverse environmental impact, it is possible scenarios 1a, 1b, and 1c may substantially reduce CO emissions in areas above 1,800 feet. For intermediate altitudes (1,800 feet to 4,000 feet) these scenarios may produce an incremental CO benefit that is greater than that calculated for the proportional standards in scenario 3 (18,000 metric tons). In areas above 4,000 feet, the CO reduction may be much like that for scenario 2 which also controls emissions to statutory levels (331,000 metric tons). These potential reductions for scenarios 1a, 1b, and 1c total approximately 349,000 metric tons (Figure VII-2).

If the catastrophic failure rates assumed for scenario 1 are valid, scenario 2 offers the greatest overall reduction in emissions of all the alternative scenarios (Figure VII-2). In this scenario, it is unnecessary to replace nonfeedback systems with feedback systems as in scenario 1. Therefore, the possibility of additional catastrophic failures is avoided along with any potential CO penalty. If the failure rates prove to be significantly less, however, scenario 1 may offer slightly greater benefits than the combined total of scenarios 2 and 3 (Figure VII-2).

The emission reductions for scenarios 3a and 3b are relatively small (Figure VII-2). The proportional standards in these scenarios have a benefit only at intermediate altitudes from 1,800 to 4,000 feet. There is no additional control above 4,000 feet since the base scenario already provides emission control to proportional levels at those elevations.

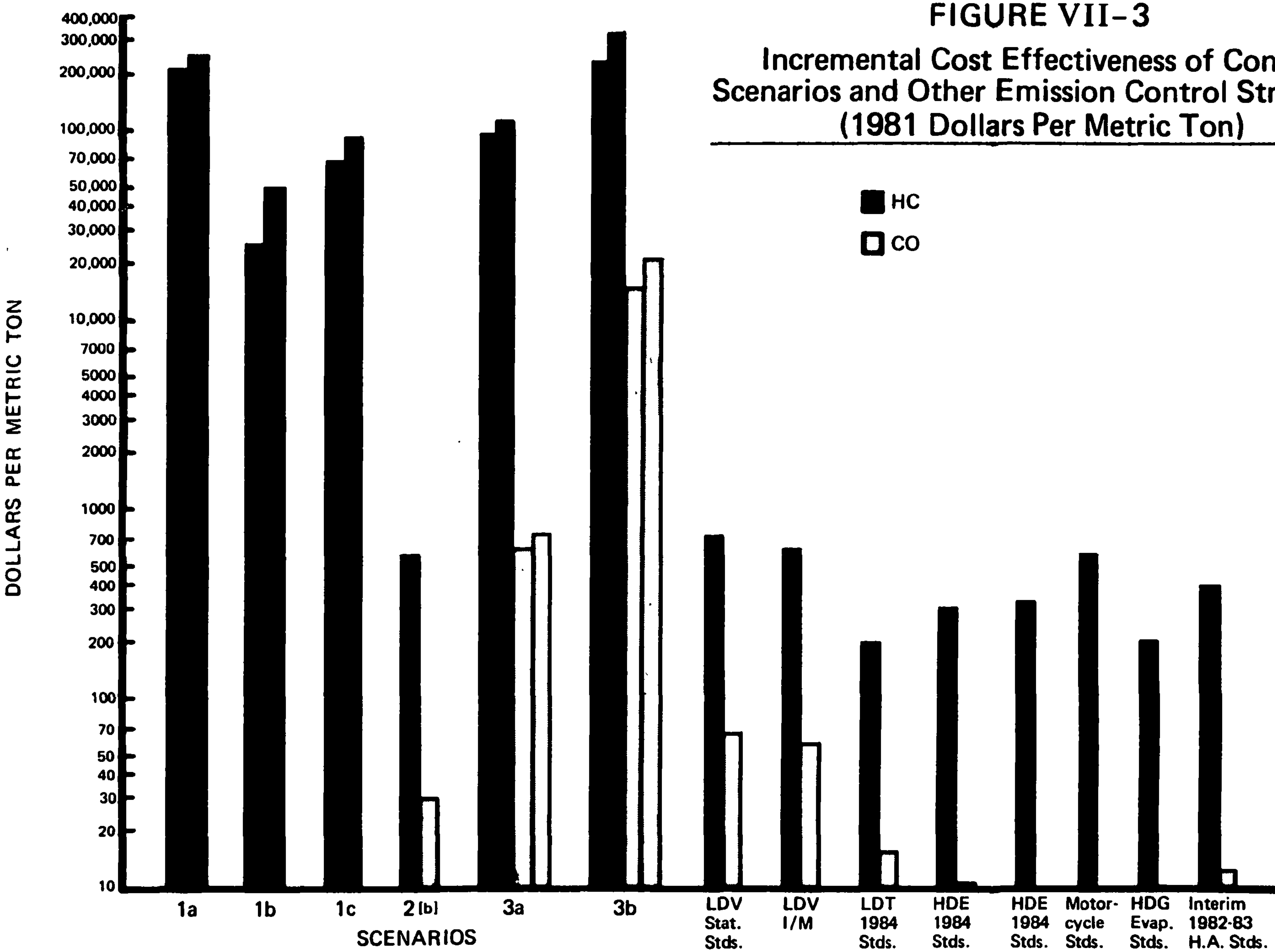
C. Cost Effectiveness

The cost effectiveness of further reducing LDGV emissions in high-altitude areas of the country was calculated in Chapter VI by dividing the total cost per vehicle for each alternative control strategy by the respective pollutant reductions. Figure VII-3 shows the incremental cost-effectiveness values ($/metric ton) for each control scenario. The cost effectiveness of scenario 1 was not calculated because of the possibility that CO emissions might increase, although it was calculated for a possible decrease. The cost-effectiveness calculation for scenario 2 was expanded to evaluate a "worst case" assumption that no fuel economy benefit would accompany implementing the more stringent high-altitude standards of this control strategy. Therefore, the range of values for scenario 2 is based on the inclusion or exclusion of the estimated fuel increment. Figure VII-3 also contains cost-effectiveness values of other mobile source emission regulations for comparison.

Scenario 2 is the most cost-effective option being considered (Figure VII-3). It would reduce HC emissions at a

FIGURE VII-3

Incremental Cost Effectiveness of Control Scenarios and Other Emission Control Strategies [a] (1981 Dollars Per Metric Ton)



[a] THE COST EFFECTIVENESS FOR CO CONTROL IN SCENARIO 1 IS NOT PRESENTED BECAUSE OF THE POSSIBILITY THAT EMISSIONS OF THIS POLLUTANT MAY INCREASE BEYOND THE BASE SCENARIO.

[b] ONLY THE HIGH-COST ESTIMATE IS SHOWN FOR SCENARIO 2. THE LOW ESTIMATE WAS NOT SHOWN BECAUSE IT INCLUDES AN ESTIMATED FUEL ECONOMY BENEFIT, WHICH IS TENTATIVE AT THIS TIME.

cost of up to $575 per metric ton, compared to $12,600 to $121,000 per metric ton for scenario 1 and $95,000 to $325,000 per metric ton for scenario 3. Under scenario 2, CO emissions would be reduced at a cost of up to $30 per metric ton. The cost effectiveness of potential CO reductions under scenario 1 was found by assuming that the benefit would be the total of those listed for scenarios 2 and 3 (0.25 metric tons per vehicle). Using this value, reducing CO emissions under scenario 1 ranges from $535 to $5,100 per metric ton. The cost effectiveness of CO emission reductions under scenario 3 ranges from $6,200 to $21,100 per metric ton.

Scenarios 1 and 3 have extremely poor (i.e., high) cost-effectiveness values for one basic reason. While emission reductions are achieved solely on vehicles above 1,800 feet (roughly 5 percent of the fleet), vehicles sold below this altitude (95 percent of the fleet) must also bear the additional cost of applying high-altitude control systems. This approach generally tends not to be cost effective because the added cost is not offset with an attendant emissions benefit.

Figure VII-3 shows that scenario 2, even under the high cost estimates, is the only alternative control scenario analyzed which is comparable to other mobile source emission control regulations. Therefore, scenario 2 appears to be be a cost-effective approach to reducing high-altitude emissions from LDGVs.

Compared to the interim (1982-83) high-altitude standards, scenario 2 is less cost effective. This is to be expected because the benefits of each succeeding increment of pollution control are generally more costly to attain. The important point is that if further emission reductions are necessary to attain and maintain the NAAQS in high-altitude areas, further control of motor vehicle emissions in these area appears to be cost effective.

IV. RANKING OF THE ALTERNATIVE HIGH-ALTITUDE SCENARIOS

Although alternative control strategies are not directly comparable based solely on cost and benefits, they generally can be compared based on their cost effectiveness. Cost effectiveness is, therefore, the primary decision-making criterion.

The alternative control scenarios analyzed in this report are ranked as follows in order of their ability to reduce high-altitude emissions and their incremental cost effectiveness:

1. Scenario 2 - Fixed-point proportional standard with exemptions;

2. Scenario 3a - Continuous proportional standard with exemptions and a ceiling of 6,000 feet;

3. Scenario 3b - Continuous proportional standard without exemptions and a ceiling of 6,000 feet;

4. Scenario 1b - Continuous statutory standard with exemptions and a ceiling of 6,000 feet;

5. Scenario 1c - Continuous statutory standard without exemptions and a ceiling of 6,000 feet; and

6. Scenario 1a - Continuous statutory standard without exemptions and a ceiling of 10,200 feet.

Scenario 2 ranks first. It is by far the most cost effective and is projected to provide the largest air quality benefit of the alternative scenarios. Scenarios 3a and 3b are ranked second and third, respectively, in order of increasing cost. Although these scenarios reduce HC less than scenarios 1a, 1b, and 1c, they ranked higher because of the potential for increased CO emissions which result in scenarios 1a, 1b, and 1c. This potential penalty, in addition to their very high price of scenarios 1a, 1b, and 1c, relegates them to be ranked last. Therefore, scenario 1b is fourth, scenario 1c is fifth, and scenario 1a is sixth, in order of their increasing cost.

V. EVALUATION OF THE ALTERNATIVE SCENARIOS BASED ON THEIR SENSITIVITY TO THE ASSUMPTIONS OF THE ANALYSIS

The complexity of analyzing alternative high-altitude standards for 1984 and later model year motor vehicles necessitates the use of simplifying assumptions and projections. No matter how carefully considered, however, these estimates are subject to error and individual interpretation. Since the choice of scenario 2 as the best alternative control strategy may depend on these estimates, the sensitivity of this choice to the underlying assumptions must be explored.

The sensitivity evaluation will be conducted in two parts. First, the critical assumptions concerning the technical requirements and catastrophic failure rates of electronic control systems in addition to the number of low-altitude vehicles operating at high altitude will be reviewed to determine if any other scenario might be ranked first instead of scenario 2. Second, the merits of scenario 2 itself will be evaluated by reviewing the assumptions concerning the associated change in fuel economy, the fleet mix of feedback and nonfeedback systems, the number of exemptions, the use of low-altitude vehicles in high-altitude areas, and the level of the emission standards.

A. Reexamination of the Control Scenario Ranking

For scenarios 1a, 1b, and 1c the data in Figures VII-1 through VII-3 can be used to show that even if a favorable case is constructed with regard to the technical requirements and catastrophic failure rates, these scenarios would still remain very cost ineffective. The emissions consequence of reducing the catastrophic failure rate for feedback systems used in the analysis has already been discussed in detail. The potential CO benefit of such a change, therefore, can be assumed to be as great as the combined total for scenarios 2 and 3 (0.25 metric tons per vehicle). Since the effect of catastrophic failures is not as significant for HC emissions, the reduction in this pollutant is unchanged from that shown for scenario 1 in Figure VII-2. Also, assume that the emission control requirements were overestimated because of the limited amount of available data. A favorable case would involve reducing the emission control cost below the low estimate of $265 per vehicle for scenario 1b by a third to perhaps $175 per vehicle. This could result from using the upper range of fuel economy benefits or by not replacing nonfeedback systems with feedback systems. Even these extremely favorable costs and emission benefits would yield cost-effectiveness values in excess of $8,300 per ton of HC and $350 per ton of CO. These values are still much higher than those for scenario 2 (Figure VII-3). For scenarios 3a and 3b the same type of sensitivity analysis can be performed with similar results.

The environmental benefits of implementing scenarios 1a, 1b, 1c, 3a, and 3b increase if a significant number of vehicles operating at high altitude are assumed to be low-altitude vehicles. This would increase the gaseous emissions under the base scenario since some vehicles would be emitting at uncontrolled levels. By implementing continuous control strategies, every vehicle would meet the appropriate standards at high altitude regardless of where it was originally purchased. This would increase the benefits of high-altitude regulations under scenarios 1 and 3. A hypothetical "worst case" was constructed in Chapter VII to evaluate the cost effectiveness of such an assumption. The sensitivity analysis in that chapter assumed that one out of every ten vehicles operated at high altitude originated from a low-altitude area. This made very little difference in the cost effectivenss of scenario 1 but did make scenario 3 significantly more cost effective. For example, the cost of reducing HC under scenario 3 decreased from a range of $95,000 to $325,000 per metic ton to a range of $43,200 to $148,000 per metric ton. The cost of reducing CO decreased from a range of $6,200 to $21,100 per metric ton to a range of $3,400 to $11,500 per metric ton. However, these improved cost-effectiveness values remain substantially more expensive than other emission control strategies. Therefore, scenario 2 remains the most reasonable alternative.

B. Reexamination of the Merits of Scenario 2

The sensitivity analysis has thus far shown that scenario 2 is the most desirable alternative strategy analyzed in this report. Now, scenario 2 itself will be evaluated. Specifically, even the high cost estimates which exclude the expected fuel economy benefit show it is reasonably cost effective and that its cost to the consumer is not excessive (about $15 per vehicle). However, how sensitive is this to the assumptions of the analysis and would concerns about these assumptions detract enough from the merits of scenario 2 to remove it from further consideration? These questions are discussed below.

The sensitivity analysis, contained in Chapter IV and V, shows that the alternative scenarios are especially sensitive to five of the assumptions that are necessary to complete this study. First, the analysis is very sensitive to changes in fuel consumption which should result from the installation of high-altitude emission control hardware. In fact, the net cost of scenario 2 was found to be so sensitive to this, that the lower limit of the possible fuel economy improvements (the range was 0 to 4 percent for nonfeedback controlled vehicles) was included in the cost-effectiveness values. Therefore, the "worst case" (i.e., the lower limit), has already been accounted for. If the upper limit of 4 percent improvement were included in the cost-effectiveness analysis, the potential net savings would be greater than that which already may be possible. Because of the extreme sensitivity of the analysis to projected changes in fuel economy, this factor must be carefully reevaluated as additional information becomes available.

Second, the cost effectiveness should be considerably better if many manufacturers switched from feedback systems to nonfeedback systems. Such a change has already been made by Ford and is accounted for in EPA's emission control estimates. Ford originally intended to utilize feedback systems, but switched to nonfeedback systems because of their lower selling price. Whether other manufacturers will do this is unknown. This analysis has generally assumed that manufacturers currently using feedback systems will continue to do so. However, these manufacturers have stated that the competitive nature of the automotive market will force a continued reevaluation of their commitment to feedback systems. Because nonfeedback systems have no inherent ability to compensate for the effects of altitude on vehicle emissions, the benefit of controlling these systems in scenario 2 should be greater than the benefits of controlling feedback systems. For this reason, the introduction of more nonfeedback systems into the market should improve the cost effectiveness of scenario 2.

Third, the desirability of scenario 2 is also very dependent on the number of vehicles that could be exempted. Because the exemption provision has such a pervasive effect on the economic, energy, and social implications of any high-altitude standard, it will be briefly discussed further.

In the future, the number of vehicles that may need to be exempted from the proportional standards under the base scenario and from the statutory standards under scenario 2 was estimated in Chapter II to be about 5 and 15 percent, respectively, of the current high-altitude fleet. These are only rough estimates because of the dynamic nature of the motor vehicle fleet composition. Furthermore, this study assumes that the exemption criteria used in the 1984 high-altitude regulations would be patterned after the interim high-altitude standards where exempted vehicles may not be sold above 4,000 feet. This criterion precipitates one of the most significant issues involved in scenario 2: what type of vehicles would be available at high altitude under the base scenario but would be unavailable under scenario 2?

The justification for granting exemptions from the interim high-altitude standards (base scenario) was that exempted vehicles generally would be low-powered vehicles that were designed primarily for the low-altitude market. When these vehicles are driven at high altitude, the lower air density degrades their performance to such a degree that they would only be sold in small numbers. Hence, the impact of exemptions would be minimal. From this, it can logically be assumed that the vehicles which have somewhat more power than the exempted vehicles must be good sellers, because they provide better fuel economy. Under scenario 2 some of these high fuel economy vehicles, which would be sold in the absence of such a regulation, would become unavailable. Such vehicles could represent 10 percent of the current market (15-5 percent). This could have three consequences: 1) an adverse consumer reaction may be generated, 2) it appears to be contrary to national energy policy, and 3) there may be an adverse economic impact.

On a fleet-wide basis, the expected fuel economy penalty from eliminating some of the more fuel efficient vehicles at high altitude would be offset by the greater fuel economy benefit that is expected to accompany statutory standards. This benefit occurs because in order to comply with the standards, manufacturers must reduce excessively fuel-rich engine operations. It could also be argued that the fuel efficiency benefit of the exempted vehicles may be more imagined than real. Those vehicles requiring exemptions generally operate with power enrichment at high altitude. This operation results in additional fuel being metered into the combustion chamber to maximize power output. However, using this extra fuel also decreases fuel economy, sometimes very significantly. Because the effect of increasing altitude is to reduce an engine's power output, a high fuel economy vehicle at low altitude which rarely operates in power enrichment may operate a significant amount of the time in this mode at high altitude to compensate for the power loss that occurs at higher elevations. This could, theoretically, make a relatively higher powered vehicle more fuel efficient when operated at high altitude, since enough engine power would be available to prevent or minimize excursions into power enrichment. Therefore, the potential fuel economy impact of granting exemptions cannot be settled at this time. However, the present analysis assumed no fuel economy penalty due to the increased exemptions; any excursion from this assumption could be in the direction of a fuel penalty and added cost.

The potential for adverse consumer reaction is also speculative. Further technical achievements may reduce the number of exempted vehicles. The mass marketing of throttle body injection with its more precise fuel metering and, hence, better emissions control capability may reduce the need for exemptions. Also, as better information becomes available, the exemption criteria may be refined to resolve apparent problems regarding the number and type of exempted vehicles. Finally, other options involve waiving the high-altitude requirements for some vehicles, thereby allowing them to be sold at higher elevations, or requiring these vehicles to meet a less stringent high-altitude standard.

Fourth, the incremental cost-effectiveness of scenario 2 relative to the other scenarios could be affected by low-altitude vehicles being driven in high-altitude areas. In Chapter V, the environmental consequences of a high-altitude fleet comprised of 10 percent low-altitude vehicles were discussed as part of the sensitivity analysis. This was considered to be the upper limit of possible low-altitude vehicle use at high altitude. As explained in that chapter, emissions at high-altitude would be greater under the fixed-point strategies (scenario 2 and the base scenario) if a certain fraction of the vehicles were low-altitude vehicles, as opposed to all high-altitude vehicles. This is because many low-altitude vehicles cannot compensate adequately for the effects of less dense air under these scenarios. However, under a continuous strategy (scenarios 1 or 3), this trend would not be true since low-altitude vehicles at higher elevations would be able to adjust. Since the emission reduction potentials of the various scenarios are affected by the presence of low-altitude vehicles, cost effectiveness is also affected. In Chapter VII it was determined that in the "worst case," the cost effectiveness of scenario 2 would increase for HC control from $580 per metric ton to $625 per metric ton. Similarly, the cost of CO removal increases from $30 per metric ton to $35 per metric ton.

The fifth, and final, assumption that will be reviewed was not specifically analyzed in the previous chapters and concerns the emission reductions that may be achievable if scenario 2 was implemented. The costs and benefits of this scenario are based on the assumption that statutory standards would be promulgated at high altitude. These standards were chosen as a readily identifiable alternative to the proportional standards of the interim (1982-83) high-altitude program and also to be consistent with statutory requirements for 1984 and later. The previous discussion in this section demonstrated that high-altitude regulations, as with any requirement, must be chosen to moderate or eliminate a complex mixture of potentially adverse impacts (e.g., environmental, economic, energy, and model availability). The most efficient standards, therefore, may be at some level other than the statutory standards. While it appears that more stringent control beyond the proportional standards is feasible and cost effective perhaps down to the levels of the statutory standards, less control may provide the majority of the needed environmental benefits in a more cost-effective manner. Only further study can identify the optimum level of control.

The above discussion has served to identify some potentially negative effects of implementing scenario 2. It has also served to show that some of these effects can neither be proven or disproven at this time. In addition, the exact level of the emission standards in scenario 2 which ultimately may be chosen will depend on a complex mixture of variables representing the technical feasibility, total cost, and the number of exemptions that may be required. The appropriate level for high-altitude standards appears to be below the proportional values and may be as low as the statutory values contained in this analysis. As with any program that attempts to improve public health and is in its early stages of development, further study can be expected to define the exact level of the standards and to resolve or mitigate potential adverse effects. Therefore, it appears that the air quality benefits of continuing the existing proportional standards at high altitude may be improved upon if a control program incorporating aspects similar to scenario 2 is adopted.

VI. COMPARISON OF SCENARIO 2 TO THE BASE SCENARIO

This section compares the future air quality benefits of the base scenario and scenario 2, and examines whether the incremental benefits of scenario 2 are great enough to merit further evaluation with regard to the effects on LDGTs and LDDs. This decision will be made by reviewing the benefits of the two scenarios in relation to the future air quality needs of high-altitude regions, as well as further considering of the basic assumptions with which scenario 2 was developed.

Before discussing the air quality modeling results for the two scenarios, a brief discussion of the expected effects of incremental control strategies is useful. Any single incremental strategy will usually yield much smaller air quality benefits than those achieved with the original controls. Most of the controls producing dramatic results have already been implemented; future gains in air quality will depend on a combination of incremental control strategies. Each strategy may affect air quality slightly, but in combination, they can significantly improve it. For example, controlling LDTs as well as LDVs at high altitudes would provide greater benefits. Also, in presenting the results of air quality models, the absolute values of ambient pollutant concentrations or violations of the air quality standards are subject to greater error than are the relative differences among the control strategies being analyzed.

Figures VII-4 and VII-5 show estimated impacts of scenario 2 and the base scenario on the air quality of major high-altitude cities. Figure VII-4 shows that scenario 2 could slightly reduce the maximum ozone concentrations beyond those achieved by the base scenario (generally being about a 1 percent improvement for some of the years studied). Figure VII-5 shows that in 1989 and 1990, one less violation of the ozone NAAQS is projected to occur under scenario 2 for the high-growth no-I/M case. With I/M, scenario 2 does not appear to provide any additional reduction in NAAQS violations.

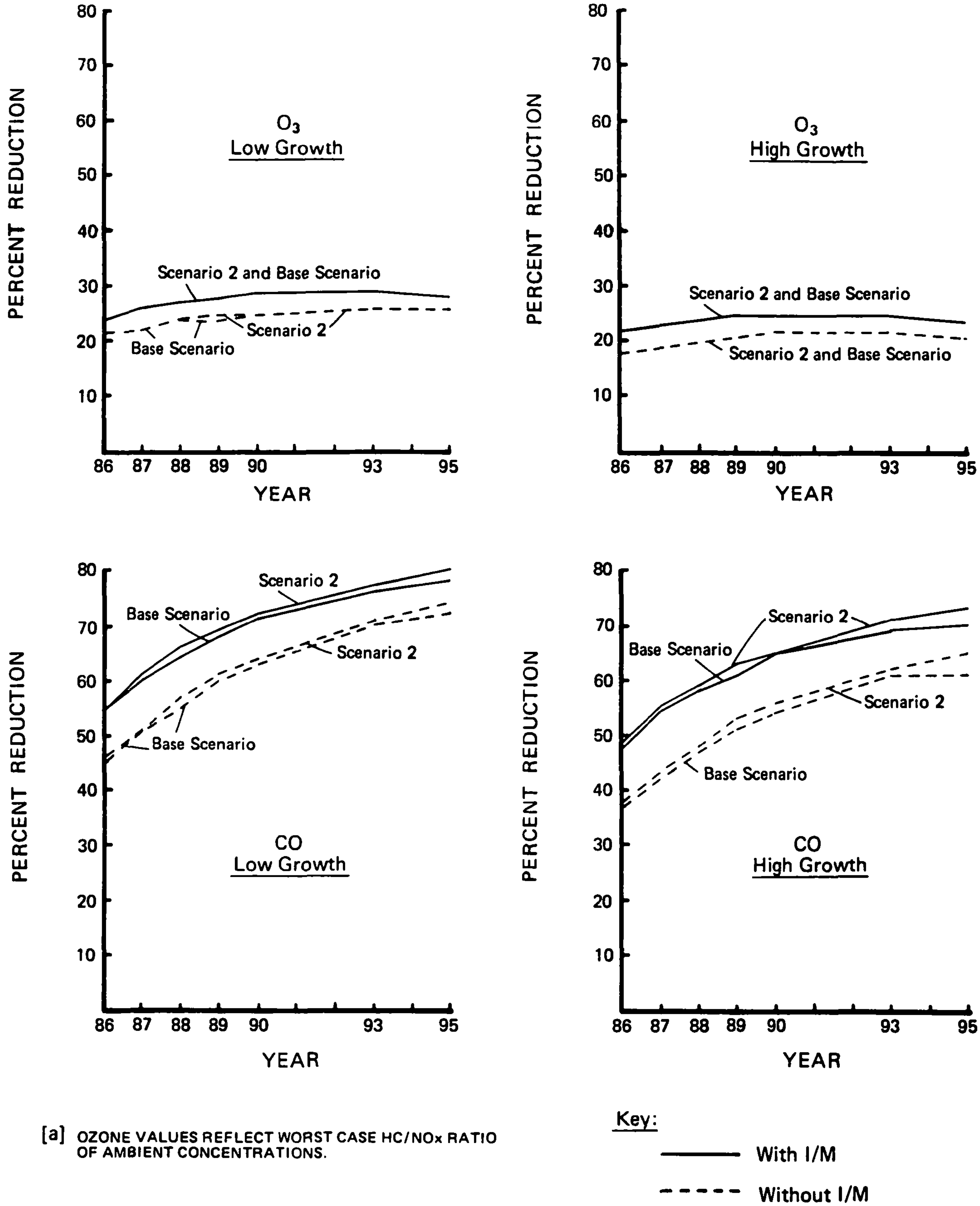
The differences in ambient CO concentrations resulting from the two scenarios, however, are more significant than those shown for ozone above. The benefits of implementing scenario 2 are projected to be somewhat larger and occur with greater frequency. Figure VII-4 shows that in essentially all years, there is a 1 to 3 percent improvement under both growth assumptions, with and without I/M.

