REGULATORY ANALYSIS AND ENVIRONMENTAL IMPACT OF FINAL EMISSION REGULATIONS FOR 1984 AND LATER MODEL YEAR HEAVY DUTY ENGINES

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF MOBILE SOURCE AIR POLLUTION CONTROL

DECEMBER 1979

REGULATORY ANALYSIS AND ENVIRONMENTAL IMPACT OF FINAL EMISSION REGULATIONS FOR 1984 AND LATER MODEL YEAR HEAVY DUTY ENGINES

PREPARED BY

OFFICE OF MOBILE SOURCE AIR POLLUTION CONTROL

APPROVED BY

Michael P. Walsh, Deputy Assistant Administrator for
Mobile Source Air Pollution Control

Date: December 11,1979

NOTE

This document has been prepared in satisfaction of the Regulatory Analysis required by Executive Order 12044 and the Economic Impact Assessment required by Section 317 of the amended Clean Air Act. This document also contains an Environmental Impact Statement for the Final Rulemaking Action.

Table of Contents

CHAPTER I

SUMMARY

A. Overview of Rulemaking

As the total amount of urban emissions from light-duty vehicles and trucks is reduced, the portion which heavy-duty vehicles contribute to those emissions becomes an increasingly significant factor. For example, it is expected that the fraction of total mobile source urban non-methane hydrocarbon (HC) emissions arising from heavy-duty vehicle operation will climb from 12% in 1976 to 36% in 1999. Similarly, heavy-duty carbon monoxide (CO) emissions may expand from 15% to 43% in the same time frame. It is in light of these expectations that Congress has mandated stricter controls on the gaseous emissions from heavy-duty engines.

This rulemaking follows from the Congressional requirement that EPA propose regulations to reduce by at least 90% the emitted levels of pollutants from heavy-duty vehicles — both HC and CO, relative to a baseline of uncontrolled (pre-1970) emissions. (Oxides of nitrogen (NOx) reduction will be addressed in separate regulations, though the present regulations do include a NOx standard such that no further control should be required under the new test procedures.) The purpose of this specific document is to present the results of EPA analyses of the environmental and economic impacts and the cost effectiveness of the regulations. The reader will find chapters devoted as well to the make-up of the heavy-duty industry and to alternative actions considered by the agency.

The accompanying regulations define levels for the Congressionally mandated gaseous emission standards for heavy-duty engines. Also introduced here are requirements that the standards be met on a test procedure which prescribes transient engine operation. The shift from the steady-state procedures completes an EPA development program which yielded test cycles derived from actual in-use vehicle operation; such transient testing, it is reasoned, more accurately assesses on-the-road emissions than do the previous procedures. The procedure is designed around an engine test and requires that emission numbers be determined on a useful-work-produced basis (i.e., grams per brake horsepower-hour or g/BHP-hr).

The HC and CO emissions standards which appear in this rulemaking represent a 90 percent reduction from the average measured emissions of twenty-three 1969 gasoline heavy-duty engines. Numerically, the standards are 1.3 g/BHP-hr for HC and 15.5 g/BHP-hr for CO.

The NOx standard being promulgated in this regulation was derived from data developed in a separate test program in which 1979 engines were tested. The average of these baseline results was adjusted so that in 1984 most engines should require no further NOx control than they currently have.

Several other aspects of this rule distinguish it from the current heavy-duty engine regulations. First, a new definition of "useful life" and revised durability requirements will alter the certification procedure. An engine's "useful life" is reached whenever 1) the average lifetime of its engine family is reached or 2) the mechanical integrity has deteriorated to the point of requiring a rebuild. However, in no case can this useful life period be less than 50,000 miles. The manufacturers will determine their own deterioration factors based on procedures which each develops. This procedure will be used until the statutory heavy-duty NOx emissions standards are finalized. At that time, a new durability procedure is expected to be promulgated.

Another change in EPA's past course involves a provision affecting parameter adjustment. In it, the Administrator will be allowed to require that certain adjustable emission-affecting parameters be set at other than recommended settings for certification; the purpose is to encourage design of engines with emission characteristics that are less susceptible to in-use maladjustment.

Additionally, EPA introduces in these regulations an idle test procedure to facilitate the promulgation of emissions warranty regulations under §207(b) of the Clean Air Act. Idle operation occurs in situations that involve fairly direct exposure of people to CO and comprises a significant portion of heavy-duty operation.

Also being promulgated are regulations to control heavy-duty diesel crankcase emissions. The current HC emission regulations place controls only on crankcase emissions from gasoline-fueled engines. Under the implemented changes, no crankcase emissions from naturally-aspirated heavy-duty diesel engines will be permitted.

Finally, an assembly-line emissions testing program known as the Selective Enforcement Audit (SEA) will be implemented. This program will aid in ensuring that actual production engines meet the emission levels to which they are certified. SEA's are initiated by a test order from EPA and cover only one engine configuration per test order. The number of SEA's a manufacturer must undergo each year is based primarily, but not exclusively, on projected annual sales. The goal in an SEA is to ascertain whether or not the engines tested meet a 10% Acceptable Quality Level (AQL). This AQL would require virtually all engines to meet applicable standards after adjustment for deterioration with only 10% allowed to exceed standards to provide for test variability and isolated instances of nonconformity.

Failure of an SEA may lead to suspension or revocation of the engine's certificate of conformity. The manufacturer would then be permitted to make running changes or quality control changes to the engine and then undergo another SEA. Another possibility will be for the manufacturer to request a Production Compliance Audit (PCA) to determine the compliance level of the engine configuration, and then pay a Noncomformance Penalty (NCP) based on the "marginal cost" of compliance between engines in compliance and the nonconforming engines. The provisions for PCA's and NCP's which were in the proposed rulemaking are not being finalized at this time. However, EPA intends to finalize them in time for the 1984 model year.