The projected number of NAAQS violations for CO are shown in Figure VII-5. Implementing scenario 2, without I/M, could reduce the number of violations under the low-growth case by one in 1986 and 1989. If higher growth rates without I/M are assumed, scenario 2 may provide 1 to 3 fewer violations in 1987 through 1990. Under the high growth, with I/M case, two less violations are shown in 1986 and one less in 1987.

To summarize the discussion thus far, the air quality models show scenario 2 is projected to have a positive impact on air quality in high-altitude regions, although the impact is relatively small. This is not surprising, however, because scenario 2 is an incremental control strategy and needed improvements in air quality will only come by combining several incremental controls (e.g., light-duty trucks, each having a small benefit of its own).

FIGURE VII-4

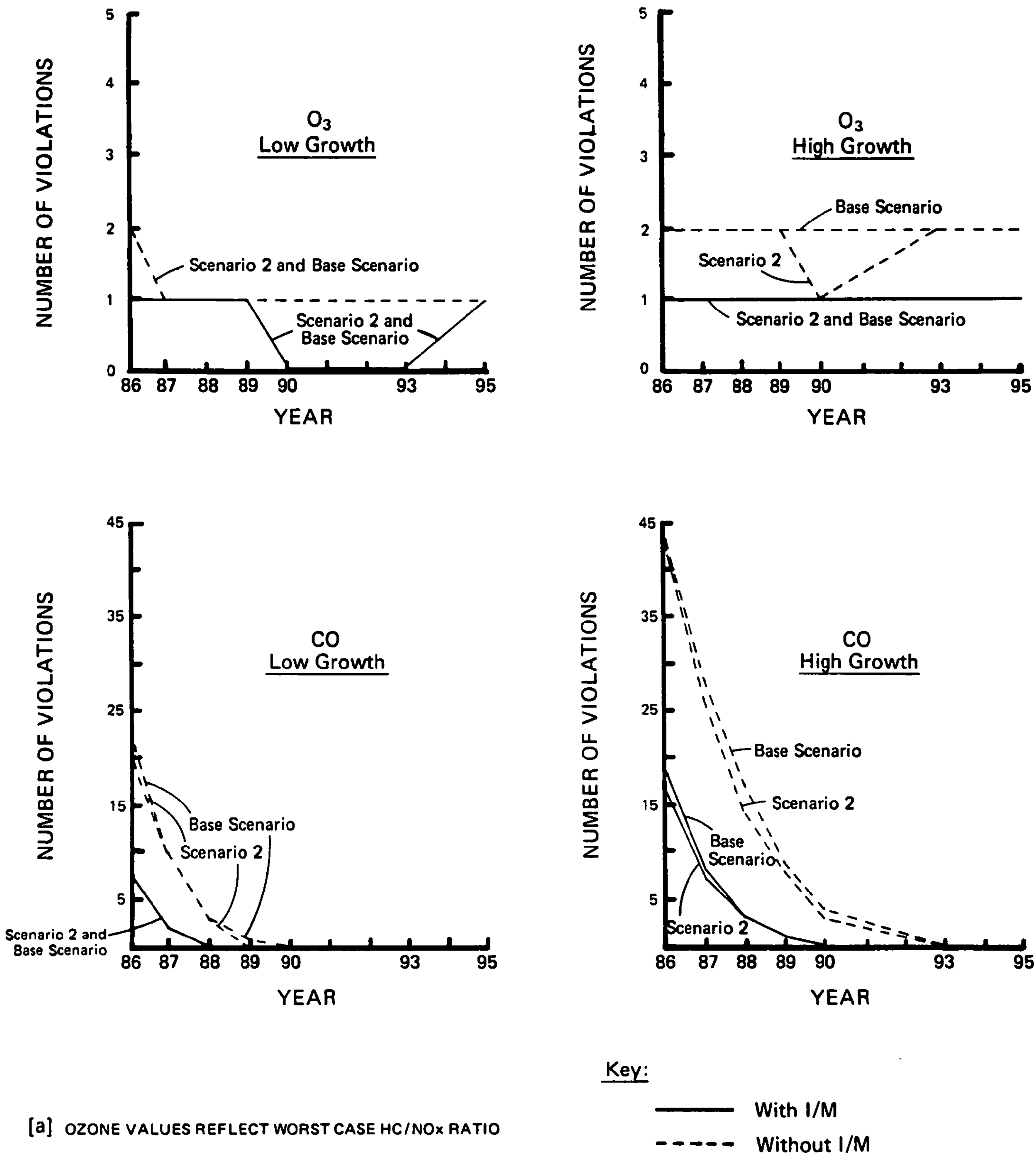
Average Percent Reduction in Expected CO and Ozone Concentrations from 1979 Base Year in Selected High-Altitude Cities [a]



[a] OZONE VALUES REFLECT WORST CASE HC/NOx RATIO OF AMBIENT CONCENTRATIONS.

FIGURE VII-5

Number of CO and Ozone NAAQS Violations in High-Altitude Cities [a]



[a] OZONE VALUES REFLECT WORST CASE HC/NOx RATIO

Before making a final decision on the merits of scenario 2, it remains to be shown whether even the small benefits of this scenario are needed to improve the air quality of high-altitude regions. To evaluate this question, the NAAQS attainment dates and trends in high-altitude air quality will be used. As shown in Figure VII-5, high-altitude cities appear to require additional emission reductions in future years since the NAAQSs for ozone and CO are never projected to be achieved by the 1987 statutory deadline even when scenario 2 is implemented with an inspection/maintenance program. Also, the trend lines in Figure VII-4 show that by about 1990 to 1993, improvements in ozone and CO pollution often may have generally slowed and in some cases may have essentially stopped so that air pollution levels might not continue to decline and could possibly increase under some conditions. Specifically, ozone may be a problem in some areas since compliance with the NAAQS is projected to be achieved in all high-altitude cities only under the low-growth, with-I/M strategy (Figure VII-5). The NAAQS for CO is predicted to be attained between 1988 and 1990 under the low-growth cases, but for the high-growth cases, attainment may be postponed until 1990 with I/M and between 1990 and 1993 without I/M (Figure VII-5). However, as alluded to above, the CO trend lines in Figure VII-4 for the high-growth cases generally show a reduction in the rate at which additional improvements in emission concentrations for subsequent years are achieved, especially in the base scenario. Because of this and the uncertainty associated with the projections, continued compliance with the NAAQS may not be assured. Therefore, additional emission control beyond that provided by the base scenario appears to be justified at this time.

The discussion contained in Chapter V pointed out the uncertainties involved with the computer models which produced the air quality projections in this report. These uncertainties may cause the projections to be better or worse than those documented here. In particular, there are a number of identifiable reasons why the analysis may underestimate the number of violations of the NAAQS. To simplify the analysis, EPA assumed that all 1984 and later model year vehicles operated at high altitude meet the appropriate emission standards in each scenario. While this is valid for the vast majority of vehicle miles traveled (VMT), it is reasonable to expect that some mileage would occur from unregulated low-altitude vehicles operated by visitors or permanent residents who had moved from low-altitude areas. Many of these uncontrolled low-altitude vehicles will pollute significantly more than high-altitude vehicles which are subject to regulation. Also, the air quality models upon which this analysis is based assumed an ambient temperature of 75°F. In reality, the average temperature in high-altitude areas during periods of unhealthy air is much lower. At lower ambient temperatures the amount of pollution from motor vehicles increases, especially CO emissions. This potential increase in emissions is not accounted for in this analysis. Therefore, the number of NAAQS violations in high-altitude areas could be somewhat greater than shown in Figure VII-5.

In summary, the data contained in Figures VII-4 and VII-5 indicate that additional cost-effective forms of pollution control may be needed to attain or assure compliance with the NAAQS in high-altitude regions of the country. However, as indicated in the previous paragraph and in Chapter V, the air quality projections presented above could be subject to error in either direction. Detailed analysis of the air quality of those areas just above or below the NAAQS would be necessary to confirm the need for additional controls such as those provided by scenario 2.

VII. CONCLUSIONS

The analyses in this report indicate that implementing an alternative program similar to scenario 2 will provide additional emission control for high-altitude regions in a cost-effective manner. For this reason, scenario 2 merits further consideration regarding LDGTs and LDDs.

Chapter VIII

Control of Light-Duty Trucks

I. INTRODUCTION

This chapter analyzes the effect of high-altitude standards for light-duty gasoline-fueled trucks (LDGTs). Specifically, implementing fixed-point statutory standards (scenario 2) relative to fixed-point proportional standards (base scenario) will be examined with regard to technology, economic impact, enviromental impact, and cost effectiveness. As described in Chapter VII, scenario 2 was found to be a viable alternative control strategy for LDGVs. The statutory standards of this scenario for light-duty trucks will be assumed to be implemented in 1984 as was the case for light-duty vehicles.

It should be noted that high-altitude LDT standards are not mandated in section 206 of the Act as are the high-altitude LDV requirements. If LDT standards at high altitude are warranted, however, EPA may establish such standards under the general rulemaking authority of section 202.

II. TECHNOLOGY ASSESSMENT

For light-duty gasoline-fueled vehicles (LDGVs) under scenario 2, EPA projected that all vehicles with nonfeedback (open-loop) control would require three fixed-step aneroids and a recalibration of engine-related control parameters. Also, all LDGVs would require larger charcoal canisters for evaporative HC emission control (Chapter III).

There are two basic similarities between these LDGVs and all LDGTs which lead to the conclusion that these technologies should apply to LDGTs also: 1) both LDVs and LDTs certify using the same test procedures, and 2) current emission control technology on many LDGVs at low altitude, (i.e., nonfeedback controlled systems) is very similar to that needed for LDGTs to meet their more stringent 1984 low-altitude standards.[1] Therefore, LDGTs will require a recalibration of engine control parameters and the addition of three fixed-step aneroids to meet the high-altitude exhaust emission standards, since EPA estimates that essentially all such vehicles will be equipped with nonfeedback systems at low-altitude in 1984 and later model years. Similarly, complying with the statutory evaporative HC standard will require a 25 percent increase in charcoal loading of the storage canister.

III. ECONOMIC IMPACT

As with LDGVs, the cost of implementing alternative high-altitude standards for LDGTs will be determined incrementally to the base scenario (i.e., the fixed-point proportional standard) (Table II-4, Chapter II). Under the base scenario, LDGTs will have the same control hardware as shown for the base scenario in Table VI-2 of the Economic Impact chapter for nonfeedback LDGVs. In that table, nonfeedback controlled vehicles required engine recalibrations in addition to one fixed-step aneroid.

The remainder of this section will follow the same outline as the Economic Impact chapter for LDGVs. Thus, the cost to manufacturers, the cost to users, the aggregate costs, and the socioeconomic impact will be examined separately.

A. Cost to Manufacturers

The cost to manufacturers has two elements: variable costs and fixed costs.

1. Variable Costs

The only variable cost resulting from 1984 high-altitude exhaust emission standards is the cost of two additional aneroids for all LDGTs. The estimated cost of these two devices for LDGVs, based on discussions in Chapter IV, is $14-18. The additional production of aneroids for LDGTs over that of LDGVs lower costs, because of the economies of scale. To be conservative, however, the same costs based on LDGV production volumes will be used here for LDGTs.

The variable cost for the high-altitude evaporative standards is also the same as that previously estimated for LDGVs in Chapter V. Complying with the statutory evaporative HC standard is estimated to increase the total hardware cost for LDGTs by $2-3 to a total of $16-21 per vehicle.

2. Fixed Costs

Fixed costs include development and certification costs.

a. Development costs. Development costs for scenario 2 are estimated incrementally from the base scenario. Under the base case, all 1984 LDGTs have to be redesigned at low altitude to comply with the more stringent HC and CO standards implemented in that model year. All nonexempt LDTs sold at high-altitude (it is assumed LDTs require the same percentage exemption as LDVs), would also have to undergo development to meet the new proportional standards which would accompany the more stringent low-altitude standards.

Scenario 2 would have no effect on low-altitude development efforts since high-altitude control technology (aneroids) should not affect low-altitude engine calibrations (a more complete discussion is presented in Chapter V), Scenario 2, however, could affect beneficially high-altitude development.

In the preceding paragraph, it was assumed that LDTs will require the same exemptions as LDVs (i.e., 5 percent for the base scenario and 15 percent for scenario 2). The greater number of exemptions in scenario 2 implies that fewer engine families will undergo development at high altitude than in the base scenario, based on the relationship between engine families and vehicle sales outlined in Appendix III. Rather than account for this potential savings, no development cost increment ($0) will be assumed in this analysis to be conservative.

b. <u>Certification</u>. The incremental certification costs for LDGTs in 1984 is the additional cost over what is assumed to take place under the base scenario. Under this scenario, it is projected that all nonexempt engine families will have to be recertified at high altitude due to the new proportional standards beginning in 1984. As previously discussed with regard to development costs, the additional exempted engine families in scenario 2 would reduce the certification costs in relation to those already occurring in the base scenario. To be conservative, this potential certification savings is not accounted for in this analysis. Instead the incremental certification cost is considered to be $0, as it was for incremental development costs.

B. Cost to Users

The sticker price increase for users of high-altitude vehicles is simply the control hardware cost since there is no increment in development or certification associated with scenario 2. This cost is about $16-21 per high-altitude LDGT.

The net vehicle cost of scenario 2 includes not only the sticker price increase but also any increment in maintenance or fuel economy. There should be no additional maintenance requirements as a result of implementing the control hardware described above. However, the addition of two aneroids could result in a fuel economy benefit. As with LDGVs, the fuel economy benefit is estimated to be about 2 percent (see Chapter III for the derivation of this fuel economy benefit). For LDTs, a 2 percent fuel economy benefit represents a cost savings of about $85 per vehicle. This is based on an average LDGT life of 120,000 miles accumulated over a period of 12 years,[2] a fuel economy estimated to be the proposed 1985 CAFE standard of 21 mpg, an unleaded gasoline price of $1.30 per gallon, and discounting the resulting fuel savings (at 5 percent per year) to year of purchase. Again referring back to the LDGV economic analysis contained in Chapter V, the sensitivity of scenario 2 to the estimated fuel economy benefit was so great that a cost range was used for the net vehicle cost. This sensitivity is even more significant with regard to LDGTs since the fuel economy benefit applies to all light trucks sold at high altitude instead of only a portion of the fleet. Therefore, the net vehicle cost for LDGTs will be estimated in a similar manner. The lower limit of the range is found by including the fuel economy benefit and the upper limit is found by excluding it. This results in a potential savings of $69 or a potential cost of $21 per vehicle.

C. Aggregate Costs

The projected number of 1984-88 LDGTs sold in areas above 4,000 feet (excluding California) is approximately 409,000. This figure was derived from nationwide sales estimates made by Data Resources Corporation,[3] and the same estimates of population distribution according to altitude used to determine LDGV emissions in Chapter IV. These supporting data can be found in Table VIII-1.

The aggregate costs of the high-altitude standards apply to the first five years of this regulation or 1984-88. However, the present value in 1984 will be used, so that the cost can be compared on an equivalent basis to the aggregate cost for LDGVs. Based on a 1984-88 high-altitude LDGT production of 409,000, the 5-year aggregate cost of scenario 2 varies from a potential savings to about $7 million.

The costs for LDGTs are summarized in Table VIII-2.

D. Socioeconomic Impact

The price increase of a light-duty truck was estimated to be a maximum of $21. Given the range of variability in the analyses, this is comparable to the maximum sticker price increase of $15 estimated for LDGVs under scenario 2 (see Chapter V). The LDGV analysis concluded that such a sticker price increase should not affect a dealer's sales or a consumer's ability to purchase a vehicle. The same conclusion should hold here for LDGTs, because both the absolute cost increase and the percentage increase in the purchase price of these vehicles is comparable to that estimated for LDGVs. Thus, the sticker price increase for LDGTs should not significantly affect sales.

There are no incremental capital costs associated with implementing scenario 2. Manufacturers of LDGTs will already incur such expenses under the base case because of the new proportional standards taking effect in 1984.

Thus, as similarly analyzed for LDVs, the increase in costs due to this regulation should have little socioeconomic impact, if any, on manufacturers, dealers, and users.

Table VIII-1

Light-Duty Truck Sales Projections[3,4]

Year	Nationwide LDT Sales[a] (10^6 trucks)	Nationwide LDGT Sales[a] (10^6 trucks)	LDGT Sales[b] Above 4,000 Feet (trucks)
1984	3.24	2.93	82,000
1985	3.36	2.98	83,000
1986	3.40	2.93	82,000
1987	3.46	2.89	81,000
1988	3.54	2.92	81,000
5-Year Sum	17.0	14.65	409,000

[a] Light-duty truck.
Light-duty gasoline-powered truck.

[b] These values were determined by assuming that the number of new vehicle sales is directly proportional to population distribution. Since 3.1 percent of the U.S. non-California population resides above 4,000 feet, this is also the fraction of nationwide non-California sales that is expected to occur in high-altitude areas of the country.

Table VIII-2

Summary of Costs for LDTs ($1981)

Hardware	Development	Best Estimate Fuel Economy[a]	Net Total[b]	Incremental Capital Costs to Manufacturers[c]	Aggregate Costs[d] (millions)
$16-21	$0	-85	$-69 to 21	$0	up to $7

[a] Because of the uncertainty associated with this fuel economy estimate, its use is speculative at this time.
[b] No maintenance or certification costs expected.
[c] Includes 15 percent cost of capital.
[d] Based on a production of 409,000 for high-altitude sale between 1984-88. Present value is in 1984.

IV. ENVIRONMENTAL IMPACT

This section explores the effects of scenario 2 on LDGT emissions and the resultant air quality. The same basic methodology used in Chapter III to describe the environmental impact of LDGV control will be followed below.

A. Total Emissions

1. Methodology

As was the case with the LDGV analysis, total lifetime emissions will be determined from LDGTs sold over a 5-year period. For reasons discussed earlier, this time increment is 1984-88. To determine these emissions, three factors were multiplied together: 1) the number of miles the average LDGT is driven in its lifetime, 2) emission factors (the amount of pollutant emitted per truck per mile of travel), and 3) the number of trucks sold above 4,000 feet (the initial control altitude for scenario 2). These factors are discussed below.

For the purposes of this study, the average lifetime mileage for light-duty trucks is 120,000 miles.[2] To determine lifetime emissions, emission factors were determined for trucks that were halfway through this average lifetime (i.e., at 60,000 miles). It is important to remember that scenario 2 applies only to those vehicles and trucks sold above 4,000 feet and that the high-altitude emission data available were based on tests conducted at Denver (elevation 5,300 feet). Thus, the average lifetime emission rates in this study for LDGTs sold above 4,000 feet were based on tests at 5,300 feet.

As mentioned earlier, 100 percent of the future high-altitude LDGT fleet is expected to use open-loop emission control technology. Table VIII-3 contains the LDGT emission factors for the base case and scenario 2 based on this technology. Table VIII-3 also contains evaporative HC emission factors for LDGTs. Light-duty gasoline-fueled trucks and vehicles have the same evaporative hydrocarbon emission characteristics and, thus, the same emission standard under the 1982 and 1983 interim high-altitude emission regulations. Therefore, the evaporative HC emission factors developed in Chapter IV for LDGVs under the base scenario and scenario 2 also apply in the case of LDGT evaporative HC emissions.

By combining the mileage, emission factor and sales data described above, the total exhaust and evaporative emissions from 1984-88 LDGTs in areas above 4,000 feet can be determined. These are presented in Table VIII-4 for both the base scenario and scenario 2.

Table VIII-3

Emission Rates for 1984-88
Light-Duty Gasoline Trucks at 5,300 Feet[a]

Pollutant		Base Scenario	Scenario #2
HC	Zero-Mile Emission Level (g/mi)	0.78	0.63
	Deterioration Rate (g/mi/10,000 miles)	0.14	0.14
	Average Lifetime Emission level (g/mi)	1.62	1.47
CO	Zero-Mile Emission Level (g/mi)	9.85	7.13
	Deterioration Rate (g/mi/10,000 miles	1.35	1.35
	Average Lifetime Emission level (g/mi)	17.95	15.23
NOx	Zero-Mile Emission Level (g/mi)	1.26	1.26
	Deterioration Rate (g/mi/10,000 miles)	0.04	0.04
	Emission Level (g/mi) (g/mi)	1.5	1.5
Evap. HC	Zero-Mile Emission Level (g/mi)	0.13	0.10
	Deterioration Rate (g/mi/10,000 miles)	0	0
	Average Lifetime Emission Level (g/mi)	0.13	0.10

[a] Emission Rate = Zero-Mile Level + (cummulative Mileage/10,000), (deterioration rate); cumulative mileage equals 60,000 miles, one-half of lifetime.

Table VIII-4

Lifetime Emissions from 1984-88 LDGTs
Sold Above 4,000 Feet
(10^3 metric tons)

Pollutant	Base Scenario	Scenario 2	Reductions (base scenario minus scenario 2)
HC	79.5	72.1	7.4
CO	880.9	747.5	133.4
NOx	73.6	73.6	0
Evap. HC	6.38	4.91	1.47
Total HC	85.88	77.01	8.87

2. Discussion of Results

From Table VIII-4, it can be seen that scenario 2 is predicted to reduce total HC emissions from 1984-88 LDGTs by approximately 8,870 metric tons, compared to the base scenario. Similarly, CO emissions are predicted to decrease by roughly 133,400 metric tons. No NOx reductions would be realized since the high-altitude NOx standards under scenario 2 would be the same as under the base scenario.

Referring back to Chapter IV, one sees that scenario 2 is shown to lower HC and CO emissions from LDGVs sold above 4,000 feet by approximately 13,800 metric tons and 331,000 metric tons, respectively. Thus, combining the effects of scenario 2 on LDGVs and LDGTs yields total 5-year HC reductions of roughly 22,670 metric tons and total CO reductions of approximately 468,400 metric tons. As can be seen, roughly a third of the total HC and CO emission reductions result from LDGT control. The consequences of controlling LDGT emissions on air quality in high-altitude areas are discussed in the following section.

B. Air Quality

The air quality discussion in this chapter is an extension of that found in Chapter IV for LDV control; both use the same models, study sites, and growth rates. The only difference is the addition of emission controls on LDTs (both gasoline and diesel) to the base scenario and scenario 2. The LDV emission factors are unchanged. Due to the large number of composite emission factors (average emission factors for a given vehicle category in a given year), they are included in reference 4.

Tables VIII-5 through VIII-8 present the results of the air quality analysis in two ways: 1) percent reductions in pollutant concentrations from a baseline year (1979), and 2) changes in the projected number of NAAQS violations. To clarify the air quality consequences of controlling LDTs at high altitude, the tables also include the effects of LDV control only. The inclusion of this information allows LDT standards to be evaluated by determining: 1) the air quality differences between the base scenario and scenario 2 with and without truck control, and 2) the resulting air quality change when more stringent truck control is included with LDV standards in scenario 2. Both of these methods of evaluation are discussed below.

Tables VIII-5 and VIII-6 show that scenario 2 with truck control may result in lower ambient CO concentrations and slightly fewer violations of the CO NAAQS than under the base scenario with truck control. These benefits are first apparent in 1986 where one less violation is expected for the high

Table VIII-5

Average Percent Reduction in Expected
Second Highest 8-Hour CO Concentrations from 1979
Base Year in Six High-Altitude Cities
(Low and High Growth)[a]

	Year											
	1986				1990				1995			
	With I/M		W/O I/M		With I/M		W/O I/M		With I/M		W/O I/M	
Scenario	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Base - With Truck Control	55	49	46	38	72	66	64	56	79	72	73	64
Base - Without Truck Control	55	48	45	37	71	65	63	54	78	70	72	62
#2 - With Truck Control	56	50	47	39	73	67	66	57	81	75	76	67
#2 - Without Truck Control	55	49	46	38	72	65	64	56	80	73	74	65

[a] The cities examined are Denver, Colorado Springs, Ft. Collins, Greeley, Albuquerque, and Salt Lake City.

Table VIII-6

Number of Violations of CO NAAQS
in Six High-Altitude Cities (low and high growth)[a]

Scenario	1986 With I/M Low	1986 With I/M High	1986 W/O I/M Low	1986 W/O I/M High	1990 With I/M Low	1990 With I/M High	1990 W/O I/M Low	1990 W/O I/M High	1995 With I/M Low	1995 With I/M High	1995 W/O I/M Low	1995 W/O I/M High
Base - With Truck Control	7	16	20	43	0	0	0	3	0	0	0	0
Base - Without Truck Control	7	18	21	43	0	0	0	4	0	0	0	0
#2 - With Truck Control	5	15	18	39	0	0	0	2	0	0	0	0
#2 - Without Truck Control	7	16	20	43	0	0	0	3	0	0	0	0

[a] The cities examined are Denver, Colorado Springs, Ft. Collins, Greeley, Albuquerque, and Salt Lake City.

Table VIII-7

Average Percent Reduction in Expected Maximum
1-Hour Ozone Concentrations from 1979 Base Year
in Denver and Salt Lake City (low and high growth)[a]

	Year											
	1986				1990				1995			
	With I/M		W/O I/M		With I/M		W/O I/M		With I/M		W/O I/M	
Scenario	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Base - With Truck Control	24-32	22-28	21-27	18-24	29-38	25-33	25-34	22-29	28-37	24-31	26-35	21-28
Base - Without Truck Control	24-32	22-28	21-27	18-24	29-37	25-33	25-33	22-28	28-36	24-31	26-34	21-28
#2 - With Truck Control	24-33	22-29	21-27	18-24	29-38	25-33	26-34	22-29	29-37	24-32	26-35	22-29
#2 - Without Truck Control	24-32	22-29	21-27	18-24	29-37	25-33	25-34	22-29	28-37	24-31	26-35	21-28

[a] Note that a range of values are reported. These reflect two different ratios of HC/NOx ambient concentrations, as discussed in Chapter IV. Values from the higher ratio are listed first.

Table VIII-8

Number of Violations of Ozone NAAQS in Denver and Salt Lake City (low and high growth)[a]

Scenario	1986 With I/M Low	1986 With I/M High	1986 W/O I/M Low	1986 W/O I/M High	1990 With I/M Low	1990 With I/M High	1990 W/O I/M Low	1990 W/O I/M High	1995 With I/M Low	1995 With I/M High	1995 W/O I/M Low	1995 W/O I/M High
Base - With Truck Control	0-1	0-1	0-2	1-2	0-0	0-1	0-1	0-2	0-1	0-1	0-1	1-2
Base - Without Truck Control	0-1	0-1	0-2	1-2	0-0	0-1	0-1	0-2	0-1	0-1	0-1	1-2
#2 - With Truck Control	0-1	0-1	0-2	1-2	0-0	0-1	0-1	0-1	0-1	0-1	0-1	1-2
#2 - Without Truck Control	0-1	0-1	0-2	1-2	0-0	0-1	0-1	0-1	0-1	0-1	0-1	1-2

[a] Note that a range of values are reported. These reflect two different ratios of HC/NOx ambient concentrations, as discussed in Chapter IV. Values from the lower ratio are listed first.

growth with I/M case and two less violations are expected for the low-growth with I/M case (Table VIII-6). For 1990 and beyond, no violations are expected due to the combined effects of more stringent low-altitude standards and I/M. Chapter IV showed that without truck control the number of violations under scenario 2 and the base scenario was the same until 1988 with I/M. Thus, including light trucks under scenario 2 appears to yield fewer violations two years sooner than would otherwise be possible.

Without I/M, the CO benefits of controlling trucks under scenario 2 first appear in 1986, when four less violations are expected with high growth and two less violations are expected with low growth. Similarily, without truck control, the total number of violations appear greater for scenario 2 in this year under either the low- or high-growth cases. In 1990, one less violation is projected for the high-growth without-I/M case under scenario 2 than under the base scenario when truck control is considered. Air quality benefits without LDT control also appear in this year but again the total number of violations is projected to be greater than in the with-truck control option. Looking only at scenario 2, adding truck control should result in four fewer violations during 1986 and one less in 1990 under the high-growth case and two less violations in 1986 under the low-growth case. Thus, adding truck control to scenario 2 resulted in a larger projected air quality benefit than when only light-duty vehicles were controlled. This was true whether or not I/M was present.

With regard to ozone air quality, Table VIII-7 shows that adding LDT control to scenario 2 could lower ambient ozone concentrations below what the base scenario would provide. With I/M, in 1986 and 1995 the additional reduction could be 1 percent for the low- and high-growth cases. Without I/M, the reduction is 1 percent more in 1990 for scenario 2 with truck control under the low-growth case than for the base scenario. Adding more stringent truck control to scenario 2 when I/M is assumed could reduce ozone concentrations by 1 percent in each year studied under the low-growth case and by 1 percent in 1995 under the high-growth case. When no I/M program is assumed, implementing more stringent truck control in this scenario should result in a benefit during 1990 of up to 1 percent under the low-growth case. In 1995, the benefit could be 1 additional percent under high growth. It can be seen from Table VIII-8 under both growth cases, that adding truck control did not further reduce the number of NAAQS violations occuring under scenario 2 compared to the base scenario in the with-I/M situations. Without I/M, there could be one less violation in 1990 under high growth. Since, however, there appears to be no difference in ozone NAAQS violations when more stringent LDT standards are added to scenario 2, this benefit must be attributed to LDV control.

C. Summary of Air Quality Information

The analysis in this section predicted that adding LDGT control to scenario 2 would lead to additional reductions in HC emissions beyond those of the base scenario by approximately 8,870 metric tons from the 1984-88 LDGTs sold above 4,000 feet. It would also lower CO emissions from these trucks by 133,400 metric tons more than the base scenario over their lifetime.

Fewer violations of the CO NAAQS are projected when LDT control is added to scenario 2 under both low and high growth, but because of I/M, no violations under either the base scenario or scenario 2 are projected beyond 1990. Without I/M, adding truck control could also result in fewer violations of the CO NAAQS than would be expected under scenario 2 without truck control. This is true under both low and high-growth rates. Attainment of the CO standard is not projected until after 1990 when high growth and no I/M are assumed. Adding LDT control to scenario 2 did not result in fewer violations of the NAAQS for ozone with or without I/M. Thus, any cost-effective HC control strategy should be seriously considered as a partial means of attainment.

As was mentioned earlier concerning the air quality projections contained in Chapter IV, the air quality projections made here must be used with some caution. Much of the input data to the model, growth rates for vehicle-miles traveled (VMT), VMT breakdown by vehicle class, and average speed, are based on national averages and not local data. Also, relatively simple models have been used, modified rollback and EKMA. These models require relatively simple data which were easily available for all the areas of concern. Air quality projections using input data specific to individual locations and the use of more sophisticated models, as is often done by local or state agencies, could result in more accurate projections. Also, as has been mentioned earlier, the emission factors projected for future years are not firm, especially for those equipped with feedback controls. Changes in these factors in the future could go in either direction. Thus, the number of violations of the NAAQS projected in any given year must be seen as an estimate and could actually occur a number of years earlier or later. Since the need for statutory control is, unfortunately, based on whether or not high-altitude areas achieve the NAAQS, a conclusive determination of the need for statutory control over proportional control cannot be made at this time.

V. COST EFFECTIVENESS

Results from the cost and total emission sections of this chapter will be combined to determine the cost effectiveness of adding LDGT control to scenario 2. The same procedure outlined in Chapter V to determine the cost effectiveness of LDGV control is followed in this section. The results of this analysis are shown in Table VIII-9 along with the incremental cost effectiveness of LDGV control for scenario 2 as determined in Chapter V. The incremental cost effectiveness of combined LDGV and LDGT control is also presented in Table VIII-9.

As this table shows, adding control of light-duty gasoline-fueled trucks to scenario 2 makes it a slightly more cost-effective approach. Under "worst case" assumptions, the cost of removing HC is reduced from $575 per metric ton for LDGVs only to $535 per metric ton for both classes of vehicles. The cost effectiveness of CO removal is unchanged under worst case assumptions.

Table VIII-10 lists the cost effectiveness of other control strategies already adopted. (This same table also appears in Chapter VI.) From this table, it can be seen that when LDGT control is added to scenario 2, it becomes more cost effective than three of the other existing HC strategies and two of the other existing CO strategies.

Table VIII-9

Incremental Cost Effectiveness of Scenario 2

Vehicle Type	Cost[a] (dollars per vehicle)		Emission Reductions (10^{-3} metric tons) per vehicle		Incremental Cost Effectiveness (dollars/metric ton)			
					HC		CO	
	Low	High	HC	CO	Low	High	Low	High
LDGV	-11	15	13.0	239.9	neg.	575	neg.	30
LDGT	-69	21	21.7	326.2	neg.	485	neg.	30
LDGV and LDGT[b]	-24	16	15.0	259.7	neg.	535	neg.	30

[a] 1981 dollars discounted to 1984. The low estimates are based on the inclusion of tentative fuel-economy benefits.

[b] Combined LDGV and LDGT costs were obtained by weighting the individual LDGV and LDGT costs according to sales above 4,000 feet.

Table VIII-10

Cost Effectiveness Comparison With Other Emission Control Strategies (1981 dollar per metric ton)

Control Program	Baseline Emissions[a]	Emissions After Control Strategy Implemented	Cost Effectiveness HC	Cost Effectiveness CO
LDV Statutory[6] Standards	HC 0.9 CO 15	HC 0.41 CO 3.4	734	67
LDV I/M[7]	--	--	640	58
LDT 1984[1] Standards	HC 1.7 CO 18	HC 0.8 CO 10	195	15
HDE 1984 Standards[8][b]				
(gasoline)	HC 1.5 CO 25	HC 1.3 CO 15.5	305	10
(diesel)	HC 1.5 CO 25	HC 1.3 CO 15.5	325	--
Motorcycle Neg. Standards[9]	HC 9 CO 34.67	HC 8-22.5[c] CO 27.4	582	
HDG Evap.[10][d]	HC 1.8	HC 0.17	200	--
Interim 1982-83 HA Standards[11]	HC 1.47 (cars) 4.19 (trucks CO 16.23 (cars) 73.02 (trucks)	HC 1.33 (cars) 3.78 (trucks) CO 13.21 (cars) 55.65 (trucks)	393	12

[a] Emission levels are in g/mi except for the HDE 1984 standards which are in grams per brake horsepower-hour.

[b] The baseline and after-control strategy emission values were based on different test procedures (see ref. [9]).

[c] Sliding scale based on engine displacement (cubic centimeters).

[d] The evaporative standard is in terms of g/test and converted to g/mi here to facilitate comparison.

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Chapter IX

Control of Light-Duty Diesel Gaseous Emissions

I. INTRODUCTION

This chapter addresses the effects of high-altitude gaseous emission standards on light-duty diesel-powered vehicles and trucks (LDDVs and LDDTs). As was the case with the discussion of light-duty gasoline-fueled trucks in the previous chapter, this analysis focuses on comparisons between scenario 2 and the base scenario. This format will be followed since scenario 2 was found to be the most cost-effective of the control strategies which were analyzed in this report as alternatives to the base scenario for further reducing emissions from light-duty gasoline-fueled vehicles in high-altitude areas (Chapter VII).

To remain consistent with the previous analyses, the years being studied in this chapter with regard to costs and total emissions are 1984-88 for both LDDVs and LDDTs. In reality, it may be desirable to delay additional high-altitude control one year beyond the first year of the more stringent high-altitude standards for light-duty gaseous vehicles (LDGVs), because the 1.0 g/mi NOx standard may be waived up to 1.5 g/mi for LDDVs until 1985 (as allowed in section 202(b)(6)(B) of the Act). In fact, such NOx waivers have already been granted for many 1984 model year LDDVs. Delaying the implementation date of the more stringent high-altitude standards for one year would prevent manufacturers from having to design, build, and certify vehicles to meet high-altitude standards that would be in existence for only one year. However, such a delay would require amending the Act. In any event, for the purposes of this analysis assuming that the LDDV statutory standards (including 1.0 g/mi NOx) begin in 1984 instead of 1985 is insignificant.

II. TECHNOLOGY ASSESSMENT

Very little actual data exist with which to quantify the types of technology which may be needed by LDDVs and LDDTs to comply with the statutory standards of scenario 2. Also, unlike gasoline engines, the effect of decreasing air density cannot be compensated for completely in diesel engines. Gasoline engines burn a homogeneous air/fuel mixture of fairly constant proportions. When air density decreases, which reduces the mass of air in the cylinder, the air/fuel ratio can be retained at its optimum value by either opening the throttle to allow more air, or by metering less fuel. This works well until the power requested of the engine approaches its maximum and power enrichment sets in.

A diesel engine burns a heterogeneous air/fuel mixture with no throttle to control the air flow. Thus, at high altitude, less air will enter the combustion chamber at all times unless the engine is turbocharged. Generally, this reduction in cylinder air will not affect combustion dramatically, because the overall air/fuel mixture is very lean (excess air). However, there will be definite effects near full power. Full power is usually limited by smoke level, which is an indication that some of the fuel is not burning due to a lack of oxygen. If the vehicle is operated at full power at high altitude, even less air is available, and HC and CO emissions will increase dramatically under full-power operation.

The easiest solution to this "full-power" problem is to limit the maximum fuel flow at high altitude relative to that at low altitude. Limiting the maximum fuel rate can be accomplished with a simple manual adjustment and this technique is expected to be used, to varying degrees, by most diesel manufacturers to meet the current interim (1982-83) high-altitude standards. Reducing the maximum fuel flow keeps the engine out of excessively rich operating modes. It also reduces the maximum power of the engine. Since most diesel-powered vehicles are not overpowered, this may be a serious drawback if the maximum fuel rate must be significantly altered, especially in hilly regions. While this fact would tend to reduce sales of these vehicles at high altitude, the majority of the effect is there even without high-altitude emission control since the additional fuel does not increase engine power at high altitude to the same extent as it does at low altitude.

The above discussion applies most directly to situations where fairly high NOx levels are allowed, and hence, no exhaust gas recirculation (EGR) is needed to control NOx emissions. As EGR is added to the combustion chamber for NOx control, which will generally be required under the 1.0 g/mi standard, the effective air/fuel ratio (i.e., the oxygen/fuel ratio) decreases. Theoretically, the adverse effect on HC and CO emissions of further reducing the amount of combustion air by moving to high altitude may be exacerbated by the use of EGR. This could make controlling these emissions to the requisite levels in conjunction with the 1.0 g/mi NOx standard more difficult than is currently the case for 1982 and 1983.

Table IX-1 shows the available data regarding the effect of altitude on the emissions from diesels both with and without EGR. It must be noted that because of the paucity of information, firm conclusions as to the effect of EGR on high-altitude emissions and the requisite control technology are difficult to make. Based on the available data, however, it appears that EGR may not necessarily exacerbate HC and CO emission increases at higher elevation. Therefore, the control technique that is currently used to comply with the current 1982-83 HC and CO proportional standards (i.e., limiting the

Table IX-1

Average FTP Emission Levels of Diesel-
Powered Passenger Cars (no EGR)

Vehicle	Test Site	HC (g/mi)	CO (g/mi)	NOx (g/mi)	F.E. (mi/gal)	Part. (g/mi)
		In-Use Vehicles[1]				
1980 Volkswagen 90 CID	High	.57	1.88	1.09	35.3	.40
	Low	.22	.78	1.05	39.5	.26
1979 Olds 260 CID	High	1.39	2.21	1.29	20.5	.98
	Low	.68	1.50	1.43	22.9	.78
1979 Olds 260 CID	High	.97	2.57	1.56	20.6	1.82
	Low	.39	1.49	1.67	24.2	1.13
1974 Peugeot 129 CID	High	6.74	8.88	.98	21.0	2.43
	Low	3.86	3.83	.93	25.2	.897
1977 Mercedes 147 CID	High	.65	1.04	1.51	25.8	.47
	Low	.25	.67	1.29	31.8	.36
Average (all vehicles)	High	2.06	3.32	1.28	23.6	1.22
	Low	1.08	1.65	1.27	27.6	.69
Increase		91%	101%	1%	-14%	78%
Average (w/o Peugeot)	High	.89	1.93	1.36	24.3	.92
	Low	.38	1.11	1.36	28.2	.63
Increase		134%	74%	0%	-14%	46%

Experimental Vehicles with Analog EGR Control[2]

Vehicle	Test Site	HC (g/mi)	CO (g/mi)	NOx (g/mi)	Part. (g/mi)
#04530, GM 5.7 L, 4000 # IW	High	.60	2.3	.83	1.04
	Low	.34	1.4	1.18	.46
#04531, GM 5.7 L, 4000 # IW	High	.44	.98	1.21	.54
	Low	.22	1.04	1.48	.34

maximum fuel flow) should also be sufficient to comply with similar HC and CO standards in the base scenario.

Of course the vehicles equipped with EGR systems in Table IX-1 do not attain the 1.0 g/mi NOx standard at low altitude, so it is possible that if the rate of EGR was increased to meet the standard, HC and CO emissions could indeed be negatively affected. However, to attain the 1.0 g/mi NOx standard will require more than just simply increasing the EGR rate. Advanced electronic (analog) units are expected to be used. These more sophisticated systems should provide manufacturers with the flexibility to tailor the rate of EGR in such a way as to mitigate any negative effect on HC and CO at high altitude. Also, if limiting the maximum fuel flow in conjunction with more advanced analog EGR systems is insufficient to attain the proportional standards of the base scenario, other control techniques can be easily used, such as manually readjusting the fuel injection timing. Therefore, the proportional standards of the base scenario should be readily attainable with no additional hardware.

Complying with the statutory standards of scenario 2 will be more difficult. Although the two previously described control techniques also may be sufficient to attain these more stringent standards, it is likely that additional emission control will be needed. This emission reduction may be achieved by modifying the EGR system on high-altitude vehicles. Returning to Table IX-1, it is clear that even though NOx emissions naturally decrease with increasing elevation, this effect is even greater for EGR equipped vehicles. Manufacturers can take advantage of this NOx phenonmenon to control HC and CO levels by reducing the rate of EGR at high altitude and allowing NOx to increase slightly back to the level of the NOx standard. This would ease any negative effect of EGR on HC and CO emissions and make these pollutants easier to control via limiting the maximum fuel flow and resetting injection timing.

Nevertheless, it is possible that these techniques will be insufficient in controlling emissions from worst case vehicles. In these few instances, it may be necessary to employ more sophisticated digital electronic EGR systems at high altitude. However, the potential need for such complex systems would be eliminated entirely if such vehicles were eligible for exemption from the high-altitude requirements. Therefore, to comply with scenario 2, high-altitude LDDVs are expected to require manual adjustments to limit the maximum fuel rate and recalibrate fuel injection timing, in addition to using a differently calibrated electronic control module for EGR.

For high-altitude LDDTs, the requisite emission controls are essentially analogous to those for LDDVs. The only important difference is that the low-altitude NOx standard for light trucks (2.3 g/mi) is considered less stringent than the NOx standard for passenger cars (1.0 g/mi), so many LDDTs will not be equipped with EGR systems, while those that are will use simple non-electronic units. For those LDDTs without EGR, the high-altitude standards should generally be somewhat easier to achieve since the increase in HC and CO will not be exacerbated by this NOx control technique. For the purposes of this study, however, EPA will assume that all LDDTs are equipped with non-electronic EGR systems to be conservative and to simplify the analysis. Therefore, to comply with the base scenario, high-alititude LDDTs will require a manual adjustment to limit the maximum fuel rate and recalibrate fuel injection timing, if necesary. To comply with scenario 2, these vehicles are expected to require the above two adjustments, in addition to changing the EGR valve.

III. ECONOMIC IMPACT

As in the previous chapters of this report, the cost of implementing the more stringent high-altitude standards of scenario 2 will be determined incrementally to the cost of continuing the proportional standards under the base scenario.

The only difference in hardware between the two scenarios is that LDDVs and LDDTs are expected to require differently calibrated electronic EGR modules and EGR valves, respectively, to comply with scenario 2. Since in each case this is a replacement of an existing unit, there is no incremental hardware cost associated with the change, as discussed more fully in Chapter V regarding similar modifications to LDDVs.

Although there are no incremental hardware costs, all diesel vehicles sold in high-altitude areas will require development to recalibrate the fuel-metering device, injection timing, and optimize the EGR control. This may entail additional development and certification costs than would occur under the base scenario in some cases. For LDDVs, eight non-California engine families were sold in 1980. It is assumed that twice this amount will be sold in 1984 due to the dramatic increase expected in future diesel sales. Since 15 percent of the engine families are assumed to be exempt under scenario 2, a total of 14 engine families should require development testing. The number of development tests estimated here will be the same as that estimated for the 1982 and 1983 interim standards,[6] or 20 development tests per engine family. The development costs for diesel-powered vehicles should also be the same as previously estimated for the gasoline-fueled LDVs and LDTs, or $500 per test. The total development cost is then $140K for LDDVs and should occur one year prior to the implementation date of this regulation, or 1984. As discussed earlier for LDGVs in Chapter V, there is no difference between the certification requirements of the base scenario and scenario 2. Therefore, no additional certification costs for LDDVs will be incurred by implementing scenario 2.

For LDDTs, all engine families will undergo development testing under the base scenario in 1984 to comply with the more stringent proportional standards taking effect in that year. Therefore, there is no increment in either development or certification for LDDTs under scenario 2.

The development costs for LDDVs can be amortized over each affected diesel vehicle. First, the diesel vehicle production at high altitude must be determined. The number of 1984-88 LDDVs sold in areas above 4,000 feet (excluding California) have already been projected to be approximately 221,000. These figures were derived from nationwide sales estimates made by Data Resources Corporation, projections of diesel production taken from the recently promulgated standards for control of particulate emissions from light-duty diesels[7], and the same estimates of population distribution used to determine LDGV emissions in Chapter III. These supporting data are contained in Table IX-2. If the development cost were recovered over the LDDVs projected to be sold at high altitude from 1984 to 1988, and if a 10 percent discount rate is applied, the cost per vehicle is roughly $1. Thus, meeting scenario 2 will increase the purchase price of the average high-altitude LDDV by $1 over that which would occur under the base scenario. For LDDTs, there will be no increase in purchase price.

The aggregate cost of adding light-duty diesel control to scenario 2 can now be determined. Based on the above-mentioned cost per LDDV, the production volume listed in Table IX-2, and a 10 percent discount rate, the 5-year aggregate cost is approximately $166,000 (1981 dollars discounted to 1984).

IV. ENVIRONMENTAL IMPACT

In this section, the effects of scenario 2 on emissions with regard to light-duty diesel-powered vehicles and trucks are explored. The same basic methodology used in Chapters V and IX to estimate the environmental impact of LDGV and LDGT control are followed below. Since the air quality modeling results in those chapters included diesel control, this topic will not be readdressed here. Only the effect on emissions is presented.

A. Methodology

As mentioned earlier in Chapters IV and VIII, total lifetime emissions will be determined from LDDVs and LDDTs sold from 1984 to 1988. To determine these emissions, three factors are multiplied together: 1) the number of miles the average LDDV or LDDT is expected to be driven in its lifetime, 2)

Table IX-2

Light-Duty Diesel Sales Projections
(10^3 Vehicles or Trucks) [6,7]

Year	Nationwide LDDV Sales	LDDV Sales[a] Above 4,000 Feet
1984	1,100	31
1985	1,300	36
1986	1,600	45
1987	1,900	53
1988	2,000	56
5-Year Sum	7,900	221

[a] These values were determined by assuming that the number of new vehicle sales is directly proportional to population distribution. Since 3.1 percent of the U.S. non-California population resides above 4,000 feet, this is also the fraction nationwide non-California sales that is expected to occur in high-altitude areas of the country.

emission factors (the amount of pollutant emitted per vehicle or truck per mile of travel), and 3) the number of diesel-fueled vehicles and trucks sold above 4,000 feet, the initial control altitude for scenario 2 and the base scenario.

The average lifetime mileage for light-duty vehicles is assumed to be 100,000 miles and that of light-duty trucks, 120,000 miles.[6,8] To estimate lifetime emissions, emission factors were determined for LDDVs and LDDTs that were halfway through their average lifetimes (i.e., at 50,000 and 60,000 miles, respectively). Since the same methodology was followed to determine emission factors for LDDVs and LDDTs as was used to determine those for LDGVs, the discussion of this topic in Chapter III is equally applicable here and will, therefore, not be repeated. It is important to remember, however, that scenario 2 applies only to those vehicles and trucks sold above 4,000 feet and that the high-altitude emission data available were based on tests conducted at Denver (elevation 5,300 feet). Thus, the average lifetime emission rates in this study for LDDVs and LDDTs sold above 4,000 feet were based on tests at 5,300 feet. These are presented in Table IX-3.

By combining the mileage, emission factor and sales data previously presented in Table IX-2, the total exhaust emissions from 1984-88 LDDVs and LDDTs in areas above 4,000 feet can be determined. These are presented in Table IX-4 for both the base scenario and scenario 2.

B. Discussion of Results

Table IX-4 shows that scenario 2 would reduce HC emissions from 1985-89 LDDVs by approximately 3,320 metric tons compared to the base scenario and lower HC emissions from LDDTs sold in the same years by 1,190 metric tons. Similarly, CO emissions would decrease by roughly 21,000 and 6,260 metric tons from LDDVs and LDDTs, respectively. No NOx reductions would be realized since the high-altitude NOx standards under scenario 2 would be the same as under the base scenario.