B. Industry Description

The "heavy-duty industry" discussed here refers to that collection of companies which manufactures the trucks, buses, and engines found in on-the-road applications whose gross vehicle weights (GVW) exceed 8,500 pounds. The rather complex picture presented by the numerous manufacturers and their diverse product lines is simplified somewhat by the realization that only a few of these companies are responsible for the bulk of the industry's production.

General Motors, Ford, Chrysler, and International Harvester (IHC) share over 99% of the heavy-duty gasoline engine market; Cummins Engine, Detroit Diesel, Mack, Caterpillar and IHC are the primary diesel engine producers. Only GM (including Detroit Diesel) and IHC make both types of engines in significant quantities.

Vehicles in the industry are produced in many configurations (single unit or tractor, gasoline or diesel, various axle arrangements and load capacities, etc.)by a number of manufacturers, but, as with the engines, most vehicles are built by the largest producers. GM (Chevrolet and GMC), Ford, Chrysler (Dodge), and IHC make over four fifths of all U.S.-built trucks.

The applications of trucks to real world tasks vary widely depending on load capacity, ranging from personal transportation and agriculture, to construction, trade, and "for hire" uses. The companies and individuals who purchase trucks and buses take advantage of the diversity of available products and choose vehicle-engine combinations which economically fulfill their needs.

C. Impact on the Environment

As previously noted, the amount of emissions produced by heavy-duty vehicles are becoming an increasingly significant portion of the total amount of urban emissions. In fact, it is expected that the fraction of total HC and CO emissions from heavy-duty engines will increase threefold in the time period 1976 to 1999. In view of these expectations, Congress has mandated stricter controls on the gaseous emissions from heavy-duty engines.

As a result of the stricter controls, heavy-duty gasoline vehicles will exhibit lifetime improvement of 1 ton in HC and 28.6 tons in CO relative to the scenario of a continuation of 1979 standards. Lifetime diesel HC emissions will be reduced by 0.77 tons. The effect which this reduction would have on total mobile source urban emissions translates to a 17 percent improvement in HC and 30 percent for CO by 1999, again compared to the case of no new heavy-duty regulations.

On the basis of further calculations EPA estimates that as a result of the rulemaking, the ambient levels of ozone and CO will be reduced in 1999 by 2 percent and 7 percent, respectively.

Secondary emission effects; water, noise and energy consumption effects; and commitment of scarce resources are all expected to be negligible as a result of promulgation of the regulations.

D. Costs

The increased costs which the heavy-duty engine manufacturers, and ultimately the consumer, will have to bear as a result of this regulation consists of costs for purchase and installation of new test facilities, for development and installation of new emission control systems, and for certification and SEA testing. For the diesel manufacturers, the new test facilities (mainly dynamometers and emission system development and hardware) will be the primary costs. For gasoline manufacturers, the emission controls will be highest. There are additional costs falling upon the operators of gasoline engine-equipped vehicles which are addressed below.

An increase of approximately $394 can be expected in the price of a gasoline engine, $253 of which is attributable to the manufacturing costs of the catalyst system. The remaining $141 is primarily attributable to profit, overhead, and equipment acquisition and modification costs, amortized over 5 years. For diesel engines, a first price increase of $195 is expected. Of this $195 increase, $56 is due to emission control development and hardware, and the remainder is found primarily in overhead, profit and new facilities related to the transient test procedure and SEA. It is because catalyst control will not be required of the diesel manufacturers that their production costs will be less than for the gasoline producers. Certification costs for both engine types are not expected to rise appreciably.

No increased operating costs are expected to fall upon the users of diesel-equipped vehicles. However, gasoline vehicle operators will incur the additional costs of unleaded fuel. Offsetting these costs is the reduced frequency of replacement of spark plugs and the exhaust system. In addition, EPA expects that the manufacturers will be able to achieve at least a 4 percent fuel economy gain in gasoline-fueled engines. This could lead to a discounted fuel savings of $788 per vehicle over its lifetime. The anticipated net increase in operational costs for the gasoline vehicle user amounts to about $259 (present worth on January 1, 1984, assuming a 10 percent interest rate), ignoring the fuel economy benefit.

The aggregate total costs for all heavy-duty engines produced in the five-year period beginning in model year 1984, discounted to the effective date of the regulations (January 1, 1984), is found to be $705 million for gasoline engines and $243 million for diesels. This aggregate cost includes the increased first cost for each engine plus increased operating costs, but does not include the fuel economy benefit for gasoline-fueled engines.

Because EPA expects the 1984 heavy-duty regulations to have only slight impacts on industry-wide sales, the industry's employment and production should not suffer. Also, users of heavy-duty vehicles and of other vehicles should expect no burden as a result of the rulemaking.

E. Alternatives

As EPA has proceeded with the development of a final rulemaking based upon analysis of comments received in response to the February NPRM, alternatives and options in essentially all aspects of the rulemaking have been evaluated. These alternatives fall into three broad areas: 1) alternatives to specific elements of the rulemaking, 2) alternative timing for implementation of the rulemaking, and 3) alternative levels of stringency for the emission standards. Each of these will be summarized separately.

1. Alternatives to Specific Elements of the Rulemaking

The test procedure was one of the most controversial aspects of the proposal. The alternative is to promulgate a regulation using either the 9- or 13-mode steady-state tests. The fundamental question relating to the test procedure relates to the ability of the steady-state procedure to adequately characterize in-use emissions of heavy-duty engines. Available data indicates that steady-state procedures are deficient in this regard. Therefore, the transient procedure will be used.

Alternatives relating to the redefinition of "useful life," durability testing, parameter adjustment, allowable maintenance, assembly-line testing with 10 percent AQL, and diesel crankcase control are treated in detail in the Summary and Analysis of Comments.

2. Alternative Timing for Implementation of the Rulemaking

The NPRM called for implementation of the regulation in 1983 in accordance with the 1977 Clean Air Act. Several comments were submitted by the manufacturers. EPA staff has analyzed the many comments of the manufacturers, and has concluded that gasoline-fueled engines could possibly comply by 1983 at a high risk. Some families of diesel engines could also comply, but those requiring significant reductions could not. Therefore, EPA has chosen to delay implementation of the regulation until 1984.

3. Alternative Levels of Stringency of the Standards

The Clean Air Act requires that EPA "conduct a continuing pollutant specific study concerning the effects of each air pollutant emitted from heavy-duty vehicles or engines and from other sources of mobile source related pollutants on the public health and welfare." The intent of requiring these reports was to provide some of the framework needed to evaluate the statutory standards for heavy-duty vehicles.

The statute provides for emission standards for both gasoline-fueled and diesel engines representing a 90 percent reduction from a 1969 gasoline-fueled engine baseline. Two alternatives are considered in this regulatory analysis. One considers an 85 percent reduction from baseline and the other considers a 95 percent reduction from baseline.

The effect of changing the stringency of the standard is significant over the average life of a heavy-duty vehicle. Analysis indicates that relaxing the standard to the 85 percent level would increase HC emissions by a factor of 1.4 for gasoline engines. A similar change occurs for CO. On the other hand, increasing the stringency would reduce HC by a factor of 1.7 for gasoline enignes and by 2.0 for diesel engines. Diesel CO emissions are unaffected by a change in the standard because they are already lower than the 95 percent reduction standard.

In terms of expenditure, the 85 percent standard would reduce the cost per engine from $477 to $426 for gasoline engines. For diesel engines, the 85 percent standard would reduce the per engine cost from $195 to $178. No gasoline or diesel engine cost differences were estimated for the 95 percent standard because the target CO level for gasoline engines and the target HC level for diesel engines are so low that the feasibility of this option is questionable.

F. Cost Effectiveness

Cost effectiveness as applied to pollution controls is the cost of control per ton of reduction in pollutant. EPA's calculations yield cost effectiveness numbers for gasoline engines of $238 per ton of HC and $8 per ton of CO reduction. Diesel costs are expected to be applied toward HC control, hence the entire cost is allocated to HC. The estimated cost effectiveness for this diesel HC control is $253 per ton of reduction. Also evaluated in this report are incremental cost-effectiveness values for the various components of the overall rulemaking.

It is EPA's position, especially in light of the benefits of the transient procedures, that the 1984 heavy-duty regulations are indeed cost effective.

CHAPTER II

INTRODUCTION

A. Heavy-Duty Engine Exhaust Emission Regulation Background

Heavy-duty engine exhaust emissions were first regulated by the State of California beginning in 1969 (see Table II-A for a summary of actual standards). The 1969 California emission standards were expressed only in terms of exhaust gas concentration, applied only to gasoline-fueled engines, and covered only HC and CO emissions. EPA adopted the California standards and test procedures for gasoline-fueled engines beginning in 1970, and imposed exhaust and smoke emission standards for diesel engines.

The next improvement in heavy-duty engine emission measurement techniques occurred with the introduction of revised heavy-duty engine test procedures (for both gasoline-fueled and diesel engines) by California for 1973. These regulations called for mass measurement of the pollutants, and extended the standards to NOx emissions by including a standard for HC + NOx. These procedures were adopted by EPA for 1974. These procedures, while different for gasoline-fueled and diesel engines, basically required the operation of engines on an engine dynamometer at several steady-state speeds. Samples of engine exhaust were collected during the various stages of gasoline "9 mode" and diesel "13 mode" tests, and quantities of HC, CO and NOx pollutants were determined. Emissions were measured as a function of the useful work performed by the engine, and expressed in grams of pollutant emitted per engine brake horsepower-hour (g/BHP-hr). The result was that an engine with high horsepower was allowed to pollute more than one with less horsepower, since it performs more useful work. These procedures remained in effect through 1978 with only minor technical improvements.

As part of an EPA heavy-duty test procedure development and technology assessment program begun in 1972, EPA evaluated the 1974-78 steady-state heavy-duty engine test procedures in an attempt to relate emissions measured on the test procedure to actual on-the-road HDV exhaust emissions. The data evaluated indicated that at emission levels below the 1974-78 standards, the results of emission tests using the 1974-78 test procedures were inadequate predictors of on-the-road CO and NOx emissions, i.e., a given reduction in emissions measured on the current test procedure results in a much smaller reduction in actual on-the-road emissions.1/

In 1977, EPA therefore adopted modifications to the 1974-78 test procedures which improved the accuracy of the test procedures enough to allow the promulgation of more stringent standards. The combination of the revised test procedures and new standards were

Table II-A

Heavy-Duty Engine Exhaust Emission Standards

	Federal					California				
Year	Option	HC	CO	NOx	HC+NOx	Option	HC	CO	NOx	HC+NOx
1969		NR	NR	NR	NR		275[a]	1.5[a]	NR	NR
1970-71		275[a]	1.5[a]	NR	NR		275	1.5	NR	NR
1972		275	1.5	NR	NR		180	1.0	NR	NR
1973		275	1.5	NR	NR		—	40[b]	—	16[b]
1974		—	40[b]	—	16[b]		—	40	—	16
1975-76		—	40	—	16		—	30	—	10
1977-78		—	40	—	16	A	—	25	—	5
						B	1.0	25	7.5	—
1979	A	1.5[c]	25	—	10[c]	A	1.5[c]	25	7.5	—
	B	—	25	—	5	B	—	25	—	5
1980-83	A	1.5[c]	25	—	10[c]	A	1.0	25	—	6
	B	—	25	—	5	B	—	25	—	5
1984		1.3[d]	15.5[d]	10.7	—		0.5	25	—	4.5
1985		1.3[d]	15.5[d]	75%[e]	—					

[a] HC = parts per million; CO = % mole volume. Used for Federal Standards 1970-73 and California Standards 1969-72.