Referring back to Chapter IV, one sees that scenario 2 would lower HC and CO emissions from LDGVs sold above 4,000 feet by approximately 17,940 metric tons and 331,000 metric tons, respectively, for the 5-year period studied. In Chapter VIII, the effects of scenario 2 on LDGTs were combined with those from LDGVs to yield total 5-year HC reductions of roughly 22,670 metric tons and total CO reductions of approximately 468,400 metric tons from these sources. When benefits from adding LDDV and LDDT control to scenario 2 are included, total additional 5-year HC emission reductions beyond those provided by the base scenario are roughly 27,180 metric tons while CO emissions would be further reduced by approximately 495,700 metric tons. Thus, approximately 17 percent of the total HC emission reductions and 6 percent of the total CO emission

Table IX-3

Emission Rates for 1985-89 Light-Duty Diesel-Fueled Vehicles and Trucks at 5,300 Feet[a]

Pollutant		Base Scenario LDDV[b]	Base Scenario LDDT[b]	Scenario #2 LDDV	Scenario #2 LDDT
HC	Zero-Mile Emission Level (g/mi)	0.54	0.76	0.39	0.61
	Deterioration Rate (g/mi/10,000 miles)	0.03	0.06	0.03	0.06
	Average Lifetime Emission Level (g/mi)	0.69	1.12	0.54	0.97
CO	Zero-Mile Emission Level (g/mi)	2.22	2.77	1.27	1.98
	Deterioration Rate (g/mi/10,000 miles)	0.05	0.09	0.05	0.09
	Average Lifetime Emission Level (g/mi)	2.47	3.31	1.52	2.52
NOx	Zero-Mile Emission Level (g/mi)	0.75	1.89	0.75	1.89
	Deterioration Rate (g/mi/10,000 miles)	0.05	0.07	0.05	0.07
	Average Lifetime emission Level (g/mi)	1.0	2.31	1.0	2.31

[a] Emission Rate = ZML + (M)(DR)
Where:
ZML = Zero-Mile Level
M = Cumulative Mileage/10,000 (Cumulative mileage = 50,000 miles for LDDVs and 60,000 miles for LDDTs)
DR = Deterioration Rate

[b] Light-Duty Diesel Vehicle
Light-Duty Diesel Truck

Table IX-4

Lifetime Emissions from 1985-89
LDDVs and LDDTs Sold Above 4,000 Feet
(10^3 metric tons)

Pollutant	Base Case LDDV	Base Case LDDT	Scenario 2 LDDV	Scenario 2 LDDT	Reductions (base case minus scenario 2) LDDV	Reductions (base case minus scenario 2) LDDT
HC	15.25	8.87	11.93	7.68	3.32	1.19
CO	54.59	26.22	33.59	19.96	21.00	6.26
NOx	22.1	18.30	22.1	18.30	0	0

reductions result from LDD control. This shows that controlling light-duty diesel motor vehicles can produce significant reductions in HC emissions.

V. COST EFFECTIVENESS

Results from the economic and environmental impact sections of this chapter were combined to determine the cost effectiveness of adding LDDV and LDDT control to scenario 2. The same procedure outlined in Chapter V to determine the cost effectiveness of LDGV control was followed in this section. The results of this analysis can be found in Table IX-5 along with the incremental cost effectiveness of LDGV and LDGT control for scenario 2 as determined in Chapters V and VIII. The incremental cost effectiveness of combined LDV and LDT control is also presented in Table IX-5.

As shown in Table IX-5 controlling LDDVs and LDDTs to the levels associated with scenario 2 is more cost effective than controlling LDDVs and LDDTs to the same levels. It is not surprising then, that adding the control of light-duty diesel-fueled motor vehicles to scenario 2 makes it a more cost-effective approach than if only light-duty gasoline-fueled motor vehicles were controlled more stringently. For the worst case analyzed, the cost of removing HC is reduced from $535 per metric ton to $465 per metric ton. The cost effectiveness of CO removal for the worst case analyzed remains unchanged at $30 per metric ton.

Table IX-6 lists the cost effectiveness of other control strategies already adopted. (This same table also appears as Table VI-3 of Chapter VI.) From this table it can be seen that when LDDV and LDDT controls are viewed either spearately or in conjunction with LDDVs and LDGTs, the cost effectiveness of scenario 2 is among the most cost efficient approaches to reducing emissions of HC and CO.

Table IX-5

Incremental Cost Effectiveness of Scenario 2

Vehicle Type	Costs[a] (dollars per vehicle)		Emission Reductions (10^3 metric tons per vehicle)		Incremental Cost Effectiveness (dollars/metric ton)			
					HC		CO	
	Low	High	HC	CO	Low	High	Low	High
LDGV	-11	15	13.0	239.9	neg.	575	neg.	30
LDGT	-69	21	21.7	326.2	neg.	485	neg.	30
LDGV and LDGT	-24	16	15.0	259.7	neg.	535	neg.	30
LDDV	1		15.0	95.0	35		5	
LDDT	0		18.0	94.8	0		0	
All Light-Duty Vehicles and Trucks	-21	14	15.1	236.9	neg.	465	neg.	30

[a] 1981 dollars discounted to the year of vehicle purchase. The low estimates for gasoline-fueled vehicles are based on the inclusion of tentative fuel-economy benefits.

Table IX-6

Cost-Effectiveness Comparison With
Other Emission Control Strategies
(1981 dollars per metric ton)

Control Program	Baseline Emissions[a]	Emissions After Control Strategy Implemented	Cost Effectiveness HC	Cost Effectiveness CO
LDV Statutory Standards[10]	HC 0.9 CO 15	HC 0.41 CO 3.4	734	67
LDV I/M[11]	--	--	640	58
LDT 1984 Standards[12]	HC 1.7 CO 18	HC 0.8 CO 10	195	15
HDE 1984 Standards				
(gasoline)	HC 1.5 CO 25	HC 1.3 CO 15.5	305	10
(diesel)	HC 1.5 CO 25	HC 1.3 CO 15.5	325	--
Motorcycle	HC 9	HC 8-22.5[c]	582	Neg.
Standards[14]	CO 34.67	CO 27.4		
HDG Evap.[15][d]	HC 1.8	HC 0.17	200	--
Interim 1982-83 HA Standards[9]	HC 1.47 (cars) 4.19 (trucks) CO 16.23 (cars) 73.02 (trucks)	HC 1.33 (cars) 3.78 (trucks) CO 13.21 (cars) 55.65 (trucks)	393	12

[a] Emission levels are in grams per mile except for the HDE 1984 standards which are in grams per brake horsepower-hour.

[b] The baseline and after-control strategy emission values were based on different test procedures (see reference 13).

[c] Sliding scale based on engine displacement (cubic centimeters).

[d] The evaporative standard is in terms of g/test and converted to g/mi here to facilitate comparison.

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Chapter X

Light-Duty Diesel Particulate Emissions

I. INTRODUCTION

As mentioned earlier, section 206(f) of the Clean Air Act requires that the light-duty vehicle emission control provisions of section 202 apply in high-altitude areas beginning with the 1984 model year. In addition to gaseous pollutants, EPA has also established particulate standards for diesel-powered vehicles under section 202. Since particulate emissions are addressed by section 206(f) of the Act, they have been included within the scope of this report also.

Previous chapters discussed various aspects of controlling gaseous emissions from light-duty vehicles and trucks at high altitude. Much of those analyses compared the various control strategies outlined in Chapter II to a base scenario, which called for a continuation of the interim 1982-83 high-altitude standards. Because particulate emissions from diesel-powered light-duty vehicles and trucks (LDDVs and LDDTs) are not controlled by the interim program, they are being addressed separately below.

This chapter specifically analyzes the technology expected to be needed to reduce particulate emissions at high altitude. Unlike the previous analyses that evaluated the control of gaseous emissions, this analysis will not specifically include estimates of the cost of control. The available emissions data are too limited to project the necessary control technology with the confidence needed to justify assigning a definite cost to the technology. In fact, the data are so limited that it is not possible to definitively determine what the actual "proportional" diesel particulate standard should be. All that can be done at this time is to estimate the proportional level and roughly identify what technology would likely be needed to meet both the proportional and low-altitude levels at high altitude. Some judgment will then be made concerning the cost which is associated with the two levels. Likewise, the lack of emissions data also prevents the accurate determination of the overall emissions reduction and air quality benefit resulting from control. Thus, these calculations will also not be performed.

II. CONTROLLING PARTICULATE EMISSIONS FROM HIGH-ALTITUDE LIGHT-DUTY DIESELS

The amount of data available on the effect of high altitude on diesel particulate emissions is extremely limited. That which is available is shown in Table X-1. Even within this small data set, the information from one vehicle (Peugeot) is not very useful because its HC emissions are extremely high for a diesel and it is likely that some malfunction was present.

Table X-1

Average FTP Emission Levels of Diesel-Powered Passenger Cars

Vehicle	Test Site	HC (g/mi)	CO (g/mi)	NOx (g/mi)	F.E. (mi/gal)	Part. (g/mi)
		In-Use Vehicles without EGR[1]				
1980 Volkswagen	High	.57	1.88	1.09	35.3	.40
90 CID	Low	.22	.78	1.05	39.5	.26
1979 Olds	High	1.39	2.21	1.29	20.5	.98
260 CID	Low	.68	1.50	1.43	22.9	.78
1979 Olds	High	.97	2.57	1.56	20.6	1.82
260 CID	Low	.39	1.49	1.67	24.2	1.13
1974 Peugeot	High	6.74	8.88	.98	21.0	2.43
129 CID	Low	3.86	3.83	.93	25.2	.90
1977 Mercedes	High	.65	1.04	1.51	25.8	.47
147 CID	Low	.25	.67	1.29	31.8	.36
Odometer-52206						
Average (all vehicles)	High	2.06	3.32	1.28	23.6	1.22
	Low	1.08	1.65	1.27	27.6	.69
Increase		91%	101%	1%	-14%	78%
Average (without Peugeot)	High	.89	1.93	1.36	24.3	.92
	Low	.38	1.11	1.36	28.2	.63
Increase		134%	74%	0%	-14%	46%

Experimental Vehicles with Analog EGR[2]

Vehicle	Test Site	HC (g/mi)	CO (g/mi)	NOx (g/mi)	Part. (g/mi)
GM	High	.60	2.3	.83	1.04
5.7 L, 4000 # IW	Low	.34	1.4	1.18	.46
GM	High	.44	.98	1.21	.54
5.7 L, 4000 # IW	Low	.22	1.04	1.48	.34

Ignoring this vehicle, the first set of vehicles shows that particulate emissions increase by an average of 46 percent when tested at high altitude. Since these vehicles represent as near an uncontrolled baseline as is available, the best estimate of a proportional diesel particulate standard would be roughly 46 percent (an even 50 percent will be used hereafter) higher than the low-altitude standard. This, of course, is only a rough estimate due to the small number of vehicles tested. Thus, in 1985, the proportional diesel particulate standard for light-duty vehicles would be 0.3 g/mi relative to the 0.2 g/mi low-altitude standard and would be 0.39 g/mi for light-duty trucks relative to the low-altitude standard of 0.26 g/mi.

Now that the proportional standard has been estimated, the next step is to estimate what technology will be needed to meet this level and the low-altitude standard at high altitude. Unfortunately, even less data are available here than were available earlier. What is available is shown in the lower half of Table X-1.

The two vehicles shown in the lower half of Table X-1 are General Motors' diesels equipped with analog EGR to reduce NOx emissions from an uncontrolled level of around 1.7-2.0 g/mi. As can be seen, the effect of altitude on particulate emissions increases as NOx is controlled. This is not unexpected since increased levels of EGR reduce the amount of oxygen available for combustion. When moved to high altitude, these vehicles are already operating richer than normal and the effect of altitude is simply to move further in the same direction. With diesels, the effect of a given shift in the air/fuel ratio has an ever increasing effect on smoke and particulate emissions as the air/fuel ratio is lowered. Thus, a greater effect occurs with higher levels of EGR.

While not unexpected, this effect is important since by 1985 all light-duty diesels will be required to meet a 1.0 g/mi NOx standard and most, if not all, vehicles will be equipped with EGR to reach this level. This means that if not controlled at all, the particulate emissions of these vehicles at high altitude will likely be more than 50 percent higher than their low-altitude levels and will exceed a proportional standard.

At the same time, however, hydrocarbon emissions will be reduced to meet at least the 0.57 g/mi proportional standard regardless of whether or not particulate emissions are controlled. As shown in Table X-1, all but one vehicle will need some adjustment at high altitude to meet the 0.57 g/mi standard. Any adjustment for hydrocarbon emissions, such as limiting maximum fuel flow or adjusting injection timing, should also reduce particulate emissions. This is likely to bring particulate levels within the proportional levels. This must remain only a projection, however, since no high-altitude particulate levels are yet available from 1982 diesels certifying to the interim gaseous emission standards.

Even if the hydrocarbon controls were not totally sufficient, however, the EGR systems which will be on diesels by 1985 should be able to be adjusted to ensure that a proportional particulate standard can be met. For example, the data in the lower half of Table X-1 show essentially the same vehicle at two NOx levels (two different EGR rates). The first vehicle with a low NOx level emits 1.04 g/mi particulate at high altitude; a 126 percent increase over low altitude. Note, however, that the second vehicle having a lower EGR rate achieves essentially the same NOx level at high altitude that the first one achieved at low altitude. In other words, the effect of altitude compensated for the reduction in the EGR rate. However, the high-altitude particulate emissions in this case are only 0.54 g/mi, which is only a 17 percent increase over the original 0.46 g/mi level of the first vehicle. This is well below the 50 percent allowance discussed above and occurred before the application of any obvious control to the maximum fuel rate to prevent locally rich combustion (though this might also increase NOx emissions somewhat). Thus, with simple controls such as adjustment to the present analog EGR system and the maximum fuel rate, a proportional particulate standard should be achievable.

These controls should be very inexpensive since no new hardware should be required. The primary cost will be associated with having to develop special high-altitude calibrations, but this is already accounted for in the compliance costs for the proportional gaseous emission standards. Therefore, the cost of adding a proportional particulate standard to the proportional gaseous emission standards should be very small or negligible.

It should be mentioned that this report has not explicitly considered the effect of trap-oxidizer technology on high-altitude particulate emissions. Trap-oxidizers are expected to be used by most vehicles to meet the 1985 particulate standard.[1] No data are available on the effect of high altitude on the particulate emissions of a trap-equipped vehicle. However, on the basis of all the information available on the effects of trap-oxidizers on particulate emissions, these traps are generally proportional control devices. That is, they reduce emissions by a constant proportion regardless of the absolute emission levels entering, within reasonable limits. Thus, the above argument should hold for vehicles with or without traps.

There is one aspect of a trap-oxidizer for which the argument may not hold rigorously. While the trap is a proportional control device, its size is somewhat dependent on the absolute amount of particulate matter entering it per mile. At least some trap-oxidizers are expected only to burn-off the trapped particulate periodically and the number of miles these vehicles can be driven between burn-off will depend on the size of the trap. At high altitude, then, if more particulate were entering the trap due to higher engine-out emissions, the number of miles before burn-off became necessary would be reduced. If the burn-off cycle is controlled "intelligently" via electronic or mechanical controls, then the frequency of burn-off could be simply increased and the problem solved. This should be relatively inexpensive and could easily be performed when the other engine parameters are adjusted for high altitude.

Even if burn-off is not controlled intelligently, there may be another factor operating at high altitudes which would automatically increase the frequency of burn-off. The lower air density at high altitude will decrease the air/fuel ratio at any given power level of a diesel engine. The result is that both the combustion and exhaust temperatures will increase at high altitude at any given load. Since sufficient exhaust temperature is the key to burn-off, the trap-oxidizer should burn-off at lower loads at high altitude than at low altitude, increasing the frequency of burn-off. Given that the increase in engine-out particulate emissions should only be on the order of 15-20 percent (as estimated above), this frequency of burn-off should only have to increase by the same amount, which is fairly small. While only these general arguments can be presented at this time, it would appear that the trap size should not need to be increased on high-altitude vehicles and that proportional control of particulate emissions should be inexpensive even for vehicles equipped with trap-oxidizers.

It should be mentioned at this point that light-duty trucks have not been specifically addressed. The reason for this is that no hard data exist on the effect of high altitude on particulate emissions from light-duty trucks. From the low-altitude particulate data available on these trucks,[3] and the fact that the engine used is essentially the same as those for light-duty vehicles, it is expected that the same conclusions will hold for light-duty trucks as did for light-duty vehicles. In the case of either diesel vehicles or trucks, more data are needed before any definitive conclusions can be drawn concerning the feasibility of a high-altitude particulate standard. However, at this time, EPA expects that a proportional standard should be inexpensive to achieve for either vehicle class.

This brings up the question of the feasibility of meeting the low-altitude particulate standards at high altitude. As described above, using the little data that are available, the particulate emission increase after simple controls are applied may be only 15-20 percent higher than low-altitude levels.

With the addition of sophisticated analog EGR systems to achieve the statutory gaseous emission standards, it is possible that particulate emissions could be reduced 15-20 percent to achieve the low-altitude levels at high altitude with no additional cost. Unfortunately, there are no data to support or reject this projection.

At this time, the best that can be said is that any additional controls that are added to reduce HC and CO emissions down to the statutory standards should also further reduce particulate emissions. In any case, based on the General Motors' data in Table X-1, the high-altitude particulate level achievable by diesels should be fairly close to the low-altitude standards since even simple EGR systems result in high-altitude particulate levels only 15-20 percent higher than at low altitude. At this time, the best approach appears to be to evaluate the effect of gaseous emission control on particulate emissions as more data on the former become available. The achievable particulate level could then be simply defined as the level resulting from the control of gaseous emissions to their appropriate level. Of course, the effect of this control technology on particulate emissions should be considered when calculating the cost effectiveness of control.

III. SUMMARY

It would appear that a high-altitude proportional particulate standard, when definitively determined, would be inexpensive and achievable. In addition, further reductions from proportional levels may be achievable from the application of gaseous emission controls at little or no extra cost. However, it is not possible to determine if the current low-altitude particulate standards would be fully achievable at high altitude. Due to the severe limitations of the existing data base, the only firm conclusions which can be made concerning control beyond proportional levels is that: 1) the reductions in particulate emissions resulting from the application of gaseous emission controls should be considered in determining the effectiveness of these controls; and 2) the maximum level of particulate control that is feasible may be the particulate level resulting from the application of these gaseous emission controls.

References

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2. General Motors Closing Comments to the U.S. EPA Public Hearing on the 1984 High-Altitude Requirements of the 1977 Clean Air Act Amendments, April 22, 1980.

3. "Regulatory Analysis of the Light-Duty Diesel Particulate Regulations for 1982 and Later Model Year Light-Duty Diesel Vehicles," U.S. EPA, OANR, OMS, ECTD, SDSB, February 20, 1980.

Chapter XI

High-Altitude Standards as a Consequence of Revised Low-Altitude Standards

I. INTRODUCTION

The previous chapters in this report analyzed various alternative high-altitude standards which were based on the current low-altitude gaseous standards of 0.41 g/mi HC, 3.4 g/mi CO and 1.0 g/mi NOx for light-duty vehicles (LDVs). Recently, however, the debate concerning amendments to the Clean Air Act (CAA) has included the possibility of revising certain of the statutory low-altitude emission standards for LDVs upward from the current levels. Although such a revision remains speculative at this time, the effect of less stringent low-altitude standards on potential high-altitude standards will be evaluated in this chapter to maximize the value of this report regardless of the level of the low-altitude standards.

This chapter discusses the effects of revised low-altitude standards on both gasoline-fueled LDVs (LDGVs) and diesel-powered LDVs (LDDVs). Like previous chapters, the standards affecting LDVs are assumed to be effective beginning in the 1984 model year.

The effect of revised gaseous emission standards on the technical feasibility of complying with the requisite diesel particulate standards for LDDVs is not specifically addressed in this chapter. However, it should be pointed out that by revising the NOx standard upward from 1.0 g/mi, diesel particulate standards may be less costly to attain at high-altitude than estimated in Chapter X. The principle control strategy for reducing NOx emissions from LDDVs is the use of exhaust gas recirculation (EGR). Unfortunately this type of NOx control method, besides generally increasing particulate emissions, also appears to increase the sensitivity of particulate emissions to altitude, making attainment of the high-altitude particulate standard more difficult. Therefore, by revising the NOx standard upward, less EGR will be required and the accompanying lower particulate emissions along with the decreased altitude sensitivity should result in easier and less costly control.

II. DEFINITION OF CONTROL SCENARIOS

The high-altitude LDV control scenarios analyzed in this chapter depend on what the revised statutory low-altitude standards may be. Since the exact levels of any future low-altitude standards have not been determined, an assumption regarding possible standards is necessary. This analysis assumes exhaust emission levels of the revised statutory low-altitude standards are 0.41 g/mi HC, 7.0 g/mi CO, and 1.5

to 2.0 g/mi NOx (Table XI-1). A range of possible NOx requirements is used to indicate the level of control that appears to be most frequently discussed. No significant difference in control technology at either low or high altitude is expected within this range of NOx control. The evaporative HC emission standards at low altitude are assumed to remain unchanged at 2.0 gram/test (Table XI-1). Now that the statutory low-altitude standards are known, the high-altitude control scenarios can be defined.

As in previous chapters, there are many possible strategies for controlling motor vehicle emissions in high-altitude areas of the country. These strategies consist of a combination of variables including: 1) the basic philosophy of high-altitude emission control, 2) the allowable emission levels for each standard, and 3) the availability of exemptions for certain low-power vehicles. In order to limit the analysis in this chapter to only those possible scenarios that are the most reasonable, each of these variables is discussed below based on the conclusions of previous chapters as they relate to the possibility of "revised" high-altitude standards. A more complete general discussion of these variables can be found in Chapter II.

A. The Philosophy of High-Altitude Control

This report analyzes two basic philosophical options. The first option specifically requires that motor vehicles continuously meet the appropriate emission standards at all elevations without modification. Standards of this type are referred to as "continuous" standards throughout this document. The second option requires that all vehicles sold at high altitude (above 4,000 feet) must be capable of meeting high-altitude standards either automatically or after modification when tested at 5,300 feet. Standards of this type are referred to as "fixed-point" standards throughout this document.

This analysis is restricted to considering only fixed-point standards. Chapters II through VII showed that the continuous strategies analyzed in this report were unreasonably burdensome by seriously restricting model availability at high altitude, requiring expensive and complicated emission control technology on some vehicles, and by specifically controlling emissions at elevations above approximately 6,000 feet, which are not expected to have an air quality problem. Also, they were found not to be cost effective. The primary cause of the poor cost effectiveness was that while every vehicle in the nation had to be equipped with hardware to ensure high-altitude emission control, these costs were not offset by the emission reduction that occurred only for those vehicles operating at high altitude (about 3 to 4 percent of all LDVs).

Table XI-1

Revised Statutory and Revised Proportional
Emission Standards for Light-Duty Vehicles

Revised Standard	Vehicle	Year of Implementation	Gaseous Standards HC (g/mi)	CO (g/mi)	NOx (g/mi)	Evap.HC[a] (g/test)
Statutory	LDGV[b]	1984	0.41	7.0	1.5-2.0	2.0
	LDDV[c]	1984	0.41	7.0	1.5-2.0	N/A
Proportional	LDGV	1984	0.57	11	1.5-2.0	2.6
	LDDV	1984	0.57	11	1.5-2.0	N/A

[a] Evaporative emission standards are not applicable (N/A) to diesel-powered vehicles. The low volatility of diesel fuel produces few evaporative emissions.
[b] Light-duty gasoline-fueled vehicle.
[c] Light-duty diesel-powered vehicle.

These findings should remain valid even if the low-altitude standards are revised upward to the levels assumed in this report. For example, the control strategies which require compliance with statutory standards up to an elevation of 10,200 feet would continue to be very difficult to achieve in a cost-effective manner. Achieving such standards would probably entail either exempting the majority of the fleet from the certification requirements, in which case model availability at high altitude would be drastically reduced, or would entail using alternatives such as turbocharging the engines of many if not most of the vehicles in the entire nation, in which case the cost would be prohibitive. Even compliance with continuous control strategies up to 6,000 feet would remain cost ineffective because control hardware would be required on all vehicles in the nation, while the benefit in the form of reduced emissions would be realized only from those vehicles operated at higher elevations. Therefore, fixed-point standards appear to be a reasonable approach to solving high-altitude air pollution problems.

B. The Levels of the Standards

This report considers two levels of high-altitude emission standards. The first level is referred to as "statutory" standards and requires that the same numerical standards be met at both low and high altitudes. The statutory standards are assumed in this chapter to be 0.41 g/mi HC, 7.0 g/mi CO, 1.5-2.0 g/mi NOx, and 2.0 g/test evaporative HC (Table XI-1).

The second level is referred to as "proportional" high-altitude standards. These "proportional" reduction standards are considered to be equally as stringent as the low-altitude standards at their respective altitudes, although the high-altitude standards would have a higher numerical value for HC and CO since motor vehicles naturally emit more of these pollutants at higher elevations. For NOx, which normally decreases with increased altitude, the numerical value of high-altitude standard is the same as the low-altitude standard. (Chapter III contains a more detailed discussion of these natural phenomena.) This is consistent with the Congressional mandate in section 202(f) of the Act which specifically forbids a standard at high altitude from being numerically more stringent than the corresponding low-altitude standard.

The proportional high-altitude emission standards at an elevation of 5,300 feet that correspond to the assumed low-altitude standards of this chapter are 0.57 g/mi HC, 16 g/mi CO, 1.5-2.0 g/mi NOx, and 2.6 g/test evaporative HC. However, as discussed in more detail in the control technology section which follows, there appears to be little or no difference in the requisite control hardware and cost of compling with either a 16 g/mi or an 11 g/mi CO standard at high altitude. This means that the more stringent 11 g/mi CO standard would be a more efficient and cost effective requirement than the 16 g/mi CO standard, since a greater benefit (i.e., fewer emissions) will result from spending about the same amount of money. Put another way, this means that high-altitude consumers would receive a greater return on their investment in emission control hardware which is made when a new vehicle is purchased. For these reasons, EPA believes that 11 g/mi CO is a more appropriate level of control when options to implementing statutory standards at high altitude are discussed, as is done in this report. Therefore, when proportional high-altitude requirements are analyzed in this chapter, the levels will be 0.57 g/mi HC, 11 g/mi CO, 1.5-2.0 g/mi NOx, and 2.6 g/test evaporative HC (Table XI-1).

C. High-Altitude Exemptions

Modifying some motor vehicles to comply with the high-altitude exhaust emission standards shown in Table XI-1 may be technically difficult. (Chapter III contains a more detailed explanation of this difficulty.) These vehicles generally should be low-power, high fuel economy cars that are designed principally for the low-altitude market. Although these vehicles perform acceptably at lower elevations, they may have extremely poor performance when operated at high altitude because the less dense air at higher elevations reduces the engine's power output. Such poor performers either would not be sold or would be sold in small numbers at high altitude, even in the absence of high-altitude regulations.

In the earlier chapters of this report, exemptions to the high-altitude certification requirements were found to be an effective way to reduce the overall cost of the standards or, in some cases, were found to prevent potentially negative effects on model availability throughout the nation. In Chapter II, the volume of exemptions was estimated based on worst case assumptions for fixed-point statutory standards and fixed-point proportional standards corresponding to the current low-altitude emission standards of 0.41 g/mi HC, 3.4 g/mi CO, and 1.0 g/mi NOx. In this chapter, the low-altitude standards have been revised upward but the corresponding statutory and proportional high-altitude levels are still considered to be as stringent relative to the revised standards as the high-altitude standards considered in the preceding chapters of this report. Since the relative difficulty of complying with the standards is regarded as being the same, it is assumed that the need for exemptions will not change significantly. Therefore, the previously estimated volume of exemptions will be used here as shown below:

1. Five (5) percent of the fleet for high-altitude control scenarios with fixed-point proportional standards; and

2. Fifteen (15) percent of the fleet for high-altitude control scenarios with fixed-point statutory standards.

As in the previous chapters, this analysis includes exemptions to illustrate the effect of including such provisions in future high-altitude regulations. As additional data become available it may be preferable to implement other schemes such as waivers that would allow vehicles certified to only low-altitude standards to be sold in high-altitude areas.

D. Selecting the High-Altitude Control Scenarios

The preceding discussion identified two control scenarios for analysis in this chapter. The scenarios are:

1. Fixed-Point Statutory Standards

The numerical values of these standards are the same as the revised low-altitude standards which are assumed in this analysis, 0.41 g/mi HC, 7.0 g/mi CO, 1.5-2.0 g/mi NOx, and 2.0 g/test evaporative HC. Vehicles sold above 4,000 feet beginning in the 1984 model year must comply with these levels when tested at an elevation of 5,300 feet. Exemptions for approximately 15 percent of the existing fleet will be available.

2. Fixed-Point Proportional Standards

The numerical values of these standards are 0.57 g/mi HC, 11 g/mi CO, 1.5-2.0 g/mi NOx, and 2.6 g/test evaporative HC. Although the 11 g/test CO high-altitude standard is not truely proportional to the 7.0 g/mi CO low-altitude standard, the technical difficulty of meeting it is considered to be essentially equivalent to complying with a 16 CO high-altitude standard which is the actual proportional value. (This is explained in greater detail below.) Because of this equivalent difficulty, the 11 g/mi CO standard is referred to as being the proportional requirement in this chapter.

In this scenario, vehicles sold above 4,000 feet beginning in the 1984 model year must comply with the proportional levels when tested at an elevation of 5,300 feet. Exemptions for approximately 5 percent of the existing fleet will be available.

One further remark concerning the control scenarios is necessary before beginning the analysis. The primary purpose of this report is to respond to the requirements of section 206(f)(2) of the Act. This section provides certain guidelines which are useful in defining the analytical methodology in this chapter of the report. First, the Act basically requires a review of the economic impact and technical feasibility of statutory standards of high altitude. Second, the technical feasibility and air quality consequences of proportional standards are to be evaluated. In the preceding chapters, the methodology used to respond to the guidelines of section 206(f)(2) was the evaluation of all alternative scenarios by comparison to a continuation of the fixed-point proportional standards contained in the 1982 and 1983 high-altitude regulations. This approach was used primarily to avoid useless repetition of the detailed analyses which supported the existing high-altitude standards.[1,2,3,4] Since compliance with the proportional standards in this chapter is expected to be similar to compliance with the current proportional standards, the same analytical methodology will be used here to remain consistent with the previous analyses in this report. Therefore, implementing revised statutory standards (0.41 g/mi HC, 7.0 g/mi CO, and 1.5-2.0 g/mi NOx and 2.0 g/test evaporative HC) will be analyzed with regard to the incremental costs and benefits that will accrue beyond those of continuing a program with revised proportional standards (0.57 g/mi HC, 11 g/mi CO, 1.5-2.0 g/mi NOx and 2.6 g/test evaporative HC). To provide additional continuity with previous chapters, the fixed-point proportional standards will be referred to as the "revised" base scenario and the fixed-point statutory standards will be referred to as the "revised" scenario 2 throughout the remainder of this analysis.

III. TECHNOLOGY ASSESSMENT

High-altitude exhaust emission control technology depends upon the control hardware that will be used at low altitude. Therefore, before the requisite high-altitude control hardware can be estimated the low-altitude requirements must be defined.

A. Low-Altitude Control Hardware

The control technology which may ultimately be used for LDGVs to comply with the assumed low-altitude standards of 0.41 g/mi HC, 7.0 g/mi CO, and 1.5-2.0 g/mi NOx are estimated in an EPA draft document entitled, "Motor Vehicle Emission Standards for Carbon Monoxide and Nitrogen Oxides."[5] In that report, EPA estimated that 100 percent of the LDGVs may be equipped with "open-loop" (nonfeedback) systems under the revised low-altitude standards. These systems do not require the more sophisticated electronic microprocessor control of closed-loop (feedback) systems which are often currently used to meet the more stringent 3.4 g/mi CO and 1.0 g/mi NOx standards. Open-loop systems do not monitor the fuel/air ratio entering the engine's combustion chambers as do closed-loop systems, but instead use essentially fixed calibrations to control fuel metering. Also, about 60 percent of the fleet is expected to be equipped with air pumps and about 40 percent of the fleet will use a less costly pulse air injection system. This compares to current systems which almost always utilize an air pump in conjunction with an oxidation-reduction catalyst or an oxidation catalyst.

For LDDVs, the revised standards should be achievable without the addition of any new emission control hardware. More specifically, EPA expects that little or no EGR will be required to achieve the revised NOx standards since little or no EGR was required to meet similar Federal emission standards in the 1980 model year (2.0 g/mi NOx), or the 1981-82 model years (waivers to 1.5 g/mi NOx were granted for some diesels).

B. Revised Base Scenario Control Hardware

This section assesses the emission control technology that will be required to make a low-altitude vehicle comply with high-altitude proportional standards. This assessment will be conducted in two parts. First, the requisite control hardware that may be necessary to comply with the revised proportional standards of 0.57 g/mi HC, 16 g/mi CO, and 1.5-2.0 g/mi NOx will be identified. Second, the requisite hardware for compliance with revised proportional standards of 0.57 g/mi HC, 11 g/mi CO and 1.5-2.0 g/mi NOx will be identified. The difference in these two parts is simply that in one case the revised CO standard is 16 g/mi, while in the other it is 11 g/mi.

1. Control Technology for Proportional Standards Including a 16 g/mi CO Requirement

As discussed in Chapters III and IX, the general control strategy for reducing emissions from open-loop (nonfeedback) vehicles to proportional levels is to recalibrate the fuel metering device (e.g., carburetor) so that the excessively rich fuel/air mixtures which normally occur at higher elevations are corrected. This same emission control technique should be useful in reducing emissions to the revised proportional levels analyzed in this chapter because it corrects the same problem of overly rich fuel/air mixtures in both cases (current versus revised low-altitude standards). Also, in each case the allowable high-altitude emissions from a vehicle certified at low altitude will be limited to the same percent increase. (This percentage is based on the ratio of the high-altitude standard to the respective low-altitude standard.) Therefore, the recalibration in both cases (i.e., leaner fuel/air mixtures) should be somewhat similar. However, the emission control systems for current standards are expected to be different than for the revised standards and the effect this may have on the effectiveness of the control technique which has been identified needs further attention.

There are emission control devices that are currently in use on vehicles which may not be part of the emission control system if the standards are revised upward. These devices include: 1) the NOx reduction catalyst on many gasoline-fueled vehicles, and 2) the air pump on most of the gasoline-fueled vehicles. The effects of removing these hardware items on the effectiveness of recalibrating fuel/air ratios will be examined separately below.

An exhaust catalyst basically functions by promoting chemical reactions which remove a percentage of the harmful emissions coming from the engine's combustion cylinders. Therefore, as the amount of a particular pollutant entering the catalyst is increased, only a portion of it will be removed, the remainder passes through the catalyst into the atmosphere.

Under the current high-altitude standards, leaning the fuel/air ratio to reduce HC and CO emissions will increase NOx emissions coming from the combustion chambers. It is possible, although unlikely with regard to proportional standards, that this control strategy by itself could lead to excess NOx emissions for some vehicles. The important point is that even with the reduction catalyst the manufacturer of such a vehicle would probably have to manipulate other engine control parameters to reduce NOx emissions from the combustion chambers because the reduction catalyst would remove only a portion of the excess. These engine control parameters may include more careful recalibration of the fuel metering to prevent excessive leaning, recalibrating ignition timing, or recalibrating exhaust gas recirculation (EGR) rates.

EPA assumes the degree of fuel management (i.e., leaning) will be somewhat similar to that currently needed to comply with proportional high-altitude regulations even if the standards are revised upward, because both types of standards (current versus revised) limit the increase in emissions from low- to high-altitude by the same percentage. Although manufacturers are not expected to use reduction catalysts to comply with revised standards, they would be confronted with essentially the same task as is currently the case with these devices if NOx emissions from some vehicles were to increase beyond acceptable levels. That is, the emissions coming out of the engine need to be controlled since, as described above, the existence of the reduction catalyst by itself would not completely control the additional NOx. Therefore, manufacturers will have to pay more careful attention to fuel management, ignition timing, and EGR rates if indeed NOx emissions increase beyond allowable levels when the fuel/air ratio is leaned to control HC and CO. It should be emphasized, however, that under the revised proportional standards (whether they include an 11 g/mi or 16 g/mi CO standards), EPA expects that few if any vehicles will have excessive NOx emissions as a result of leaning the fuel/air ratio to achieve the requisite HC and CO control.

Now that the effects of removing the reduction catalyst have been discussed, the effects of removing the air pump and replacing it with a pulse air injection system will be assessed. The air pump adds fresh air (oxygen) to the engine's exhaust which promotes the removal (oxidation) of HC and CO. Under the current proportional standards the air pump, which is mechanically driven by a belt from the engine, may be part of the high-altitude modification on some vehicles by changing the pump's drive pulley so that it rotates faster and delivers more oxygen to the exhaust stream. Since an air pump delivers a particular volume of air at any given speed, this technique may be used to recover some of the lost effectiveness of the injection system when it is used at higher elevations where the air is less dense and, hence, there is less oxygen per volume of air. The effectiveness of recalibrating the air pump, however, is limited. Care must be taken not to increase the injection rate of fresh air to such a degree that the exhaust gas temperature is reduced too much. This would reduce the chemical reacton rate and could lead to greater HC and CO emissions. Therefore, modifying the air pump would only provide a portion of the total emission reduction which may be required; indeed, this portion may be small because of the limited effectiveness of increasing the pump's delivery rate. Manufacturers must rely on the other control options which have already been identified (e.g., fuel management and spark timing) to ensure compliance with the current proportional standards.

The pulse air injection system (PAIR) that is expected to replace the currently used air pump system on some vehicles if the standards are revised also reduces HC and CO emissions by adding fresh air to the exhaust. The PAIR system is driven by the pressure pulses in the exhaust stream which are caused by the hot gases existing the combustion chambers. This system does not possess the wide range of air delivery rates that characterize the air pump and its effectiveness can be limited for this reason. Like an air pump, PAIR delivery rates may be somewhat increased as part of a high-altitude modification when the pulse air system is not originally functioning at peak performance. If such an increase is not sufficient, the situation is analogous to the air pump, and manufacturers will have to pay more careful attention to optimizing air/fuel ratios, timing, etc. Overall, EPA expects that few, if any, vehicles equipped with PAIR will have trouble meeting proportional standards of 0.57 g/mi HC and 16 g/mi CO.

In summary, the recalibration techniques that are used to comply with the current proportional standards (i.e., primarily fuel management) also should be useful to achieve revised proportional standards since in both cases the increase in emissions from low to high altitude is limited by the same percentage. The change in emission control technology which is expected to accompany revised low-altitude standards should not significantly affect these control techniques or the requisite hardware.

2. Control Technology for Proportional Standards Including an 11 g/mi CO Requirement

In the preceding section, EPA concluded that the requisite control technology for complying with proportional standards under the revised base scenario should be essentially the same as projected for compliance with the current proportional standards which were previously analyzed in Chapters III and IX. This conclusion is primarily based on the similarity in emission control which will be required by the two sets of standards. This section investigates why essentially the same control hardware should allow compliance with either an 11 g/mi CO standard or a 16 g/mi CO standard at high altitude.

The assumed technical similarity between an 11 g/mi CO and a 16 g/mi CO standard is based primarily on EPA's recent experience with 1982 model year LDVs that have received a CO waiver from the current 3.4 g/mi CO low-altitude standard up to 7.0 g/mi. Waivers are allowed by the Clean Air Act in cases where manufacturers can demonstrate that meeting a 3.4 g/mi CO standard at low altitude would be technically infeasible considering the cost of control. Vehicles which are granted a low-altitude waiver automatically qualify for a less stringent 11 g/mi CO standard at high-altitude instead of the normal proportional 7.8 g/mi CO standard.[1]

Experience with these waivered vehicles is of value in estimating the difficulty of meeting high-altitude standards since the waivered low-altitude vehicles are currently required to meet the same CO standard as is assumed to be in effect at low-altitude in this analysis of revised standards for 1984 and later vehicles (i.e., 7 g/mi). Also, the current high-altitude standard for waivered vehicles is equivalent to the revised CO standard at high altitude, which is assumed in this chapter (i.e., 11 g/mi). During the waiver process, manufacturers must submit detailed information to EPA on the cost and technical feasibility of complying with the statutory low-altitude requirements in order to justify a less stringent standard. EPA's Motor Vehicle Emissions Laboratory has not received any comments from manufacturers of waivered vehicles stating that compliance with the 11 g/mi CO standard at high altitude would be technically difficult or that unique emission control hardware would be required beyond that needed to comply with the current proportional CO standard of 7.8 g/mi for unwaivered vehicles.

Of course this is not conclusive evidence that all 1984 and later vehicles will comply with an 11 g/mi CO standard using essentially the same control hardware as would be needed for compliance with a 16 g/mi CO standard. For example, it is possible that some vehicles equipped with nonfeedback (open-loop) emission controls systems using pulse air injection systems (PAIR) may have more difficulty meeting an 11 g/mi CO standard than a 16 g/mi CO standard because the effectiveness of the PAIR system may be degraded by the lower air density at higher elevations, as previously discussed. However, this problem is only speculative at this time. On the other hand, it is possible that any vehicle having greater difficulty in meeting the more stringent 11 g/mi CO standard may be eligible for exemption from the high-altitude certification requirements.

The above discussion illustrates that uncertainities regarding the requisite control hardware remain to be resolved. Based on the best available evidence, however, it is EPA's judgment that for the vast majority of 1984 and later high-altitude vehicles, meeting an 11 g/mi CO standard will not be significantly more difficult than complying with the current proportional standard for 1982 and 1983 vehicles and, hence, essentially the same control hardware should be required.

The emission control hardware for nonfeedback (open-loop) LDGVs complying with fixed-point proportional standards (the base scenario) was previously estimated in Chapter III. Since LDGVs complying with the revised proportional standards (the revised base scenario) are assumed to utilize the same control hardware, the estimates in Table III-4 are applicable to this analysis also. The information in that table, reproduced here in Table XI-2, shows that nonfeedback LDGVs are expected to require recalibrating and the addition of one fixed-step aneroid to the engine's fuel metering system. An aneroid is a simple mechanical device which senses changes in atmospheric pressure and properly adjusts the fuel/air ratio entering the engine's combustion chambers. This device is used on a high-altitude vehicle to prevent excessively lean fuel/air ratios which may cause engine damage if these vehicles are driven at lower elevations. (Chapter III contains a detailed discussion of this natural phenomenon.) No change to the evaporative emission system is required to comply with the proportional standard.

The requisite control technology for LDDVs was previously estimated in Chapter VIII for the base scenario. Compliance with proportional standards are expected to require limiting the maximum fuel rate and possibly a change in fuel injection timing (Table XI-2). Both of these involve physical adjustments to existing hardware.

C. Revised Scenario 2 Control Hardware

The procedure used to assess emission control requirements for the revised statutory standards in this section is similar to that already presented for the revised proportional standards.

Table XI-2

High-Altitude Emission
Control Hardware for the Revised Control Scenarios

Revised Scenario	Vehicle	Control Hardware Description	Fleet Affected
Base	LDGV	1 aneroid	100%
	LDDV	Limit maximum fuel rate	100%
		Possible fuel injection timing change	100%
Scenario 2	LDGV	3 aneroids	100%
		AIR system replacing PAIR system	40%
		Larger evaporative cannister	100%
	LDDV	Limit maximum fuel rate	100%
		Fuel injection timing change	100%

Like the proportional standards, complying with the revised statutory standards at low and high altitude is expected to require essentially the same control hardware as estimated in previous chapters for meeting the current statutory standards because of their similarity. In Chapter III, EPA estimated that nonfeedback LDGVs are expected to utilize additional recalibrations and two aneroids in addition to the one aneroid that will be required in the base scenario for a total of three (Table XI-2). The additional aneroids will control engine parameters such as the power enrichment circuit of the carburetor, EGR rate, or air injection rate. As alluded to earlier, aneroids ensure proper engine operation if a high-altitude vehicle is driven at lower elevations. As before, the relevant question is: Will these control techniques retain their effectiveness even though the basic emission control systems that are currently in use will change if the standards are revised upward?

Removal of the reduction catalyst should not significantly change the emission control techniques that were identified above. Even with a reduction catalyst, any modifications made for high-altitude NOx control will focus on the engine since changes to the catalyst system (e.g., increased noble metal loading) are uneconomical. These engine-related modifications (e.g., EGR and timing) will attempt to maintain high-altitude engine-out NOx emissions at low-altitude levels, since any increase in engine-out levels would result in some increase out of the catalyst. This normally would be unacceptable if increased NOx levels from the catalyst jeopardized complying with the emission standard at high altitude. However, the presence of the reduction catalyst could give some added flexibility since a moderate increase in engine-out NOx levels should be reduced to a much smaller increase by the catalyst.

In cases where there is a significant margin available at low altitude for increased NOx emissions, the small increase seen after the catalyst may be acceptable where the larger increase occurring in front of the catalyst would not be. In these cases, the removal of the catalyst could require the addition of more EGR under revised low-altitude standards to meet the high-altitude standards than would be needed for the same high-altitude control under the current low-altitude standards. However, these cases should arise very infrequently and the absolute increase in EGR and any resulting fuel economy effect should be quite small, if measurable at all. Thus, removal of the reduction catalyst should not have any significant negative impact on the fleet's fuel economy average.

To comply with revised statutory standards, manufacturers are expected to replace currently used air pump injection systems with PAIR systems on many gasoline-fueled vehicles. As previously stated, the effectiveness of air injection systems at higher elevations may be degraded because of the accompanying reduced air densities. While air pump systems have the ability to regain their effectiveness by increasing the amount of oxygen available to the catalyst, PAIR systems are not as flexible and may not have this capability.

Under revised proportional standards this should present no significant difficulty to manufacturers because modifying the air pump at high altitude would only provide a small emissions benefit which could be offset by more carefully recalibrating other engine control parameters when PAIR is used as a replacement. However, complying with statutory standards for some vehicles may require that all engine parameters be completely optimized for low emissions. If this is the case, even the small loss in effectiveness caused by the use of PAIR instead of AIR may not be recoverable since further optimization of other parameters may be impossible. Therefore, the lost effectiveness of the PAIR may only be recoverable by replacing such systems with mechanically-driven air pumps as part of the high-altitude modification. Although the extent of this possible replacement is unknown, to be conservative EPA will assume that all vehicles equipped with PAIR in the revised base scenario 2 will have the systems replaced with AIR to meet the more stringent requirements in the revised scenario 2. This affects 40 percent of the LDGVs (Table XI-2. Complying with the statutory evaporative HC standard at high altitude is expected to require a larger evaporative emission storage capacity. One way to accomplish this is to increase the charcoal loading of the existing storage cannister (Table XI-2).

There is very little that can be done to diesel engines to reduce high-altitude emissions other than carefully controlling the fuel injection. Of course, more exotic forms of control are available such as turbocharging, but that has been ruled out in this analysis because of its excessive cost. In essence then, the statutory levels of this scenario will have to be achieved by further limiting the maximum fuel rate for low emissions beyond that already required to meet the proportional levels in the revised base scenario, and also by recalibrating the fuel injection timing. This should be sufficient to bring most LDDVs into compliance. The reason for this optimism is that there should be little or no EGR use at the 1.5-2.0 NOx control level which could otherwise exacerbate HC and CO emissions at higher elevations by reducing the oxygen which is available to support combustion in the engine's cylinders, as may be the case under the current NOx standard of 1.0 g/mi. (Chapter IX contains a more detailed explanation of this phenomenon.) Of course, some LDDVs may be difficult to control to statutory levels but this problem should be mitigated by providing more exemptions than in the revised base scenario.

The control technology for each revised scenario is summarized in Table XI-2.

IV. ECONOMIC IMPACT

This section analyzes the economic impact of implementing the revised scenario 2 (i.e., fixed-point statutory standards with revised levels), rather than continuing with a form of the base scenario (i.e., fixed-point proportional standards with revised levels). The incremental cost analysis is composed of four distinct parts: 1) manufacturing costs, 2) consumer user costs, 3) total national or aggregate costs, and 4) socioeconomic impact.

The first three parts deal directly with the incremental costs that are associated with modifying LDVs to achieve the revised statutory standards at high altitude. These incremental costs are defined as the differences between the costs associated with modifying vehicles to comply with the proportional standards in the revised base scenario and those associated with modifying vehicles to meet the statutory standards in the revised scenario 2. The fourth part deals with the effect that higher purchase prices may have on high-altitude vehicle sales.

This analysis uses the same basic methodology as previously documented in Chapter V. To avoid needless repetition, the detailed explanation in that chapter will not be repeated here. Instead, this section will include only general descriptions of the methodology as needed. For a more complete discussion of the analytical techniques, Chapter V should be consulted.

A. Costs to Manufacturers

Manufacturing costs can be separated into two categories: variable and fixed. Each of these cost categories are discussed below.

1. Variable Costs

This category includes all of the cost components which contribute to the incremental purchase price of a high-altitude vehicle except for the cost of development and certification which is regarded as a fixed cost. Variable costs are presented in terms of the retail price equivalent (RPE) and presume that the emission control hardware is added to the vehicle on the assembly line. These costs are estimated separately for LDGVs and LDDVs.

The incremental emission control technology which will be needed by LDGVs to meet the statutory levels of the revised scenario 2 was previously estimated to include the addition of: 1) two fixed-step aneroids on 100 percent of the vehicles, 2) the replacement of the normally used pulse air injection system (PAIR) with an air pump injection system (AIR) on 40 percent of the vehicles, and 3) the use of a larger evaporative emission storage cannister on 100 percent of the vehicles.

The RPE for two aneroids was estimated in Chapter V to be approximately $14 to $18 dollars. The unit cost for replacing the PAIR system with the AIR system as original equipment can be estimated by following the methodology contained in Chapter V and using the cost information contained in an EPA report by Lindgren.[6] The cost of the AIR system is computed to be about $40 per unit.

No adjustment is necessary to reflect the small production volume of these units for high-altitude sales, as was done for aneroids, since the economy of scale has already been achieved by using the same equipment on about 60 percent of the low-altitude sales volume. The PAIR system which would normally cost about $6 will not be used, so this expense is credited toward the cost of the high-altitude modification. The RPE of adding an air pump to a vehicle as original equipment is, therefore, the cost of the AIR system ($40) minus the cost of the PAIR system ($6) or about $34 in 1981 dollars. The RPE for increasing the vehicle's evaporative emission storage capacity was estimated in Chapter V to be about $2 to $3 and would be the same here.