[b] Grams per brake horsepower-hour.

[c] Measured on 1979 test procedure (HFID for HC). Reduced 0.5 g/BHP-hr when 1978 procedure is used (NDIR for HC). NDIR is allowed in 1979 for all manufacturers, beyond 1980 only for low volume manufacturers seeking Federal certification.

[d] As measured on transient test procedure.

[e] Reduction from 1972/73 baseline for gasoline engines.

NR = No requirement.

applicable beginning in 1979. They were referred to as the "interim regulations," because EPA intended to adopt more fundamentally revised test procedures and more stringent standards later. The interim regulations allowed manufacturers the option of two sets of emission standards, one emphasizing HC control and the other NOx control. All manufacturers were allowed to postpone use of the interim (modified) test procedures to 1980. Small-volume manufacturers were allowed to retain the old test procedures indefinitely under EPA regulations, but not under California regulations. California has established progressively more stringent standards using the interim test procedures. Current EPA standards do not change beyond 1979.2/

Since 1977, EPA has continued its development of a fundamentally new, heavy-duty engine test procedure to make emission reductions measured in the laboratory more representative of percent reductions one would expect to achieve in-use. Also, the 1977 Amendments to the Clean Air Act directed EPA to promulgate new HC and CO emission standards applicable in 1983 which would require a 90 percent reduction in each pollutant from a baseline of 1969 heavy-duty gasoline engines, and a new NOx standard applicable in 1985 which would require a 75 percent reduction from a baseline of 1973 heavy-duty gasoline engines. Based on its evaluation of the 1974-78 test procedures, EPA considers the current, interim test procedures to be incapable of ensuring reductions of these magnitudes in in-use emissions. Therefore, this action consists of the promulgation of the statutory HC and CO standards as measured on a new transient engine test procedure. The new test procedure is the culmination of EPA's development work begun in 1972. Promulgation of the statutory 1985 NOx standard will be proposed at a later date.

B. Description of Statutory Heavy-Duty Engine HC and CO Emission Control

1. New Emission Test Procedures

EPA is establishing new test procedures for determining gaseous exhaust emissions (including NOx) from heavy-duty engines. Key features of the new test procedures, especially the engine operating cycle, will likely be used for measuring diesel exhaust particulates starting in a model year yet to be proposed. When the diesel particulate regulations are proposed, the need for smoke standards will be addressed. In the meantime, the current diesel smoke measurement procedures will continue to be used after the new gaseous emission test procedure is in effect. EPA also requires that all manufacturers of heavy-duty engines use the new test procedures for certification testing, i.e., that the current optional use of the 1974-1978 test procedures by low volume manufacturers be ended after 1983. Heavy-duty diesel engine manufacturers are allowed the option of certifying their engine families using the 1979 procedure for 1984 only. All heavy-duty manufacturers must use the new test procedure for the 1985 model year.

Like the current test procedures, the new procedures measure emissions from engines while mounted and operating on an engine dynamometer. However, the new procedures differ from the current test procedures in several areas. The three fundamental points of difference are the engine operating cycles over which emissions are measured, the sampling method used to collect emissions during engine operation, and the requirement for both cold and hot start test segments. These three differences in turn necessitate several related changes involving engine mapping, instrumentation, and equipment calibration. The new test procedures closely resemble the current light-duty vehicle and light-duty truck test procedures (Subpart B of CFR Title 40 Part 86) in the areas of emission sampling, instrumentation, and equipment calibration. 3/

The new test procedures contain two transient engine operating cycles, one for gasoline-fueled engines and the other for diesel engines. The two cycles were developed by EPA from data on the operating characteristics of in-use heavy-duty engines of each type. 4/ Each cycle is specified by a second-by-second listing of pairs of normalized engine speed and power values. Unnormalizing the cycle into an actual speed-power cycle requires that the curve of maximum engine power vs. engine speed be known. Determining this curve experimentally is one of the earliest steps in the test sequence. After this engine mapping is done and the results are used to compile an actual speed-torque test cycle, the test engine is allowed a long soak or is subjected to a forced cool down. It is then started from the cold condition, operated over the test cycle, shut off for a brief soak, restarted in the hot condition, and operated again over the test cycle. Tolerances on how closely the engine must follow the test cycle are specified in the procedures.

Mass emissions for each pollutant and useful work output are measured separately for the cold start and hot start segments of the test. This allows emissions from in-use cold start trips (i.e., trips which begin with the engine at ambient temperature) to be estimated separately from emissions from in-use hot start trips. The two are then weighted with the ratio of the frequencies of the two types of in-use trips and divided by the similarly weighted useful work output to get the brake-specific emissions from an "average" in-use trip.

Mass emissions from each test segment are measured by diluting the hot exhaust gas stream with cooler air and collecting a small, proportional sample of this dilute mixture in a bag. The concentrations of pollutants in this bag are measured using analytical instruments suited to such measurements (a flame ionization detector for HC, a non-dispersive infrared analyzer for CO and CO_2, and a chemiluminescence analyzer for NOx), the total volume of dilute mixture is calculated from other measurements made during engine operation, and from these the mass of each pollutant emitted during the test segment is calculated. HC emissions, and at the discretion of the manufacturer, NOx emissions, from diesel engines are an exception: these are not bagged but are continuously sampled and analyzed during the test segment using heated sample lines and a heated flame ionization detector and the chemiluminescence analyzer. The test procedure allows the use of two types of constant volume sampling (CVS) systems known to be suitable for this type of emissions sampling, plus other systems if approved in advance.