The RPE for the average high-altitude LDGV is sum of the sales-weighted costs for the various hardware items. Aneroids are expected to be installed in 100 percent of the high-altitude vehicles so its sales-weighted cost is $14 to $18 per LDGV (1.00 x $14 to $18). AIR systems will very likely be required on 40 percent of the high-altitude vehicles so its sales-weighted cost is $14 per vehicle (0.40 x $34). A larger evaporative storage capacity is estimated to be required by 100 percent of the high-altitude vehicles so its sales-weighted cost is $2 to $3 per vehicle (1.00 x $2 to $3). By adding these sales-weighted costs, the incremental RPE for the average high-altitude LDGV is $30-$35.

The emission control technology that will be needed by LDDVs to comply with the requirements of the revised scenario 2 was previously estimated to include adjusting both the maximum fuel limiter and the fuel injection timing. Thus, no added hardware should be required. These adjustments are easily performed on the assembly line and so there should be little or no measurable increase in the RPE of a high-altitude LDDV.

2. <u>Fixed Costs</u>

Based on the analysis in Chapter V, two categories of fixed costs may be affected by complying with statutory versus proportional standards at high altitude: development and certification. That chapter concluded that increases would occur in both cost categories. However, this would not be true when both the low-altitude and high-altitude standards are changing in both the statutory and proportional cases which would be the situation here.

This analysis assumes that the revised base scenario could be implemented in 1984. Since this scenario has different standards (0.57 g/mi HC, 11 g/mi CO, and 1.5-2.0 g/mi NOx) than the present proportional standards (0.57 g/mi HC, 7.8 g/mi CO, and 1.0 g/mi NOx), the automotive fleet would have to be redeveloped and then recertified if the revised base scenario were adopted. Furthermore, there should be essentially no difference in the cost of development and certification for either proportional or statutory high-altitude standards, as discussed further in Appendix III. Because of this, the fixed cost increment of implementing the revised scenario 2 in 1984 is zero since the expenditures for development and certification would already have to be made.

B. Cost to Users

The incremental cost to users of high-altitude vehicles is composed of the initial increase in purchase price and the change in fuel economy and maintenance expenditures which accrue during the life of the vehicle. Complying with the revised scenario 2 will increase the purchase price of an average LDGV by $30 to $35. For an LDDV, there should be no increase in purchase price as a result of complying with the revised scenario 2. Stated as an average for all LDVs, the sticker price increase will be about $25 to $30 based on the sales data previously discussed in Chapter IV (represented in Table XI-3).

A fuel economy benefit is expected from the additional recalibration allowed by the use of two additional aneroids at high altitude to comply with statutory standards. In Chapter V this benefit was calculated to be $80 if discounted over the life of the vehicle (present value in 1981 dollars). It is assumed that this fuel economy improvement also applies in this chapter because the same emission control strategy (e.g., leaning the fuel/air ratio) will be used to comply with both the current statutory and revised statutory standards at high altitude. The fuel savings should occur for every high-altitude LDGV built in compliance with the revised scenario 2, since each vehicle is assumed to be equipped with the two additional aneroids.

The change in fuel economy that may accompany the use of an AIR system on some high-altitude vehicles that otherwise would not require it is less clear. The air pump is mechanically driven by the vehicle's engine and, hence, absorbs some power that is then not available to power the vehicle. Adding an air pump can, therefore, result in a fuel economy loss. Often, however, when an AIR system is used at

Table XII-3

High-Altitude Sales Projections
of Light-Duty Vehicles
(thousands of vehicles)

Year	Gasoline-Fueled	Diesel-Powered
1984	293	30
1985	287	36
1986	276	45
1987	265	53
1988	262	56
5-Year Total	1,383	220

low-altitude, the settings of certain engine parameters which may have been compromised for emission control purposes can be optimized for better fuel economy because of the added flexibility provided by more air being available to the catalyst. If an AIR system is used in this manner, no fuel economy change may be observed.

The question then is: Will manufacturers recalibrate high-altitude vehicles requiring the addition of an air pump for optimum fuel economy? The answer is unknown at this time. It is possible that manufacturers will not take the opportunity to optimize these sytems because of the small high-altitude market (only 3 to 4 percent of the total). Because of this possibility, a worst case will be assumed in this analysis where the benefit of using aneroids is offset by the potential penalty of using AIR systems as part of a high-altitude modification. This fuel economy offset affects 40 percent of the high-altitude vehicles. Therefore, the fuel economy benefit of $80 for the revised scenario 2 will only apply to 60 percent of the high-altitude LDGVs. Thus, the fuel savings for the average LDGV is $48 (0.60 x $80). No fuel economy increment was found in Chapter X for LDDVs complying with the statutory standards and there is no reason to expect this to change with a revision of the low-altitude standards. Thus, none is included in this chapter.

No increment in maintenance costs are expected to occur as a result of implementing the revised scenario 2. Aneroids should not require maintenance during the life of the vehicle (Chapter VI). The possibility that AIR systems may require maintenance was explored in a recent rulemaking action and the conclusion was that any increment would be insignificant.[7] Therefore, the maintenance costs of the revised statutory standards should be zero.

The net cost to users, then, is the purchase price increase, less any fuel economy benefit. For LDGVs, the fuel economy benefit ($48) overwhelms the initial purchase price increase ($30 to $35) and results in a net <u>savings</u> to the consumer of $13 to $18. For LDDVs, the net cost is zero since there are no changes in purchase price, fuel economy or maintenance. Stated as an average for all LDVs, the overall net <u>savings</u> is $11 to $15.

It is apparent that the fuel economy increment for LDGVs dominates the results of the cost analysis. Therefore, the predicted fuel economy gain deserves to be discussed in greater detail before proceeding. In Chapter VII, this topic was explored and the conclusions from that chapter should apply here as well. The fuel economy increment associated with the use of two aneroids is based on a very limited amount of test data. Because of this, the estimated effects on fuel economy should be used with some caution and must be carefully reevaluated as additional information becomes available.

The analysis of statutory high-altitude LDV standards in this chapter is even more sensitive to the estimated fuel savings than in previous chapters. This is accounted for by the change in emission control technology that is expected to be used to comply with either the current statutory standards (scenario 2 in the previous chapters) or the revised statutory standards (the revised scenario 2 in this chapter). More than twice as many vehicles are assumed to experience a fuel economy benefit in this chapter than in previous chapters. By virtue of this great sensitivity, the fuel benefit must be used with discretion in this analysis.

Therefore, the uncertainty in the fuel economy benefit for vehicles that use two additional aneroids and do not incur the possible fuel economy offset from adding an air pump as part of their high-altitude modification (60 percent of the LDGV fleet) will be accounted for in the remainder of the analysis by using a fuel savings range of $0 to $60. The cost to users of high-altitude vehicles is restated as follows using this range as a basis for the calculation. For the average LDGV the overall net cost is -$18 to $35. The net cost for the average LDDV remains unchanged at $0. The average net cost for all LDVs is -$15 to $30.

C. Aggregate Cost to the Nation

The aggregate cost to the nation is defined as the present value of the incremental costs of implementing the revised scenario 2 for the first five years (i.e., 1984 through 1988). For this time period, the LDV production volumes were previously discussed in Chapter IV, and are presented in Table XI-3. Using these sales projections and the costs as discussed above, the 5-year aggregate cost is $32 to $40 million if no fuel economy benefit is assumed and -$15 to -$23 million if a fuel economy savings is assumed (Table XI-4).

D. Socioeconomic Impact

The incremental purchase price for the average high-altitude LDV was found to be about $30. As part of the 1982 and 1983 interim high-altitude rulemaking, the impact of a $42 price increase was reviewed and it was concluded that such an increase should not affect a dealer's sales or a consumer's ability to purchase a vehicle.[2] Since the price increment that was estimated in this chapter ($30) is less than the increment analyzed in the interim rulemaking ($42), this conclusion also should be true for the revised scenario 2. Thus, the sticker price increase for vehicles built on the assembly line should not unduly affect high-altitude sales.

Table XI-4

Summary of Costs for a Combined Fleet of LDGV and LDDV Under the Revised Scenarios

Case	Average Hardware Per Vehicle	Development Per Vehicle	Certification Per Vehicle	Average Fuel Economy Increment Per Vehicle	Average Net Total Per Vehicle	Capital Costs to Manufacturers	5-Year Aggregate Costs[a] (millions)
With Fuel Economy Benefit	$25-30	$0	$0	$0	$25 to 30	$0	$32 to 40
Without Fuel Economy Benefit	$25-30	$0	$0	-$41	-$15 to -11	$0	-$23 to -15

[a] Present value in 1984.

There is one aspect of the revised scenario 2 that may have a significant negative impact on the ability of low- and high-altitude dealers to trade new vehicles among themselves. As discussed in the technology section of this chapter, EPA has made a worst case assumption that 40 percent of the high-altitude fleet may require the addition of an AIR system to meet the statutory standards in the revised scenario 2. If this is indeed true, and there is no data at this time to prove or disprove the assumption, these particular vehicles may be prohibitively expensive to modify from a low-altitude configuration to a high-altitude configuration after production. Replacing the PAIR system with an AIR system on a vehicle after it is originally built could cost over $150. When this cost is added to the others (e.g., changing the carburetor), modifications may be quite expensive for certain vehicles. However, more data is needed before a final judgment on this issue can be made.

V. ENVIRONMENTAL IMPACT

This section discusses two basic measures of environmental impact. The first measure simply involves estimating the emission reductions resulting from implementing the revised scenario 2 which should accrue beyond those expected by continuing proportional standards under the revised base scenario. These overall reductions in HC, CO, and NOx emissions are used primarily to determine the incremental cost effectiveness of the revised scenario 2. The second measure of environmental impact is an air quality modeling analysis which projects the effect of the revised scenarios on high-altitude air quality. These models are valuable aid evaluating the ability of high-altitude Air Quality Control Regions (AQCRs) to achieve and maintain compliance with the National Ambient Air Quality Standards (NAAQS).

To avoid needless repetition of detail in this chapter, the methodology for determining both the total emissions and the air quality consequences will not be specifically presented. Instead only a general description will be provided. More specific information is available in Chapter IV which contains the environmental impact analysis of the high-altitude control scenarios that correspond to the current low-altitude standards.

A. Total Emissions

The incremental emissions benefit of implementing the revised scenario 2 over continuing the proportional standards of the revised base scenario is found by determining the total emissions for each scenario and then taking their difference. The gaseous and evaporative emission factors which are used to calculate the total high-altitude emissions are shown in Table XI-5.

Table XI-5

Emission Rates for 1984-88 Light-Duty
Gasoline-Fueled and Diesel-Fueled Vehicles at 5,300 Feet [a]

Pollutant		Revised Base Scenario		Revised Scenario 2	
		LDGV	LDDV	LDGV	LDDV
HC	Zero-Mile Emission Level (g/mi)	0.36	0.54	0.26	0.39
	Deterioration Rate (g/mi/10,000 miles)	0.23	0.03	0.23	0.03
	50,000-Mile Emission Level (g/mi)	1.51	0.69	1.41	0.54
CO	Zero-Mile Emission Level (g/mi)	5.63	2.22	3.58	2.22
	Deterioration Rate (g/mi/10,000 miles)	1.92	0.05	1.92	0.05
	50,000-Mile Emission Level (g/mi)	15.23	2.47	13.18	2.47
NOx	Zero-Mile Emission Level (g/mi)	0.95-1.27	1.11-1.49	0.95-1.27	1.11-1.49
	Deterioration Rate (g/mi/10,000 miles)	0.09-0.08	0.06	0.09-0.08	0.06
	50,000-Mile Emission Level (g/mi)[b]	1.4-1.67	1.41-1.79	1.4-1.67	1.41-1.79

Table XI-5 (cont'd)

Emission Rates for 1984-88 Light-Duty
Gasoline-Fueled and Diesel-Fueled Vehicles at 5,300 Feet [a]

Pollutant		Revised Base Scenario LDGV	Revised Base Scenario LDDV	Revised Scenario 2 LDGV	Revised Scenario 2 LDDV
Evap. HC	Zero-Mile Emission Level (g/mi)	0.13	--	0.10	--
	Deterioration Rate (g/mi/10,000 miles)	0	--	0	--
	50,000-Mile Emission Level (g/mi)	0.13	--	0.10	--

[a] Emission Rate = ZML + (M) (DR)
Where: ZML = Zero-Mile Level
M = Cummulative Mileage/10,000
DR = Deterioration Rate

[b] The 1.4 and 1.41 g/mi levels reflect a 1.5 g/mi NOx standard, while the 1.67 and 1.79 g/mi levels reflect a 2.0 g/mi NOx standard.

The total emissions and incremental benefit of the two scenarios are shown in Table XI-6 for LDVs produced during the first five years of the standards (i.e., 1984 through 1988). Implementing the revised scenario 2 should result in an incremental benefit of about 20,000 metric tons of HC, and 283,000 metric tons of CO. Of these totals, LDGVs account for about 85 percent of the HC reductions and 100 percent of the CO reductions.

B. Air Quality

This section reviews the air quality effects of high-altitude automotive emission control strategies that are based on revised low-altitude standards. This review will be conducted in three parts. First, the incremental air quality benefits of implementing the revised statutory standards instead of the revised proportional standards will be addressed. Second, the need or justification for the more stringent revised statutory standards will be discussed. Third, the impact of revising the low-altitude standards on high-altitude air quality will be reviewed. After these parts are presented, they will be summarized and conclusions regarding the need for more stringent automotive standards will be made.

The air quality projections in this section are based on the use of computer models that were easily applicable to all high-altitude areas. The reader is cautioned that such computer studies utilize a variety of assumptions in an attempt to forecast the events which will affect air pollution levels in the future. As with any projections of this type, some of the assumptions may prove to be invalid as better information becomes available. Also, due to time and resource constraints, many input data were national averages and not site-specific values. Therefore, the modeling results are most useful for determining the differences between control scenarios, while the absolute values associated with any single strategy are subject to greater error.

1. Incremental Effects

The air quality effects on each pollutant are discussed separately based on Tables XI-7 through XI-10. Nitrogen oxides (NOx) are not addressed here because there is no difference in the emission rates associated with the two revised control scenarios (Table XI-6). Hence, there would be no difference in the modeling results.

For ozone, Table XI-7 shows that under high-growth cases with inspection/maintenance (I/M) and both low- and high-growth cases without I/M, implementing the revised scenario 2 is projected to provide only a one percent improvement in the ambient concentration for a few of the years. The results are

Table XI-6

Lifetime Emissions from 1984-88 LDVs
Sold Above 4,000 Feet
(10^3 metric tons)

Pollutant	Revised Base Scenario		Revised Scenario 2		Reductions (Base Scenario minus Scenario 2)		
	LDGV	LDDV	LDGV	LDDV	LDGV	LDDV	Total
HC	208	15	195	12	13	3	16
CO	2,102	54	1,819	54	283	0	283
NOx	193-230	31-39	193-230	31-39	0	0	0
Evap. HC	17.9	0	13.8	0	4.1	0	4.1
Total HC	226	15	209	12	17	3	20

Table XI-7

Average Percent Reduction in Expected
Maximum 1-Hour Ozone Concentrations from 1979 Base
Year in Denver and Salt Lake City (low and high growth)[a]

With Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	24-32	22-28	26-34	23-30	27-35	24-31	28-36	24-32	28-37	24-32	28-36	24-31	27-35	22-29
Revised #2	24-32	22-28	26-34	23-30	27-35	24-31	28-36	24-32	28-37	24-33	28-36	24-31	27-36	23-30

Without Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	20-27	18-23	22-29	19-25	23-30	20-26	24-31	20-27	24-32	21-28	25-33	21-27	25-32	20-26
Revised #2	21-27	18-24	22-29	19-25	23-30	20-26	24-32	21-27	25-33	21-28	25-34	21-28	25-33	20-26

[a] Note that a range of values is reported here to reflect two different ratios of HC/NOx ambient concentrations, as discussed in Chapter IV. Results from the higher ratio are reported first.

Table XII-8

Number of Violations of Ozone NAAQS in
Denver and Salt Lake City (low and high growth)[a]

With Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-2
Revised #2	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1

Without Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	1-2	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	1-2
Revised #2	0-2	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	0-2	0-1	1-2	0-1	1-2

[a] Note that a range of values is reported here to reflect two different ratios of HC/NOx ambient concentrations, as discussed in Chapter IV. Results from the lower ratio are reported first.

Table XI-9

Average Percent Reduction in Expected
Second Highest 8-Hour CO Concentrations from 1979
Base Year in Six High-Altitude Cities (low and high growth)[a]

With Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	55	48	60	54	65	58	68	61	71	65	76	69	78	71
Revised #2	55	49	61	55	65	58	69	63	72	65	77	70	79	72

Without Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	46	38	51	43	56	48	60	52	64	56	71	62	73	64
Revised #2	46	38	52	44	57	48	61	53	65	57	72	63	74	65

[a] The cites investigated are Denver, Colorado Springs, Ft. Collins, Greeley, Albuquerque, and Salt Lake City.

Table XI-10

Number of Violations of CO NAAQS in
Six High-Altitude Cities (low and high growth)[a]

With Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	7	18	2	8	0	3	0	1	0	0	0	0	0	0
Revised #2	7	16	2	7	0	3	0	1	0	0	0	0	0	0

Without Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	20	43	10	26	3	16	1	8	0	3	0	0	0	0
Revised #2	20	43	9	24	3	14	0	5	0	2	0	0	0	0

[a] The cites investigated are Denver, Colorado Springs, Ft. Collins, Greeley, Albuquerque, and Salt Lake City.

somewhat similar for the projected number of National Ambient Air Quality Standard (NAAQS) violations for ozone. Table XI-8 shows that the revised scenario could produce one less violation in 1995 at high-growth rates with I/M. Without I/M there is a potential for one less violation in 1986 under low-growth and in 1990 under high growth.

Table XI-9 shows that the revised scenario 2 could reduce the ambient concentration of CO by 1 to 2 percent in most years under both high- and low-growth rates, with or without I/M. Some reductions in the number of CO NAAQS violations are associated with these reduced emission levels as shown in Table XI-10. Without I/M, two fewer violations are projected in 1987 and 1988, three less in 1989, and one less in 1990 under high-growth conditions. Under low-growth conditions, one less violation is observed in 1987 and 1989. With I/M, two fewer violations are projected in 1986 and one less in 1987 under high-growth conditions. For the low-growth case no differences are observed.

2. Air Quality Needs

The justification for greater emission reductions at high altitude can be evaluated by reviewing the projected dates of compliance with the NAAQS. This will show whether high-altitude areas should be in compliance by the 1987 statutory deadline and whether the implementation of the revised scenario 2 could help attain the NAAQS sooner. As before, the two pollutants of interest, HC and CO, will be reviewed separately.

From Table XI-8, it is clear that although the number of ozone NAAQS violations is small, there is a possibility that the standard could never be attained by all high-altitude areas under any of the cases studied. Therefore, although the HC emission reductions associated with implementing revised statutory standards will not by themselves guarantee attainment of the ozone NAAQS, they may be needed along with reductions from other sources to assure compliance with the ambient standard in all high-altitude areas. Certainly, the additional control of some HC sources in high-altitude areas will be necessary for the ozone NAAQS to be attained if these projections are accurate.

Attainment dates for the CO NAAQS are more variable (Table XI-10). Without I/M, attainment by all high-altitude areas is project to occur two years beyond the statutory deadline in 1989 with low-growth rates under the revised scenario 2. Without it, compliance could be delayed until 1990. When high-growth rates are assumed, attainment could occur sometime in the early 1990's under both revised scenarios. With I/M, the effects are similar to the without I/M case except that all of the attainment dates are earlier. Attainment is predicted by 1988 with low-growth rates and by 1990 with high-growth rates, under both revised scenarios. Thus, implementing more stringent standards appears to make no difference. Therefore, statutory standards may only be effective in helping to attain the CO NAAQS sooner in the absence of I/M. Implementing these automotive standards alone, however, may not be adequate to achieve the 1987 statutory deadline in any of the cases analyzed.

As mentioned throughout this report, any conclusions based on the absolute number of projected NAAQS violations must be conditional due to the potential errors involved. Only further study of those areas just in or out of compliance with the NAAQS will yield firm conclusions in this area.

3. Comparison of Air Quality Under "Revised" Standards and "Current" Standards

The air quality effects of adopting high-altitude standards that are based on revised low-altitude standards ("revised" scenarios) versus high-altitude standards that are based on the current low-altitude standards ("previous" scenarios) can be reviewed by comparing the information presented in this chapter to that previously presented in Chapter IV (Tables XI-11 through 14). Such a comparison shows that there is no significant difference for ozone between the two general types of standards (revised versus current). This is to be expected since the emission standards for HC are the same for the respective statutory (0.41 g/mi) and base (0.57 g/mi) control scenarios.

The same conclusion can be reached for CO with I/M, that is, there is no difference between the number of violations under the two types of standards (revised base versus current base and revised scenario 2 versus current scenario 2). Without I/M, however, the number of CO NAAQS violations under the scenarios based on revised standards is generally less than that under the previous scenarios based on current standards. Looking at the NAAQS attainment dates rather than the number of NAAQS violations, no difference between the two types of standards is evident regardless of whether or not I/M is implemented.

These results for CO appear surprising at first glance. It seems unreasonable for the generally less stringent standards of the revised scenarios to provide greater air quality benefits than are associated with the scenarios that are based upon current standards. However, this difference can be explained by recalling the discussion in Chapter IV which pointed out that many manufacturers are using computerized feedback emission control systems to comply with the current statutory standards. These systems currently exhibit a significant rate of catastrophic failure. The CO emissions from vehicles with such failed systems are very high which in

Table XI-11

Average Percent Reduction in Expected
Maximum 1-Hour Ozone Concentrations from 1979
Base Year in Denver and Salt Lake City (low and high growth)[a]

With Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	24-32	22-28	26-34	23-30	27-35	24-31	28-36	24-32	28-37	24-32	28-36	24-31	27-35	22-29
Revised #2	24-32	22-28	26-34	23-30	27-35	24-31	28-36	24-32	28-37	24-33	28-36	24-31	27-36	23-30
Previous Base	24-32	22-28	26-34	23-30	27-35	24-32	28-36	25-32	29-37	25-33	29-38	25-32	28-36	24-31
Previous #2	24-32	22-29	26-34	23-30	27-35	24-32	28-36	25-32	29-37	25-33	29-38	25-33	28-37	24-31

Without Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	20-27	18-23	22-29	19-25	23-30	20-26	24-31	20-27	24-32	21-28	25-33	21-27	25-32	20-26
Revised #2	21-27	18-24	22-29	19-25	23-30	20-26	24-32	21-27	25-33	21-28	25-34	21-28	25-33	20-26
Previous Base	21-27	18-24	22-29	19-25	24-31	20-27	24-32	22-28	25-33	22-28	26-34	22-29	26-34	21-28
Previous #2	21-27	18-24	22-29	19-25	24-31	20-27	25-32	22-29	25-34	22-29	26-35	22-29	26-35	21-28

[a] Note that a range of values is reported here to reflect two different ratios of HC/NOx ambient concentrations, as discussed in Chapter IV. Results from the higher ratio are reported first.

Table XI-12

Number of Violations of Ozone NAAQS in
Denver and Salt Lake City (low and high growth)[a]

With Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-2
Revised #2	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1
Previous Base	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-0	0-1	0-0	0-1	0-1	0-1
Previous #2	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-0	0-1	0-0	0-1	0-1	0-1

Without Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	1-2	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	1-2
Revised #2	0-2	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	0-2	0-1	1-2	0-1	1-2
Previous Base	0-2	1-2	0-1	1-2	0-1	1-2	0-1	1-2	0-1	0-2	0-1	0-2	0-1	1-2
Previous #2	0-2	1-2	0-1	1-2	0-1	1-2	0-1	0-2	0-1	0-1	0-1	0-2	0-1	1-2

[a] Note that a range of values is reported here to reflect two different ratios of HC/NOx ambient concentrations, as discussed in Chapter IV. Results from the lower ratio are reported first.

Table XI-13

Average Percent Reduction in Expected
Second Highest 8-Hour CO Concentrations from 1979
Base Year in Six High-Altitude Cities (low and high growth)[a]

With Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	55	48	60	54	65	58	68	61	71	65	76	68	78	71
Revised #2	55	49	61	55	65	58	69	63	72	65	77	70	79	72
Previous Base	55	48	60	54	64	58	68	61	71	65	76	69	78	70
Previous #2	55	49	61	55	66	59	69	63	72	65	77	71	80	73

Without Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	46	38	51	43	56	48	60	52	64	56	71	62	73	64
Revised #2	46	38	52	44	57	48	61	53	65	57	72	63	74	65
Previous Base	45	37	51	42	55	47	60	51	63	54	70	61	72	62
Previous #2	46	38	51	43	57	48	61	53	64	56	71	62	74	65

[a] The cites investigated are Denver, Colorado Springs, Ft. Collins, Greeley, Albuquerque, and Salt Lake City.

Table XI-14

Number of Violations of CO NAAQS in
Six High-Altitude Cities (low and high growth)[a]

With Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	7	18	2	8	0	3	0	1	0	0	0	0	0	0
Revised #2	7	16	2	7	0	3	0	1	0	0	0	0	0	0
Previous Base	7	18	2	8	0	3	0	1	0	0	0	0	0	0
Previous #2	7	16	2	7	0	3	0	1	0	0	0	0	0	0

Without Inspection/Maintenance

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Base	20	43	10	26	3	16	1	8	0	3	0	0	0	0
Revised #2	20	43	9	24	3	14	0	5	0	2	0	0	0	0
Previous Base	21	43	10	28	3	17	1	9	0	4	0	0	0	0
Previous #2	20	43	10	26	3	14	0	8	0	3	0	0	0	0

[a] The cites investigated are Denver, Colorado Springs, Ft. Collins, Greeley, Albuquerque, and Salt Lake City.

turn causes the average in-use emissions from this type of vehicle to be much higher than would be expected based on the standard it is certified to meet.