Useful work output is measured via the measuring systems which are integral parts of the dynamometer controls.

Procedures are specified for periodic equipment calibrations, as necessary to ensure accurate test results.

The contrasts between the new and current test procedures highlight the important features of the new procedures. The operating cycles in the current procedures consist of sequences of specified steady-state modes (9 modes for gasoline-fueled engines, 13 modes for diesel engines) rather than of second-by-second listings of speed-power pairs. The current procedures therefore test engines at fewer points in their operating ranges than will the new cycles. The current procedures do not allow measurement of emissions during transient conditions representative of in-use operation. The new procedures will. Since under the current procedures emissions are not measured during periods when exhaust gas composition and volume are changing, dilution with air and proportional sampling into a collection bag are not used. Instead, pollutant concentrations in the exhaust gases are measured directly over a small portion of each mode and combined with other measurements to calculate mass emission results. This measurement of undiluted exhaust gases requires somewhat different analytical systems. Separate cold-start and hot-start segments are not performed. Calibration procedures for equipment, and tolerances on the operating cycles, are correspondingly different.

EPA is also establishing new test procedures to be used to determine emissions of CO under idle conditions. The test procedures are simple, and can be performed immediately after the transient test procedure. The idle test procedure will be used for only gasoline-fueled engines.

2. New Definition of "Useful Life"

EPA is amending the current definition of "useful life" for heavy-duty engines. The amendment will bring the periods of use specified in the definition into closer agreement with the periods of use actually seen by heavy-duty engines before retirement or major refurbishment (e.g., rebuilding or major overhaul).

The amended definition will apply to the assembly-line testing, warranty, recall, and certification provisions of the Clean Air Act. That is, manufacturers will be required to furnish owners with Section 207(a) and 207(b) warranties covering the period of use specified in the amended definition. A manufacturer will also be liable for recall of a category of its engines if the EPA Administrator determines that a substantial number of the category does not conform to the emission standards during that period. And the longer useful life definition will be incorporated into the certification and assembly-line testing procedures via deterioration factors, as described in the next subsection.

3. Revised Certification Requirements Regarding Durability

EPA had proposed a substantially revised durability test procedure in the NPRM, and had intended to finalize the procedure with this rulemaking. However, EPA is delaying the finalization of the in-use durability testing requirements, in order to improve this proposed procedure and to optimize all components of the program. A revised durability test procedure is expected to be implemented in conjunction with the statutory heavy-duty NOx emission standard.

Beginning in 1984, and until finalization of a revised durability test procedure, the burden of durability testing will be on the manufacturers. The manufacturers will determine their deterioration factors in programs which they design and submit these deterioration factors to EPA as part of the certification process.

4. Emission Standards

The HC and CO emission standards being established by EPA are applicable to 1984 and later model year heavy-duty engines. These standards require 90 percent reductions from a baseline of 1969 gasoline-fueled engines, as measured with the new test procedures. These reductions are those mandated by the Clean Air Act as amended. The new HC and CO standards will apply to both gasoline-fueled and diesel heavy-duty engines.

For most engines, EPA is not requiring more NOx control in 1984 than was required by the 1979-83 standards. It is not possible to simply keep the 1979-83 NOx standard in 1984, however, since there was no NOx-only standard for 1979-83. Further, the test procedures being promulgated for 1984 are different than those used in 1979-83. A NOx baseline of 1979 engines tested with the new procedures was used to derive a 1984 NOx standard that is based on a statistical analysis of the NOx levels from the engines in this sample.

A separate idle standard is also included in this package for CO emissions from gasoline-fueled engines. Idle operation represents the largest single mode of heavy-duty truck operation (approximately 25 percent of the time in the CAPE-21 program), and times of prolonged idle can also be occasions of high-population exposure such as at crowded intersections, loading docks, or pickup and discharge of bus passengers.

EPA has measured emissions from a series of 1969 and 1979 engines using the new test procedure, to establish numerical standards for HC, CO, and NOx. The final standards being promulgated as a result of this testing are 1.3 g/BHP-hr (HC), 15.5 g/BHP-hr (CO) and 10.7 g/BHP-hr (NOx) in 1984. In 1985, the HC and CO standards are the same, but the NOx standard will change to a level representing a 75 percent reduction from the 1972-73 baseline test program. An exact level will be proposed at a later date. The idle CO standard for gasoline-fuled engines is 0.5 percent (by volume).

5. <u>Parameter Adjustment</u>

EPA is amending the certification and test procedures to permit the Administrator to adjust or require manufacturers to adjust engine parameters to physically accessible settings other than their recommended settings prior to emission tests of emission-data engines. This will encourage manufacturers to design engines to be less susceptible to in-use maladjustment. Such maladjustment is capable of causing in-use emissions to be substantially higher than allowed by standards. The parameter adjustment provision will help ensure that the 90% reductions in HC and CO mandated by statute are actually achieved by in-use engines.

The specifics of the parameter adjustment rule are essentially the same as those of the recent final rule on parameter adjustment for light-duty vehicles and light-duty trucks. Four types of parameters on gasoline-fueled engines may be liable to EPA adjustment in 1984: idle mixture, idle speed, initial spark timing, and choke valve action parameters. Newly introduced parameters on either type of engine may also be liable to adjustment in the year they are introduced. In addition, exising parameters on either type of engine beyond the four mentioned above may become liable to adjustment if EPA notifies manufacturers and gives sufficient lead time for compliance. Parameters will be adjusted only if EPA determines that they pose or are reasonably likely to pose significant maladjustment problems in use. Procedures are included for making and appealing these determinations.

6. <u>The Selective Enforcement Audit Program (SEA), Production Compliance Auditing (PCA) and Nonconformance Penalties (NCP)</u>

The SEA program is an assembly-line emissions testing program used to aid in ensuring that the engines produced meet the emissions level to which they are certified. SEAs are initiated by a test order from EPA and cover only one engine configuration per test order. The number of SEAs a manufacturer must undergo each year is based primarily, but not exclusively, on projected annual sales. The goal in an SEA is to ascertain whether or not the production engines tested meet a 10 percent Acceptable Quality Level (AQL). A 10 percent AQL would require virtually all engines to meet applicable standards after adjustment for deterioration with only 10 percent allowed to exceed standards to provide for test variability and isolated instances of nonconformity.

Failure of an SEA may lead to suspension or revocation of the engine's certificate of conformity. The manufacturer would then be permitted to make running changes or quality control changes to the engine configuration and then undergo another SEA. Another possibility will be for the manufacturer to request a Production Compliance Audit (PCA) to determine the compliance level of the engine configuration, and then pay a Nonconformance Penalty (NCP) based on the "marginal cost" of compliance between engines in compliance and the nonconforming engines. The provisions for PCA's and for NCP's which were in the proposed rulemaking are not being finalized at this time. However, EPA expects they will be finalized in time for the 1984 regulation.

C. <u>Organization of the Regulatory Analysis</u>

This analysis presents an assessment of the environmental and economic impacts of the heavy-duty engine regulations EPA is promulgating. It provides a description of the information and analyses used to review all reasonable alternative actions before implementing the final rule.

The remainder of this statement is divided into five major sections. Chapter III presents a general description of heavy-duty vehicles and engines, a brief description of the manufacturers of this equipment, and the market in which they compete. It also will discuss the uses to which heavy-duty vehicles are put, and describe the primary user groups.

An assessment of the primary and secondary environmental impacts attributed to the heavy-duty engine regulations is given in Chapter IV. The degree of control reflected by standards is described and a projection of air pollutant emissions for the national heavy-duty vehicle population, with the standards in place through 1999, is presented. The impacts of these regulations on urban emissions and the expected air quality benefits are considered. Secondary effects on other air pollutant emissions, water pollution and noise are also discussed in this section.

An examination of the cost of complying with the regulations is presented in Chapter V. These costs include those incurred to install emission control equipment on heavy-duty engines, costs required to purchase new emission testing cells, the costs to certify, the costs associated with the SEA program, and any increased vehicle operating costs which might occur. Analysis is made to determine aggregate cost for the 1984-88 timeframe. Finally, the impact that this regulation will have on industry and consumers will be reviewed.

Chapter VI will identify and discuss the alternatives to this rulemaking action, their expected environmental impacts, and the reasons none have been promulgated.

Chapter VII will present a cost effectiveness analysis of this rulemaking action and compare the results of this analysis with those conducted on other mobile source control strategies.

<u>References</u>

1/ "An Examination of Interim Emission Control Strategies for Heavy-Duty Vehicles (A Regulatory Support Document)", EPA OMSAPC, October 3, 1975.

2/ Current Federal heavy-duty engine emission standards and test procedures are contained in the Code of Federal Regulations, Title 40, Part 86.

3/ The new test procedure, together with a list of supporting references, is contained in "Draft Recommended Practice for Determining Exhaust Emissions from Heavy-Duty Engines Under Transient Conditions," Chester J. France and William B. Clemmens, HDV 78-07, June 1978, available from the Emission Control Technology Division, EPA, Ann Arbor, Michigan.

4/ Descriptions of the surveillance project and subsequent cycle development can be found in the references listed in the report cited in the previous footnote.

CHAPTER III

DESCRIPTION OF THE PRODUCT AND THE INDUSTRY

A. Heavy-Duty Vehicles

A heavy-duty vehicle (HDV) as defined by EPA is a vehicle whose gross vehicle weight rating (GVWR) exceeds 8500 pounds. This differs from the definition in the amended Clean Air Act which specified 6000 pounds GVW as the lower limit of HDVs. The reason for this difference is that although EPA is required to regulate all vehicles heavier than 6000 pounds GVWR to at least the levels dictated by the Act1/, light-duty trucks in 6000-8500 pounds GVWR range are dealt with under separate regulations. These regulations are aimed at the greater than 8500 pound GVWR population only.

The industry as well uses GVWR as a basis for reporting production and sales data. Their traditional categories are:

Class	Weight (Pounds - GVWR)
I	0 - 6,000
II	6,001 - 10,000
III	10,001 - 14,000
IV	14,001 - 16,000
V	16,001 - 19,500
VI	19,501 - 26,000
VII	26,001 - 33,000
VIII	33,001 and over

EPA's definition of light-duty trucks sets the division between the LDT class and heavy-duty vehicle class at 8,500 pounds GVWR. Thus, some of the Class II trucks will be included with all of those in Classes III through VIII in the heavy-duty vehicle class. For purposes of the regulatory analysis Class IIA will cover GVWR's from 6,001 to 8,500 lbs. and Class IIB will cover 8,501 to 10,000 lbs. GVWR. In 1973, EPA estimated that only about 5 percent of those trucks in weight Classes I and II have gross vehicle weights in excess of 8,500 pounds.2/ The percentage appears to be somewhat higher today based on 1977 GM, Ford and Chrysler production data. A value of 5.5% will be used in this discussion. Table III-A gives the U.S. domestic factory sales plus imports from Canada of all trucks and buses for years 1972 thru 1978.