Under the revised standards, which are being analyzed in this chapter, manufacturers are expected to comply with the less stringent emission control requirements by using nonfeedback systems. These systems do not exhibit the catastrophic failures associated with current feedback systems. Therefore, nonfeedback systems have lower average in-use emissions despite the equivalent or higher emission standards to which they are certified. This explains why the modeling results generally show better air quality results under the scenarios with "revised" standards when the benefits of I/M are excluded. Of course, it was also pointed out in Chapter IV that the in-use catastrophic failure rates that are now exhibited by feedback systems may be significantly reduced in the future as more experience with these new systems is gained. If this reduction takes place, the trend now shown in the analysis may be reversed so that the high-altitude scenarios based on current low-altitude standards show better air quality results than the control scenarios based on revised low-altitude standards.

Although the impact of the high-altitude NOx standards was not relevant to the preceding air quality discussions, it is important here, since under the current standards the allowable level is 1.0 g/mi and under the revised standards the level may be 1.5 to 2.0 g/mi. Tables XI-15 and 16 contain both the results for the "previous" scenarios (based on current standards) and those for the "revised" scenarios (based on revised standards). Table XI-15 shows that the ambient NOx concentrations are projected to be greater under the revised scenarios. Table XI-16 shows, however, that when high-growth rates are assumed, the NOx NAAQS may never be attained in Denver beyond 1987 by either set of scenarios. For low-growth rates, violations could begin in the early 1990's under the revised scenarios and in the mid-1990's if the previous scenarios are implemented. Regardless of the growth rates, the trend is toward an increase in violations near the end of this century, although the actual number of violations is small.

4. Conclusions of the Air Quality Analysis

There appears to be a small incremental benefit in ozone and CO air quality associated with controlling automotive emissions beyond the levels prescribed by the revised base scenario under some of the cases analyzed. In other cases, there appears to be no significant difference between the revised base scenario and the revised scenario 2. The current air quality modeling studies indicate that additional emission control may be needed beyond the levels of the revised base scenario since all high-altitude areas may not attain the NAAQS by the 1987 statutory deadline. However, further study would

Table XI-15

Average Percent Increase in Expected NOx
Concentrations in Denver (low and high growth)[a]

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Scenarios	2	10	4	14	6	16	8	20	10	24	16	35	20	43
Previous Scenarios	0	8	2	10	2	12	4	16	4	18	8	27	12	35

[a] Note that this table reflects increases in pollutant concentrations rather than reductions as was the convention for earlier tables on CO and ozone.

Table XI-16

Number of Violations of NOx NAAQS in Denver (low and high growth)

	1986		1987		1988		1989		1990		1993		1995	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Revised Scenarios	0	0	0	1	0	1	0	1	0	1	1	1	1	1
Previous Scenarios	0	0	0	0	0	1	0	1	0	1	0	1	1	1

be needed to firmly make this conclusion. Finally, implementing high-altitude standards that are based on revised low-altitude standards rather than retaining the current standards may have a small negative impact on NOx NAAQS violations near the end of this century.

VI. COST EFFECTIVENESS

Cost effectiveness is one measure of the economic efficiency of reducing air pollution. The incremental cost effectiveness of the revised scenario 2 for HC and CO is found by dividing half of the net cost per vehicle by the emission reduction per vehicle for each pollutant. This computation is performed in Table XI-17 for LDGVs, LDDVs, and a combination of the two vehicle types. Controlling HC emissions from LDGVs ranges up to $1,460 per metric ton. Carbon monoxide control for these vehicles ranges up to $85 per metric ton. For LDDVs, controlling both HC and CO costs nothing ($0) per metric ton because no added hardware or fixed costs are involved. When LDGVs and LDDVs are combined into a single control strategy, controlling HC emissions ranges up to $1,250 per metric ton while CO control ranges up to $85 per metric ton.

The wide range of incremental cost-effectiveness values displayed in Table XI-17 for LDGVs and the combination of LDGVs and LDDVs under the revised scenario 2 are caused by the inclusion or exclusion of the estimated fuel economy benefit that may accompany implementation of revised statutory standards at high altitude. The low estimates which include the fuel economy benefit are tenuous at this time because of the uncertainties associated with estimated change in fuel consumption.

In the worst case analyzed (i.e., no fuel economy benefit), scenario 2 is nearly twice as costly per ton of HC than the most expensive control strategy shown in Table XI-18. For CO, it is more comparable to the other strategies. On the other extreme (i.e., inclusion of the fuel economy benefit), the revised scenario 2 is more cost effective than all but one of the other control strategies. Until additional information becomes available with which to more precisely define the cost effectiveness of this scenario, implementing revised statutory standards at high altitude should be considered a viable, but unproven, alternative to the revised base scenario.

VII. SUMMARY

The analysis in this chapter supports the conclusions of the earlier chapters. Statutory standards at high altitude appear to provide a small but real air quality benefit in a potentially cost-effective manner and should be seriously considered in the overall program to reduce pollution in high-altitude areas. Nevertheless, different conclusions are possible under scenarios which assume other revised low-altitude standards.

Table XI-17

Incremental Cost Effectiveness of Revised Scenarios

Vehicle	Cost (dollars per vehicle)[a] Low	Cost (dollars per vehicle)[a] High	Emission Reductions (10^{-3} metric tons per vehicle) HC	Emission Reductions (10^{-3} metric tons per vehicle) CO	Incremental Cost Effectiveness (dollars/metric ton) HC Low	Incremental Cost Effectiveness (dollars/metric ton) HC High	Incremental Cost Effectiveness (dollars/metric ton) CO Low	Incremental Cost Effectiveness (dollars/metric ton) CO High
LDGV	-18	35	12	205	neg.	1,460	neg.	85
LDDV	0	0	14	0	0	0	0	0
LDGV and LDDV	-15	30	12	176	neg.	1,250	neg.	85

[a] The low estimates for gasoline-fueled vehicles are tentative at this time because of the uncertainties associated with the estimated fuel economy benefit.

Table XI-18

Cost-Effectiveness Comparison With Other Emission Control Strategies

Control Program	Baseline Emissions [a]	Emissions After Control Strategy Implemented	Cost Effectiveness HC	Cost Effectiveness CO
LDV Statutory[2]	HC 0.9	HC 0.41	734	67
Standards	CO 15	CO 3.4		
LDV I/M[3]	--	--	640	58
LDT 1984 [4]	HC 1.7	HC 0.8	195	15
Standards	CO 18	CO 10		
HDE 1984	HC 1.5	HC 1.3		
Standards[5][b]	CO 25	CO 15.5		
(gasoline)	HC 1.5	HC 1.3	305	10
	CO 25	CO 15.5		
(diesel)	HC 1.5	HC 1.3	325	--
	CO 25	CO 15.5		
Motorcycle	HC 9	HC 8-22.5 [c]	582	Neg.
Standards[6]	CO 34.67	CO 27.4		
HDG Evap.[7][d]	HC 1.8	HC 0.17	200	
Interim 1982-83	HC 1.47(cars)	HC 1.33(cars)	393	12
HA Standards [8]	4.19(trucks)	3.78(trucks)		
	CO 16.23(cars)	CO 13.21(cars)		
	73.02(trucks)	55.65(trucks)		

[a] Emission levels are in g/mi except for the HDE 1984 standards which are in grams per brake-horsepower-hour.

[b] The baseline and after control strategy emission values were based on different test procedures (see Reference 4 in Chapter VI).

[c] Sliding scale based on engine displacement (cubic centimeters).

[d] The evaporative standard is in terms of g/test and converted to g/mi here to facilitate comparison.

References

1. "Control of Air Pollution from New Motor Vehicles and New Motor Vehicles Engines; Final High-Altitude Emission Standards for 1982 and 1983 Model Year Light-Duty Motor Vehicles," U.S. EPA, 45 FR 66984, October 8, 1980 .

2. "Final Regulatory Analysis - Environmental and Economic Impact Statement for the 1982 and 1983 Model Year High-Altitude Motor Vehicle Emission Standards," U.S. EPA, OANR, OMS, ECTD, SDSB, October 1980.

3. "Update on the Cost Effectiveness of Inspection and Maintenance," U.S. EPA, OANR, OMS, ECTD, IMS, EPA-AA-IMS/81-9, April 1981.

4. "Summary and Analysis of Comments on the Notice of Proposed Rulemaking for High-Altitude Emission Standards for 1982 and 1983 Model Year Light-Duty Motor Vehicles," U.S. EPA, OANR, OMS, ECTD, SDSB, October 1980.

5. "Technical Feasibility of the Proposed 1982-83 High-Altitude Standards for Light-Duty Vehicles and Light-Duty Trucks," CTAB/TA/80-3, U.S. EPA, OANR, OMS, ECTD, SDSB, August 1980.

6. "Motor Vehicle Emission Standards for Carbon Monoxide and Nitrogen Oxides," U.S. EPA, OANR, OMS, ECTD, SDSB, April 1981.

7. "Cost Estimations for Emission Control Related Components/Systems and Cost Methodology Description," Rath and Strong, Inc., Lindgren, Leroy H., EPA-480/3-78-002, March 1978.

8. "Regulatory Analysis and Environmental Impact of Final Emission Regulations for 1984 and Later Model Year Light-Duty Trucks, U.S. EPA, OANR, OMS, ECTD, SDSB, May 1980.

Chapter XII

Conclusions and Recommendations

This report examined various high-altitude control scenarios, based on the current emission standards, for their effects on LDGVs, LDGTs, and LDDs. Generally, the existing proportional high-altitude emission standards for these vehicle classes have proven valuable in cost effectively improving the air quality of high-altitude areas. At a minimum, these standards should be continued for 1984 and later model years.

I. EFFECTS OF THE ALTERNATIVE SCENARIOS BASED ON CURRENT STANDARDS

A. LDGVs

EPA considered six alternative scenarios to continuing the current fixed-point proportional standards for LDGVs. The costs of these alternatives vary with their technical requirements, which in turn are based on three basic factors: 1) the maximum elevation for which control must be demonstrated; 2) the extent of exemptions, if any; and 3) the level of standards. Based on these three factors, the Agency concludes that:

1) continuing the current statutory high-altitiude requirements, as mandated in section 206 of the Act, is extremely costly, may significantly limit model availability at both low and high altitudes, and is extremely cost ineffective;

2) there is no air quality justificaton for controls above 6,000 feet;

3) any statutory standards at high altitude can provide a small incremental improvement in air quality;

4) exemptions, or similar waivers, can significantly reduce compliance costs, while maintaining acceptable model availability at higher elevation;

5) exemptions, or similar waivers, can prevent the potential for adversely affecting model availability throughtout the nation that may accompany implementing statutory standards at higher elevations beginning in 1984, as required by the Clean Air Act; and

6) fixed-point statutory standards which require vehicles sold above 4,000 feet to comply with the standards when tested at 5,300 feet and which provide for some exemptions are the most cost-effective alternative beyond continuing the current proportional requirements, of the six alternatives

analyzed. Of course, there are many other possible alternatives, one of which may be better than any of the six analyzed here.

B. LDGTs

While not specifically required by the Act, EPA finds that controlling LDGTs in addition to LDVs results in a positive impact on the ambient air quality of high-altitude areas. Controlling light trucks to statutory standards would reduce vehicle emissions of HC by 50 percent more and of CO by 40 percent more than if LDGVs were controlled alone. In addition, the Agency finds that controlling truck emissions under fixed-point statutory standards is more cost effective than the same degree of control for LDGVs.

C. LDDs

The Agency analyzed high-altitude standards for both gaseous emissions and particulate emissions for LDDs. For gaseous emissions, EPA concludes that achieving fixed-point statutory standards should be no more difficult for diesel engines than for gasoline engines, and that the cost over a 5-year period should be small. The Agency finds that particulate emissions will be reduced by the same techniques that reduce gaseous emissions, although it is too early to determine if the statutory particulate standards can be met with these techniques alone. Also, controlling gaseous emissions from LDDs to statutory high-altitude standards is expected to be more cost effective than controlling LDGVs.

D. Effects of the Scenarios Based on Revised Low-Altitude Standards

The Agency also considered the effects of the same six alternative scenarios under revised low-altitude standards. The major difference is that under revised fixed-point statutory standards of 0.41 g/mi HC, 7.0 g/mi CO, and 1.5-2.0 g/mi NOx for passenger cars, the control options might tend to reduce model availability somewhat more than they would under the current fixed-point statutory standards. Otherwise, EPA concludes that:

1) the technical difficulties of compliance would remain about the same;

2) exemptions, or similar waivers, would retain their positive effects on overall costs and model availability; and

3) fixed-point statutory standards would likely be the most cost-effective alternative to proportional standards.

Based on the assumption that revised LDV standards at low altitude are as stated above (i.e., 0.41 g/mi HC, 7.0 g/mi CO, and 1.5-2.0 g/mi NOx), these conclusions would remain valid for both gasoline-fueled and diesel-powered cars and trucks. Nevertheless, different conclusions are possible under scenarios which assume other revised low-altitude standards.

E. Recommendations

EPA recommends that section 206 of the Clean Air Act be amended to:

1) Provide the Administrator the flexibility to adopt two-car compliance strategies, and to establish high-altitude standards, within the range from proportional to statutory, for any class of motor vehicles that is necessary to attain the NAAQS for ozone and carbon monoxide after considering the technical feasibility, impact on model availability, and economic impact of any such requirements; and

2) Confirm the Administrator's authority to exempt certain vehicles from the high-altitude certification requirements or waive the high-altitude standards for certain vehicles, and to decide on the maximum number of such exemptions or waivers.

Appendix I

Perspective on the Interim High-Altitude Standards

The 1982 and 1983 high-altitude standards were promulgated on October 8, 1980.[1] During the rulemaking process, the proportional gaseous emission standards contained in those regulations were the subject of intense analysis and public debate. EPA believes that little would be served to again present the detailed analysis[2,3,4] which supports that final rulemaking in this document since the value of fixed-point proportional standards has already been demonstrated. Instead, EPA chose to concentrate on determining if any alternative control options could provide greater protection of the public health and welfare, while at the same time remaining cost effective.

However, it is important to familiarize the reader with the details of the interim high-altitude standards since these facts form the basis for one of EPA's recommendations in this report which calls for the authority to continue proportional standards at high altitude if, after further study, more stringent controls are found to be unnecessary or not cost effective.

Some of the topics discussed in this appendix are discussed in various chapters of the report but will be briefly repeated here for clarity. The information in this section was taken from EPA's final regulatory analysis of the 1982 and 1983 high-altitude regulations.[2]

I. COSTS TO MANUFACTURERS

At the time the 1982 and 1983 high-altitude standards were promulgated, manufacturers were expected to incur increased costs in three main areas: development, certification, and emission control hardware. These costs are summarized in Table API-1. The total cost to manufacturers is $23.36 million (undiscounted, 1981 dollars).

II. COST TO USERS

As a result of this regulation, users of high-altitude motor vehicles were expected to pay an average of $22 more for light-duty vehicles (LDV) and $39 more for light-duty trucks (LDT) in 1982 than in 1981 (1981 dollars). Stated as a combined average, the increase for a high-altitude motor vehicle would be $25 (1981 dollars). Furthermore, there would be no change in maintenance costs, but a small positive effect on fuel economy was expected, although because of a lack of data, no fuel economy benefit was included in the final regulatory analysis. If such a benefit had been included, the total cost of the regulation would be less.

Table API-1

Total Cost to Manufacturers
for the 1982 and 1983 Model Years[a]

Vehicle Category	Year	Development Cost (million dollars)	Certification Cost	Hardware Cost (million dollars)	Total (million dollars)
LDV	1981	4.78	341,200		5.12
	1982	4.78	341,200	1.2	6.32
	1983			1.2	1.2
Subtotal		9.56	682,400	2.4	12.64
LDT	1981	2.95	113,700		3.06
	1982	2.95	113,700	2.3	5.36
	1983			2.3	2.3
Subtotal		5.90	227,400	4.6	10.72
Total		15.46	909,800	7.0	23.36

[a] Undiscounted, 1981 dollars.

III. IMPACT ON HIGH-ALTITUDE DEALER

As a result of the interim standards, EPA estimated that 50 percent of the 1,000 high-altitude dealerships would lose about one sale during the 2-year period (1982-83) because of higher vehicle prices. The remaining dealers would not be adversely affected. EPA also estimated that "dealer trades" between high- and low-altitude dealerships would not be unduly affected because low-altitude cars must be capable of being modified to meet the high-altitude standards at a reasonable cost if they could not automatically do so.

IV. AGGREGATE COST TO THE NATION

The present value of the expected costs of the interim regulations are shown in Table API-2. The aggregate cost of $23.98 million is equivalent to a lump sum investment made at the beginning of 1982.

V. AIR QUALITY IMPROVEMENTS

Tables API-3 and API-4 show the change in Denver, Colorado area emissions and the total pollution reduction at high altitude which were expected as a result of the 1982 and 1983 proportional standards. By 1987, when Denver must be in compliance with the National Ambient Air Quality Standards, HC emissions would be reduced by 1.0 percent and CO would be reduced by 3.4 percent. The total air quality benefit was estimated to be a reduction of 33,100 tons for HC and 1,195,000 tons for CO.

VI. COST EFFECTIVENESS

Table API-5 summarizes the total pollution reductions, total cost, and resulting cost effectiveness of the high-altitude proportional standards. Under these regulations, HC and CO were expected to be reduced in high-altitude areas at a cost of $365 per ton and $10 per ton, respectively. Expressed in metric tons, the cost would be $393 for HC and $12 for CO.

Table API-2

Aggregate Cost to the Nation for
1981 and 1983 High-Altitude Standards[a]

Year	Development Cost (million dollars)	Certification Cost	Hardware Cost (million dollars)	Total	Discount Factor	Discounted Total (million dollars)
1981	7.73	457,000		8.19	1.10	9.01
1982	7.73	457,000	3.5	11.69	0.0	11.69
1983			3.5	2.5	0.91	3.19
Total						23.98

[a] Present value in 1982, 1981 dollars, 10 percent discount rate.

Table API-3

Denver Area Emissions (tons/day)

	1980		1982		1984		1987	
	HC	CO	HC	CO	HC	CO	HC	CO
Without Stds	231.7	1,927	196.8	1,687	162.2	135.8	133.7	1,011
With Stds	231.7	1,927	196.3	1,670	160.8	131.2	132.4	977
Reduction (percent)	0 (0)	0 (0)	0.5 (0.3)	17 (1.0)	1.4 (0.9)	4.6 (3.4)	1.3 (1.0)	34 (3.4)

Table API-4

Total Pollution Reductions for 1982 and 1983
(thousands of tons)

	HC	CO
LDV	11.6	258
LDT	21.5	937
Total	33.1	1,195

Table API-5

Cost Effectiveness for the High-Altitude Control Strategies

Pollutant	Reductions (thousands of tons)	Cost[a] (million dollars)	Cost Effectiveness (dollar/ton)
HC	33	12	365
CO	1,195	12	10

[a] The total cost to the nation is divided equally between the pollutants (1981 dollars).

References

1. "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; Final High-Altitude Emission Standards for 1982 and 1983 Model Year Light-Duty Motor Vehicles," U.S. Environmental Protection Agency, 45 FR 66984, October 8, 1980.

2. "Final Regulatory Analysis - Environmental and Economic Impact Statement for the 1982 and 1983 Model Year High-Altitude Motor Vehicle Emission Standards," U.S. EPA, OANR, OMS, ECTD, SDSB, October 1980.

3. "Summary and Analysis of Comments on the Notice of Proposed Rulemaking for High-Altitude Emission Standards for 1982 and 1983 Model Year Light-Duty Motor Vehicles," U.S. EPA, OANR, OMS, ECTD, SDSB, October 1980.

4. "Technical Feasibility of the Proposed 1982-1983 High-Altitude Standards for Light-Duty Vehicles and Light-Duty Trucks," CTAB/TA/80-3, U.S. EPA, ONAR, OMS, ECTD, SDSB, August 1980.

Appendix II

Supplemental Information for the Environmental Analysis

This appendix contains supplemental information to the environmental analysis. Contained are the individual model year emission rates for each high-altitude strategy analyzed (Tables APII-2 through APII-4), the low-altitude emission rates for scenarios 1, 2 and the base scenario (Table APII-5), the annual growth rates for stationary and off-highway sources (Table APII-6), and the air quality analyses performed for CO and NOx based on zero-growth rates (Tables APII-7 through APII-14).

The reader should be aware of some differences between the convention used to identify the various scenarios in this appendix and that used in the report. The relationship between these conventions is explained in Table APII-1.

Table APII-1

High-Altitude Report to Congress Control Scenarios

Appendix II Convention	Report Convention	1984+ Standards [a] LDV	1984+ Standards [a] LDT	Technology Mix for LDGV [b,c]
1	1 (without truck control)	.41/3.4/1.0	-/-/-	40.8/59.2/0
2	2 (without truck control)	.41/3.4/1.0	-/-/-	10.2/59.2/30.6
3	3 and Base (without truck control)	.57/7.8/1.0	-/-/-	10.2/59.2/30.6
4	2 (with truck control)	.41/3.4/1.0	.8/10/2.3	10.2/59.2/30.6
5	3 and Base (with truck control)	.57/7.8/1.0	1.0/14/2.3	10.2/59.2/30.6
6	2 (with revised standards	.41/7.0/2.0	-/-/-	0/0/100
7	3 and Base (with revised standards	.57/11.0/2.0	-/-/-	0/0/100
8	Not discussed, included for completeness	.57/16.0/2.0	-/-/-	0/0/100
9	No standards	-/-/-	-/-/-	10.2/59.2/30.6
10	No standards	-/-/-	-/-/-	0/0/100

[a] When no specific standards are given, the LDGT standards at low altitude are assumed to be .8/10/2.3. The strategy 9 low-altitude standards for LDGVs are assumed to be .41/3.4/1.0 and the standards assumed are .41/7.0/2.0 for strategy 10.

[b] The technology mix for the LDGTs is 100 percent oxidation catalyst (open-loop carbureted).

[c] The LDGV technology mix of x/y/z indicates that x percent of fleet is assumed to be closed-loop carbureted, y percent of the fleet is expected to be throttle body fuel injected, and z percent of the fleet is assumed to be open-loop carbureted.

Table APII-2

Hydrocarbon Emission Rates at 5,300 Feet

Vehicle Type	Model Year	Emission Rate[a] ZM	DR	Standard[b]	Scenario
LDGV	1981	.59	.21	-	All
	1982-83	.48	.21	.57	All
	1984+	.38	.18	.41	1
		.34	.19	.41	2,4
		.44	.19	.57	3,5
		.26	.23	.41	6
		.36	.23	.57	7,8
		.55	.19	(.41)	9
		.47	.23	(.41)	10
LDGTs	1984+	1.13	0.14	(.8)	1-3,6-10
		0.63	0.14	.8	4
		0.78	0.14	1.0	5
HDGV	1979-83	6.90	0.32	(1.5)	All
	1984-85	2.67	0.22	(1.3)	All
	1986+	2.34	0.22	(1.3)	All
LDDV	1984+	0.39	0.03	.41	1,2,4,6
		0.54	0.03	.57	3,5,7,8
		0.90	0.03	(.41)	9,10
LDDT	1984+	1.40	0.06	(.8)	1-3,6-10
		0.61	0.06	.8	4
		0.76	0.06	1.0	5
HDDV	1984-85	8.03	0.04	(1.3)	All
	1986+	6.83	0.04	(1.3)	All

[a] Note emission factors, EF, are calculated from EF = ZM + (DR)Y, where ZM is the zero-mile emission rate, DR is the deterioration rate per 10,000 miles and y is the number of miles divided by 10,000.

[b] () = low-altitude standard.

Table APII-3

Carbon Monoxide Emission Rates at 5,300 Feet

Vehicle Type	Model Year	Emission Rate[a] ZM	DR	Standard[b]	Scenario
LDGV	1981	10.78	3.07	(3.4/7)	All
	1982	8.13	3.12	7.8/11	All
	1983	7.75	3.12	7.8	All
	1984+	5.22	2.76	3.4	1
		3.75	2.24	3.4	2,4
		6.25	2.22	7.8	3,5
		3.58	1.92	7.0	6
		5.63	1.92	11.0	7
		8.19	1.92	16.0	8
		7.44	2.21	(3.4)	9
		11.39	1.92	(7.0)	10
LDGTs	1984+	22.69	1.35	(10)	1-3,6-10
		7.13	1.35	10	4
		9.85	1.35	14	5
HDGV	1979-83	324.55	8.37	(2.5)	All
	1984-85	104.16	5.63	(35)	All
	1986+	82.29	5.63	(35)	All
LDDV	1984+	1.27	0.05	3.4	1,2,4
		2.22	0.05	7.8	3,5
		2.22	0.05	7.0	6
		2.22	0.05	11	7
		2.22	0.05	16	8
		2.22	0.05	(3.4)	9
		2.22	0.05	(7.0	10
LDDT	1984+	3.47	0.09	(10)	1-3,6-10
		1.98	0.09	10	4
		2.77	0.09	14	5

[a] Note emission factors, EF, are calculated from EF = ZM + (DR)Y, where ZM is the zero-mile emission rate, DR is the deterioration rate per 10,000 miles and y is the number of miles divided by 10,000.

[b] () = low-altitude standard.