Heavy-duty trucks represent a heterogeneous class of vehicles, in terms of use and functional characteristics. While light-duty trucks are used by-and-large for personal transportation and agriculture, heavy-duty trucks are almost exclusively used for commercial purposes. The 1972 Census of Transportation conducted

Table III-A

U.S. Trucks and Buses by GVWR (pounds)
(U.S. Domestic Factory Sales plus Imports from Canada)

Year	0-* 8,500	8,501- 10,000	10,001- 14,000	14,001- 16,000	16,001- 19,500	19,501- 26,000	26,001- 33,000	33,000 and over	Yearly Totals
1978	3,218,772	187,336	34,014	5,959	3,982	157,168	41,516	163,836	3,812,583
1977	2,972,752	173,017	30.064	3,231	4,989	160,396	32,249	148,728	3,525,426
1976	2,525,755	147,002	43,411	67	8,920	149,293	22,918	103,098	3,000,466
1975	1,790,355	104,201	19,497	6,508	13,916	152,070	24,698	74,896	2,186,141
1974	2,088,200	121,535	8,916	8,120	24,366	215,221	32,364	160,465	2,659,187
1973	2,370,208	137,949	52,558	8,744	37,043	199,481	40,816	155,814	3,002,613
1972	1,929,883	112,321	57,803	10,353	37,492	177,723	40,150	130,328	2,496,054

* The MVMA does not split sales at 8,500 pounds GVWR, but rather publishes sales for the 0-6,000 and the 6,001-10,000 pound classes. The split in the table represents EPA's estimate.

Total Vehicles Subject to HD Regulations

1978	593,811
1977	552,674
1976	474,709
1975	395,786
1974	570,987
1973	632,405
1972	566,170

Source: FS-3, MVMA data.

by the Department of Commerce indicates that trucks are used in agriculture, construction, mining, wholesale and retail trade, manufacturing, and lumbering and forestry, as well as by the utility, service and "for hire" industries. Most functional applications of HDVs are not readily transferable to other transportation modes such as air, rail, water, or pipeline.

As Table III-B shows, the uses of heavy-duty vehicles vary with gross vehicle weight. For the lighter trucks, those in the 8,500-20,000 pound GVWR range, we find that the primary applications are in the agriculture, construction, services, and wholesale and retail trade markets, where the trucks are generally used for pickup and delivery. Personal use of trucks in this category, while limited, consists primarily of operation of motor homes built on truck chassis. Some people also use "heavy" pickup trucks for personal transportation.

HDVs in the 20,001 - 26,000 pound GVWR range find uses in the agriculture, construction, and wholesale and retail trade markets. Forestry, lumbering, and manufacturing account for most of the other applications.

The heavier trucks (26,001 pounds GVWR and over) are primarily found in the construction, wholesale and retail trade, and "for hire" markets. While the number of trucks used for mining and manufacturing is not large, these markets use the heavy trucks extensively. Trucks in this category are used only to a limited extent in the other market sectors.

Since the ultimate goal of the various commercial enterprises that use heavy trucks is to make a profit, trucks operated by these businesses are designed specifically to meet particular functional needs in an economical manner. Thus, the heavy-duty vehicles produced for the U.S. market are often "custom" built to satisfy requirements of the operational environment faced by the ultimate user. This operational environment might be defined in terms of economic variables (i.e., operating costs of alternative means of transport, value of products to be transported, operating costs of alternative types of trucks) or operational variables (i.e., distances to be travelled, qualities of the load to be transported, types of shipping procedures to be utilized, state and federal regulations on truck use, safety, operation).

Buses equipped with heavy-duty engines are usually in the 19,501 - 26,000 pound GVWR (Class VI) category. Uses of buses include school transportation as well as intercity and transit passenger service. Most school-type buses are gasoline-fueled, the remainder being diesels.

By defining their operating environment, users of heavy-duty vehicles can tell vehicle manufacturers exactly what characteris-

Table III-8

Trucks: Percent Distribution of Size Classes by Vehicle and Operational Characteristic: 1972

Characteristic	Number (Thousands)	Percent	10,000 Or Less Lbs. GVW	10,001-20,000 Lbs. GVW	20,001-26,000 Lbs. GVW	26,001 Or More Lbs. GVW
MAJOR USE						
Agriculture	4,258	21.6%	20.1%	32.1%	33.2%	10.3%
Forestry and Lumbering	187	1.0	.5	1.4	2.8	3.6
Mining	77	.4	.2	.6	.7	1.9
Construction	1,693	8.6	6.9	10.2	14.0	19.1
Manufacturing	443	2.3	1.3	3.3	4.4	8.5
Wholesale and Retail Trade	1,875	9.5	6.1	18.9	23.0	18.3
For Hire	770	3.9	.6	6.0	7.2	30.6
Personal Transportation	8,122	41.2	53.4	11.0	2.1	1.0
Utilities	505	2.6	2.5	3.1	3.8	1.9
Services	1,409	7.6	7.7	10.5	6.0	2.5
All Other	327	1.7	1.2	3.5	3.4	2.8
BODY TYPE						
Pickup, Panel, Multi-Stop, or Walk-in	14,464	73.3%	92.6%	31.3%	4.4%	2.1%
Platform	1,645	8.4	2.2	27.4	28.9	21.0
Platform w/ Added Device	336	1.8	.4	5.6	7.0	4.4
Cattlerack	479	2.5	1.4	6.7	6.7	2.4
Insulated Nonrefrigerated Van	96	.5	.1	1.2	1.2	3.1
Insulated Refrigerated Van	178	1.0	.1	2.4	2.3	5.3
Furniture Van	192	1.0	.2	3.7	2.8	3.2
Open Top Van	58	.3	.1	.6	.4	1.9
All Other Vans	610	3.1	.7	6.3	7.2	18.6
Beverage Truck	87	.5	.1	1.4	3.0	1.6
Utility Truck	370	1.9	1.7	3.4	2.0	.9
Garbage and Refuse Collector	69	.4	.1	1.3	1.4	1.2
Winch or Crane	83	.5	.1	.8	3.5	1.8
Wrecker	115	.6	.3	2.3	.6	.2
Pole and Logging	53	.3	.1	.3	1.4	2.4
Auto Transport	30	.2	.1	.2	.1	1.4
Dump Truck	468	2.4	.3	3.1	17.3	14.0
Tank Truck for Liquids	287	1.5	.1	2.3	9.7	9.1
Tank Truck for Dry Bulk	29	.2	—	.1	.6	1.5
Concrete Mixer	66	.4	.1	.2	.1	4.1
All Other	33	.2	.1	.6	.5	.6
ANNUAL MILES						
< 5,000	4,621	23.5%	22.0%	33.2%	35.8%	12.7%
5 - 9,999	5,540	28.1	30.2	25.6	25.2	13.8
10-19,999	6,598	33.5	36.2	27.8	24.0	22.4
20-29,999	1,647	8.4	8.1	8.1	8.3	11.5
30-49,999	772	4.0	2.9	4.1	4.9	13.4
50-74,999	270	1.4	.5	.9	1.5	11.5
> 75,000	300	1.5	.4	.6	.5	15.1
Total Percent		100.0%	100.0%	100.0%	100.0%	100.0%
Total Trucks	19,745		14,598	2,822	828	1,500