Table APII-4

Oxides of Nitrogen Emission Rates at 5,300 Feet

Vehicle Type	Model Year	Emission Rate[a] ZM	DR	Standard[b]	Scenario
LDGV	1981	0.52	0.09	-	All
	1982-83	0.57	0.10	1.0	All
	1984+	0.54	0.10	1.0	1
		0.58	0.10	1.0	2-5
		1.27	0.08	2.0	6-8
		0.52	0.09	(1.0)	9
		0.99	0.06	(2.0)	10
		0.95	0.09	1.5	10 with 1.5 Std.
LDGTs	1984+	0.98	0.03	(2.3)	1-3,6-10
		1.26	0.04	2.3	4,5
HDGV	1984+	7.55	0.09	(10.7)	All
LDDV	1984+	0.75	0.05	1.0	1-5
		1.49	0.06	2.0	6-8
		0.75	0.05	(1.0)	9
		1.49	0.06	(2.0)	10
		1.11	0.06	(1.5)	10 with 1.5 std.
LDDT	1984+	1.89	0.07	(2.3)	1-3,6-10
		1.89	0.07	2.3	4-5
HDDV	1984+	22.90	0.12	(10.7)	All

[a] Note emission factors, EF, are calculated from EF = ZM + (DR)Y, where ZM is the zero-mile emission rate, DR is the deterioration rate per 10,000 miles and y is the number of miles divided by 10,000.
[b] () = low-altitude standard.

Table APII-5

Selected Emission Rates at 1,800 Feet for 1984 and Later Model Years

Pollutant	Vehicle Type	Emission Rate[a] ZM	Emission Rate[a] DR	Scenario
HC	LDGV	0.37	0.17	1
		0.33	0.18	2,3
	LDDV	0.39	0.03	All
CO	LDGV	4.27	2.13	1
		3.21	1.88	2,3
	LDDV	1.27	0.05	All
NOx	LDGV	0.56	0.10	1
		0.63	0.11	2,3
	LDDV	0.75	0.05	All

[a] Note emission factors, EF, are calculated from EF = ZM + (DR)Y, where ZM is the zero mile emission rate, DR is the deterioration rate per 10,000 miles and y is the number of miles divided by 10,000.

[b] () = low-altitude standard.

Table APII-6

Annual Growth Rates for Stationary and Off-Highway Sources

Pollutant	Source	Growth Rates 1977-95 Zero Growth	Low Growth	High Growth
O_3	Off-Highway	N/A[a]	+2.5	+2.5
	Stationary Area	N/A	+0.0	0.0
	Petroleum	N/A	+0.8	+1.9
	Storage	N/A	+0.8	+1.9
	Industrial Processes	N/A	+0.8	+3.1
	Other Solvent	N/A	+0.8	+0.8
	Industrial Surface	N/A	+0.8	+3.3
CO	Off-Highway	+2.5	+2.5	+2.5
	Stationary Point	+2.4	+2.4	+2.4
	Combustion	+0.8	+0.8	+0.8
	Stationary Area	0.0	0.0	0.0
NOx	Off-Highway	+2.5	+2.5	+2.5
	Stationary Point	+3.5	+3.5	+3.5
	Combustion	+0.8	+0.8	+0.8
	Stationary Area	0.0	0.0	0.0

[a] Not Applicable. A zero-growth rate case was not analyzed for ozone.

Table APII-7

Average Percent Change in the Ambient CO Concentration Level from the Base Year With Inspection/Maintenance (zero-growth rate)

Scenario	Description	1986	1987	1988	1989	1990	1993	1995
1	Continuous All Alt. Stds.	-52	-57	-62	-66	-69	-74	-76
2	Fixed Pt. All Alt. Stds.	-52	-58	-63	-67	-69	-75	-77
3	Fixed Pt. Proportional Stds.	-52	-57	-61	-65	-69	-74	-76
4	Fixed Pt. All Alt. Stds.	-53	-58	-63	-68	-70	-76	-78
5	Fixed Pt. Proportional Stds.	-52	-58	-62	-66	-69	-75	-77
6	Fixed Pt. All Alt. Stds.	-52	-58	-62	-67	-69	-74	-77
7	Fixed Pt. Proportional Stds.	-52	-57	-62	-65	-69	-74	-76
8	Fixed Pt. Proportional Stds.	-51	-57	-61	-65	-67	-72	-75

Table APII-8

Total Number of CO NAAQS Violations With Inspection/Maintenance
(zero-growth rate)

Scenario	Description	1986	1987	1988	1989	1990	1993	1995
1	Continuous All Alt. Stds.	13	6	2	0	0	0	0
2	Fixed Pt. All Alt. Stds.	13	5	2	0	0	0	0
3	Fixed Pt. Proportional Stds.	13	6	3	0	0	0	0
4	Fixed Pt. All Alt. Stds.	12	5	2	0	0	0	0
5	Fixed Pt. Proportional Stds.	13	5	2	0	0	0	0
6	Fixed Pt. All Alt. Stds.	13	5	2	0	0	0	0
7	Fixed Pt. Proportional Stds.	13	6	2	0	0	0	0
8	Fixed Pt. Proportional Stds.	13	6	3	1	0	0	0

Table APII-9

Average Percent Change in the Ambient CO Concentration Level from the Base Year Without Inspection/Maintenance (zero-growth rate)

Scenario	Description	1986	1987	1988	1989	1990	1993	1995
1	Continuous All Alt. Stds.	-42	-48	-53	-57	-61	-66	-69
2	Fixed Pt. All Alt. Stds.	-43	-48	-54	-58	-62	-69	-72
3	Fixed Pt. Proportional Stds.	-42	-48	-53	-57	-61	-68	-70
4	Fixed Pt. All Alt. Stds.	-44	-49	-55	-60	-63	-70	-73
5	Fixed Pt. Proportional Stds.	-43	-49	-53	-58	-62	-69	-71
6	Fixed Pt. All Alt. Stds.	-43	-49	-54	-59	-62	-69	-72
7	Fixed Pt. Proportional Stds.	-43	-48	-53	-58	-62	-69	-71
8	Fixed Pt. Proportional Stds.	-42	-48	-53	-57	-61	-67	-70

Table APII-10

Total Number of CO NAAQS Violations Without Inspection/Maintenance (zero-growth rate)

Scenario	Description	1986	1987	1988	1989	1990	1993	1995
1	Continuous All Alt. Stds.	31	18	8	3	1	0	0
2	Fixed Pt. All Alt. Stds.	30	16	7	3	1	0	0
3	Fixed Pt. Proportional Stds.	31	18	8	3	1	0	0
4	Fixed Pt. All Alt. Stds.	27	15	7	2	1	0	0
5	Fixed Pt. Proportional Stds.	30	15	7	3	1	0	0
6	Fixed Pt. All Alt. Stds.	30	15	7	3	1	0	0
7	Fixed Pt. Proportional Stds.	30	16	8	3	1	0	0
8	Fixed Pt. Proportional Stds.	31	18	8	3	1	0	0

Table APII-11

Average Percent Change in Ambient NOx Concentration Level from the Base Year With Inspection/Maintenance (zero-growth rate)

Scenario	Description	1986	1987	1988	1989	1990	1993	1995
1	Continuous All Alt. Stds.	-2	-2	0	0	0	4	6
2	Fixed Pt. All Alt. Stds.	-2	-2	0	0	2	4	6
3	Fixed Pt. Proportional Stds.	-2	-2	0	0	2	4	6
4	Fixed Pt. All Alt. Stds.	-2	0	0	0	2	4	6
5	Fixed Pt. Proportional Stds.	-2	0	0	0	2	4	6
6	Fixed Pt. All Alt. Stds.	0	2	2	4	6	10	12
7	Fixed Pt. Proportional Stds.	0	2	2	4	6	10	12
8	Fixed Pt. Proportional Stds.	0	2	2	4	6	10	12

Table APII-12

Total Number of NOx NAAQS Violations With Inspection and Maintenance
(zero-growth rate)

Scenario	Description	1986	1987	1988	1989	1990	1993	1995
1	Continuous All Alt. Stds.	0	0	0	0	0	0	0
2	Fixed Pt. All Alt. Stds.	0	0	0	0	0	0	0
3	Fixed Pt. Proportional Stds.	0	0	0	0	0	0	0
4	Fixed Pt. All Alt. Stds.	0	0	0	0	0	0	0
5	Fixed Pt. Proportional Stds.	0	0	0	0	0	0	0
6	Fixed Pt. All Alt. Stds.	0	0	0	0	0	0	1
7	Fixed Pt. Proportional Stds.	0	0	0	0	0	0	1
8	Fixed Pt. Proportional Stds.	0	0	0	0	0	0	1

Table APII-13

Average Percent Change in the Ambient NOx Concentration Level from the Base Year Without Inspectio/Maintenance (zero-growth rate)

Scenario	Description	1986	1987	1988	1989	1990	1993	1995
1	Continuous All Alt. Stds.	-2	-2	0	0	0	4	6
2	Fixed Pt. All Alt. Stds.	-2	-2	0	0	2	4	6
3	Fixed Pt. Proportional Stds.	-2	-2	0	0	2	4	6
4	Fixed Pt. All Alt. Stds.	-2	0	0	0	2	4	6
5	Fixed Pt. Proportional Stds.	-2	0	0	0	2	4	6
6	Fixed Pt. All Alt. Stds.	0	2	2	4	6	10	12
7	Fixed Pt. Proportional Stds.	0	2	2	4	6	10	12
8	Fixed Pt. Proportional Stds.	0	2	2	4	6	10	12

Table APII-14

Total Number of NOx NAAQS Violations Without Inspection/Maintenance (zero-growth rate)

Scenario	Description	1986	1987	1988	1989	1990	1993	1995
1	Continuous All Alt. Stds.	0	0	0	0	0	0	0
2	Fixed Pt. All Alt. Stds.	0	0	0	0	0	0	0
3	Fixed Pt. Proportional Stds.	0	0	0	0	0	0	0
4	Fixed Pt. All Alt. Stds.	0	0	0	0	0	0	0
5	Fixed Pt. Proportional Stds.	0	0	0	0	0	0	0
6	Fixed Pt. All Alt. Stds.	0	0	0	0	0	0	1
7	Fixed Pt. Proportional Stds.	0	0	0	0	0	0	1
8	Fixed Pt. Proportional Stds.	0	0	0	0	0	0	1

Appendix III

Supplemental Information for the Economic Analysis

I. DEVELOPMENT COSTS

All vehicles except those using "unmodified electronic feedback systems" will require a unique calibration for high altitude. Calibrations are historically developed through a series of reiteration involving theoretical studies, carburetor flow bench testing, and Federal Test Procedure (FTP) testing. FTP testing is by far the most expensive portion of any calibration effort; therefore, development costs can be adequately characterized by conservatively estimating the average number of FTP tests required per engine family.

Estimating the number of FTP tests required for compliance with the standards is a problem. In reality the number is likely to be different for each engine family because of the variety of emission control systems and because calibrations within an engine family will require different degrees of development effort.

The difficulty of estimating the necessary development was not diminished by manufacturers' comments to the 1982 and 1983 interim standards, which is a major source of data for this study. Despite the fact that many manufacturers made repeated claims that high-altitude testing facilities were inadequate, a statement that should have been based on an estimate of the requisite development testing, only one manufacturer provided specific information. Therefore, in order to estimate the quantity of development testing, EPA relied primarily on its own experience with development programs at the Motor Vehicle Emissions Laboratory and on the past experience of its technical staff while they were employed in development areas of the automobile industry.

Ford estimated that 52 high-altitude calibrations would be needed and that 150 FTP tests would be required per calibration. EPA's independent estimate is in basic agreement with Ford. Historically, developing a low-altitude calibration can indeed take 150 tests. However, it is unlikely that such a great number of tests would be required to develop a suitable high-altitude calibration. EPA reasons that calibrating high-altitude hardware will be less difficult for several reasons.

Typically, low-altitude calibrations are determined simultaneously. Such a development program provides no opportunity to learn from prior experience with similar calibrations within the same engine family. Because special durability and emission-data vehicles will not be required, manufacturers will often develop high-altitude calibrations after the low-altitude hardware has been determined. The experience and information that were generated in producing low-altitude calibrations can then be used to reduce the effort required to develop high-altitude calibrations for the same vehicle configurations. Also, the overall technical problem is greatly reduced since the basic changes that must be made to compensate low-altitude hardware for the effects of higher altitude are generally well known.

Furthermore, the actual number of calibrations per engine family may be lower for high-altitude vehicles than for low-altitude vehicles. Manufacturers may develop many more low-altitude calibrations than are actually required because the potential low-altitude market is so great that the resulting small improvements in driveability and fuel economy (CAFE) justify the additional development costs. This amount of optimization may not be needed or justifiable for the smaller high-altitude market, i.e., one calibration may suffice for several low-altitude calibrations. In this situation the "worst case" calibration for several vehicle configurations within an engine family will be developed first, and, if suitable for other similar configurations, will be used unless time, financial resources, and perceived benefit dictate otherwise. Even though manufacturers may provide fewer calibrations and, therefore, less optimization at high altitudes as compared to low altitude, high-altitude consumers will still benefit from the development work which will be done. High-altitude vehicles should perform better and give better fuel economy than unadjusted low-altitude vehicles operated at high altitudes with much richer fuel-air mixtures.

Although no details were given, Ford may have based their estimate of 52 high-altitude calibrations on the fact that less optimization would be required for the high-altitude market than the low-altitude market. In 1980, Ford certified 20 light-duty motor vehicle engine families. This figure and Ford's estimate of high-altitude calibrations translates into about 2.5 calibrations per engine family. This is in contrast to Ford's 1980 certification data which shows an average of perhaps 10 calibrations per engine family. Therefore, it is reasonable to conclude that Ford expects significantly less optimization at high altitude than at low altitude.

EPA estimates that, on the average, 100 FTP tests per engine family should be sufficient to calibrate a light-duty, gasoline-fueled vehicle. This, of course, assumes that some calibrations will be more difficult to develop than others and some will be less difficult. It appears that feedback systems should generally be easier to calibrate than many non-feedback (aneroid) systems. Additionally, some non-feedback systems are also expected to be quite easy to calibrate. Manufacturers' comments to the 1982 and 1983 interim package indicated that some vehicles could comply with the standards by manipulating adjustable parameters on existing low-altitude hardware. However, to be conservative, EPA will use 150 tests per engine family to determine the manufacturer's development costs due to this regulation. The additional 50 tests will allow for expenses that are not explicitly accounted for in this analysis. These expenses include costs for additional engineering support at the manufacturers' headquarters, building prototype hardware, and bench testing.

The number of LDV engine families to be certified for 1984 is, of course, unkown at this time. EPA has assumed that approximately the same number of engine families will be certified in 1984 as was certified in 1980. In 1980 there were 109 nonCalifornia LDV gasoline engine families certified. These include families for sale in either the 49 states, excluding California, or the 50 states, including California. Engine families which are certified for sale in California only have been excluded because these proposed regulations do not apply to those vehicles. Thus, the maximum number of families that could undergo engine development is 109 families, and this would occur in scenarios 1a and 1c. In scenarios where some vehicles are exempted from sale at high altitude (scenarios 1b, 2, 3a and the base scenario) the exempt engine families will not have to undergo development. As is explained in the certification section below, it will be assumed that the fraction of engine families which will not be certified for high altitude (i.e., exempted) will be the same as that fraction of sales exempted. Also, under scenarios 3a, 3b, and the base scenario, some vehicles will not have to undergo development because these vehicles have systems with inherent capability to compensate for the effects of altitude. The percentage of these vehicles which will not undergo development is shown in Tables V-2 and V-3 of Chapter V. Again, the percentage of engine families not having to undergo development is assumed to be the same as the percentage of sales. Thus, for scenarios 1b, 2, 3a, 3b, and the base scenario, less than the total amount of families appearing in any given model year will need special high-altitude development.

There is, of course, the possibility of carryover from the base scenario of emission-data results from 1983 to 1984, thereby reducing the amount of development testing required in 1984. Since all vehicles sold at high altitude in 1982 or 1983 by definition fall under the base scenario there will be no development costs for this scenario in 1984. It is unlikely, however, that manufacturers could apply the development results of the base scenario to each of the other scenarios. Thus, to be conservative, it is assumed that carryover of emission-data results in the base scenario will not be used when determining the costs for all other scenarios in cases where vehicles are modified. For unmodified vehicles in scenarios 3a and 3b, carryover is assumed as would occur under the base scenario.

Now that the testing requirement has been estimated, the price per test remains to be determined before the cost of development can be found. Information obtained from commercial testing facilities located in Denver, Colorado, indicate that a manufacturer may run a development quality FTP test for about $375. Of course, the cost for manufacturers with their own private facilities will be less. In calculating the cost of development, EPA will use $500 per test to provide an adequate allowance for engineering and technical support, and prototype vehicle shipping expenses.

Table V-8 shows the development costs for the families with unique high-altitude calibrations. Again, the base scenario requires no development. Development costs for scenarios other than the "base scenario" are estimated to be a total of $3.38-8.18 million.

II. CERTIFICATION

Certification for this high-altitude standard will begin in 1984 for light-duty vehicles. The certification cost will differ according to each prescribed scenario and according to the certification procedure which is ultimately adopted for 1984 and later model years. For this analysis, EPA has assumed that certification will be similar to that currently used in the interim high-altitude program (i.e., actual vehicle tests will be conducted).

Under scenarios with exemptions, exempted vehicle families are prohibited from sale at high altitude and, therefore, will not require to be certified to meet a high-altitude standard. For fixed-point scenarios, manufacturers will be allowed to use their low-altitude 4,000-mile data vehicles by modifying these vehicles into the selected high-altitude configuration. For the continuously proportional or statutory standards, manfacturers must certify a 4,000-mile data vehicle with the same configuration at low and high altitude.

In all scenarios, manufacturers will not be required to build and accumulate mileage on special high-altitude certification vehicles. Deterioration factors for high-altitude vehicles will be the same as those developed with low-altitude, 50,000-mile durability vehicles. In EPA's emission factor program, deterioration rates of in-use vehicles at high and low altitudes were compared. No statistically significant difference was found between the vehicle. Therefore, the assignment of high-altitude DFs based on low-altitude DFs is justified by in-use experience.

Under all scenarios manufacturers will also be allowed to select one emission-data vehicle per engine family which is expected to have the worst emissions when tested under high-altitude conditions. This emission-data vehicle will be one of the emission-data vehicles previously selected for testing at low altitude. Thus, this regulation will not cause the manufacturers to incur the additional cost of building a new emission-data vehicle and of accumulating 4,000 miles on this vehicle.

The fraction of exempted vehicles for each scenario was derived in Chapter II of this report. It will be assumed that for each fraction of the total vehicles that are exempted, the same fraction of engine families is exempted from certification. For example, in scenario 1b, 25 percent of all vehicles are estimated to be exempt, which translates into 25 percent of all engine families.

The net certification costs for each alternative scenario should be those costs that are incremental to the certification costs that would normally have occurred for high altitude in 1984 under the base scenario which is a continuation of the existing interim standards. Therefore, manufacturers would still certify to the levels of the 1982/1983 interim standards, thus already incurring certification costs. These should be "credited" towards the total certification costs that would otherwise be required for each scenario.

After calculating first for the base scenario itself, the incremental cost will be calculated for scenario 2, which is a fixed-point statutory strategy and is very similar to the base scenario, which is a fixed-point proportional strategy. Then the costs for the continuous statutory and continuous proportional scenarios will be calculated (scenarios 1a, 1b, 1c, 3a, and 3b), again incremental to the base scenario. The summary of certification costs are shown in Table V-9.

A. Base Scenario

The base scenario is a fixed-point scenario, where manufacturers can certify an emission-data vehicle at low altitude and a modification of the vehicle at high altitude. A high-altitude standard would not affect the certification status of a "low-altitude" emission-data vehicle. Thus, only the cost of a "high-altitude" emission-data vehicle is due to the promulgation of a high-altitude standard.

In 1984 it is estimated that if there were no carryover, then 117 LDV engine families will be certified, the same number as that in 1980. This breaks down to about 109 LDVG and 8 LDDV. For the base scenario in 1984 and thereafter, it is estimated that 10 percent of emission-data vehicles will obtain carryover from the previous year. This figure was based on recent certification data for emission-data vehicles. Thus, 90 percent of the total number of LDGV engine families, or about 98 families, will be certified under the base scenario in 1984, if there were no vehicle exemptions. However, it is estimated that 5 percent of engine families will be exempted, so that 93 families will undergo certification.

The estimated cost per test is $1,900.[1] This figure includes $1,000 for testing and $900 for vehicle transportation. Approximately 1.5 tests will be performed per engine family. This estimated testing cost may be high for manufacturers with their own high-altitude facilities. These manufacturers have one less profit center to account for than do manufacturers who contract for certification at commercial facilities. To be conservative, however, this potential cost savings will not be included in this analysis.

The certification costs for the base scenario is $265,000 for 1984 and each year after. These costs have been calculated keeping in mind that 5 percent of engine families are exempted. This certification cost should be subtracted from the total certification costs of alternate scenarios.

B. Scenario 2

In this scenario, as with the base scenario, only the cost of recalibrating a "high-altitude" emission-data vehicle is due to the promulgation of a high-altitude standard. Thus, with an estimated engine family exemption of 15 percent it is estimated that 93 gasoline-fueled LDVs will have to undergo certification in 1984 and 90 percent of this number in 1985 and thereafter. The incremental cost to the base scenario is then $0 for 1984 and each year after. This cost is also shown in Table V-9 .

C. Continuous Statutory and Continuous Proportional Scenarios (Scenario 1a, b, c and 3a, b)

Under these scenarios manufacturers must show that each nonexempted vehicle can meet certification requirements at both low and high altitude. In some instances this may require the recertification of a vehicle at low altitude due to significant changes in the engine families that were already certified in a previous year. In other cases, if the manufacturer can demonstrate that new control hardware devices show no effect on previous certification results, then the low-altitude certification process need not be repeated.

In 1984, it is expected that all LDV vehicles will have to undergo certification testing at high-altitude to meet a continuous high-altitude standard with the exception of exempted vehicles or for vehicles that would not require modification to meet proportional as in scenario 3a. In this particular scenario the testing requirements for unmodified vehicles at 5,300 feet from the previous model year would be sufficient to demonstrate compliance. Therefore, the high-altitude certification costs for scenario 3a are similar to the base scenario except for the absence of exemptions.

However, not all of these vehicles will have to be recertified at low altitude, because a high-altitude standard should not always cause manufacturers to incorporate a major change in engine design that would affect previous low-altitude emission results. Many of the control hardware items previously discussed in this chapter are more or less "add-on" devices that do not affect engine operation (and, hence, emission results) at low altitude. These devices would automatically perform their emissions compensating function as the vehicle is driven at higher altitude. For example, a continuous aneroid compensates for the decrease in air density encountered at high altitudes by allowing the "bleeding" of more air. At low altitude, the continuous aneroid would not affect the air intake, thus not affecting engine operation and emission results.

However, some control hardware components may indeed cause engines to operate differently at low altitude as well as high altitude and thus, require certification at low altitude. Such control hardware would be the ELCS, a turbocharger, and the change to a feedback control system. For example, a turbocharger increases a vehicle's power for each cylinder stroke cycle regardless of altitude. Thus, upon implementation of the ELCS, turbocharger, or feedback control system, low-altitude certification is required. It is assumed that for scenarios 1a, 1b, 1c, and 3b, the percentage of vehicle families equipped with ELCS, turbochargers, or feedback control, is equal to the percentage of total vehicles sold with these components. For example, 33 percent of vehicles in scenario 1c require either ELCS, turbocharging, or feedback control, and this corresponds to 33 percent of engine families. This relationship was based on the belief that these engine families will represent the lower power to weight vehicles with higher fuel economy, and that vehicles sold from these engine families will represent an approximately equal percentage of the total vehicle market in 1984.

The number of LDV emission-data vehicles certified after 1984, or 1985-88 in this analysis, will be 90 percent of the number of vehicles certified in 1984. As previously stated this figure was based on recent certification data for emission-data vehicles. Low-altitude certification costs after 1984 should not be attributed to this 1984 high-altitude standard, since it would be normal practice for manufacturers to certify at low altitude regardless of a 1984 standard.

As discussed above, it is estimated that 109 gasoline-fueled engine families will be certified in 1984, unless families are exempted. Each durability vehicle for the low-altitude portion of certification costs about $197,000,[2] and each emission-data vehicle for normal low-altitude certification costs $27,000.[2] Each engine family has one durability vehicle and about 3 emission-data vehicles at low altitude. Again, the certification test cost is about $1,000 and approximately 1.5 tests are performed for each engine family.

The incremental certification costs are shown in Table V-9. These costs were calculated in the same manner as for scenario 2. Thus, when the certification cost of $265,000 for LDVs is "credited", the incremental costs are $0-$18,773,000 for the first year, and $0-14,000 each year after. As discussed above, this large range of costs is due to the fact that some scenarios do not require all vehicles to be certified at low altitude, and thus these vehicles will not incur the expense associated with durability and emission-data vehicles. These incremental certification costs will be carried out through the remainder of this report.

References

1. "Final Regulatory Analysis - Environmental and Economic Impact Statement for the 1982 and 1983 Model Year High-Altitude Motor Vehicle Emission Standards," U.S. EPA, OANR, OMS, ECTD, SDSB, October, 1980.

2. Light-Duty Vehicle Certification Cost, EPA Memorandum to Edmund J. Brune, from Daniel P. Hardin, Jr., March 13, 1975.