Source: 1972 Census of Transportation, U.S. Department of Commerce.

tics their truck should have when it is completed. Examples of the design parameters which may be specified include engine type (diesel or gasoline-fueled), horsepower, number of cylinders, displacement, natural aspiration vs. turbocharging, transmission, body type (single unit, or combination), gross vehicle weight, maximum load weight, vehicle length, number of axles, axle arrangement, distance between tandem axles, and tire size.

B. Heavy-Duty Vehicle Engines

One of the basic parameters that heavy-duty vehicle users must consider in determining what vehicle they need is the type of power plant they will use. Both diesel and gasoline-fueled engines are used to power heavy trucks and buses. Some tradeoffs that vehicle purchasers consider in the selection of diesel or gasoline-fueled engines for their vehicles follow:

Diesel Engines

1. Diesel fuel costs less than gasoline.
2. Diesels get up to twice the fuel mileage of comparable gasoline-fueled engines.
3. Diesels require less maintenance.
4. Diesels are generally more durable than gasoline-fueled engines and are often rebuilt.
5. The diesel rebuild interval (250,000-300,000) miles is up to three times longer than gasoline-fueled engines (100,000 - 125,000).
6. Diesels have higher resale values.

Gasoline-Fueled Engines

1. Gasoline is more readily available in most areas.
2. Gasoline-fueled engines generally start more easily in cold weather and give better overall performance.
3. Gasoline-fueled engine service and parts are more readily available.
4. Gasoline-fueled engines weigh less.
5. Gasoline-fueled engines cost considerably less than comparable diesel engines (about one-third as much).

The lighter trucks, classes IIB - VI are usually equipped with gasoline-fueled engines, as shown in Table III-C.

The heavier trucks (Classes VII and VIII) are equipped with diesel engines, as shown in Tables III-D and III-E. However, as fuel economy and fuel costs become more important to truck operators, diesel engines will become more popular in some of the lighter truck classes. Diesel engines are more fuel efficient and diesel fuel is cheaper than gasoline.

Table III-C

Gasoline Engine Usage in Heavy-Duty Vehicles

Year	8,501 10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001-and over	Yearly Totals
1978	187,336	34,014	5,959	3,982	144,923	15,597	7,160	398,971
1977	173,017	30,064	3,231	4,989	149,254	13,526	6,005	380,080
1976	147,002	43,411	67	8,920	143,077	11,597	5,561	359,635
1975	104,201	19,497	6,508	13,757	147,267	13,509	8,748	313,487
1974	121,535	8,916	8,120	24,325	211,861	19,382	19,138	413,277
1973	137,949	52,558	8,448	37,037	195,741	22,587	17,473	471,793
1972	112,321	57,803	10,138	37,487	174,019	27,482	13,855	433,105

Source: Table IIIA and Table IIID.

Table III-D

Diesel Usage in Heavy-Duty Vehicles

Year	8,501 10,000	10,001- 14,000	14,001- 16,000	16,001- 19,500	19,501- 26,000	26,001- 33,000	33,001- and over	Yearly Totals
1978	—	—	—	—	12,245	25,919	156,676	194,840
1977	—	—	—	—	11,142	18,723	142,723	172,588
1976	—	—	—	—	6,216	11,321	97,537	114,894
1975	—	—	—	159	4,803	11,189	66,148	82,299
1974	—	—	—	41	3,360	12,982	141,327	157,710
1973	—	—	296	6	3,740	18,229	138,341	160,612
1972	—	—	215	5	3,704	12,668	116,473	133,065

Source: FS-3, MVMA data.

Table III-E

Diesels Factory Sales as a Percentage of
All Heavy-Duty Vehicle Factory Sales

Year	8,501-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 and over	All HD Vehicles
1978	—	—	—	—	8%	62%	96%	32%
1977	—	—	—	—	7%	58%	96%	31%
1976	—	—	—	—	4%	49%	94%	24%
1975	—	—	—	1%	3%	45%	88%	21%
1974	—	—	—	—	2%	40%	88%	28%
1973	—	—	3%	—	2%	45%	89%	26%
1972	—	—	2%	—	2%	32%	89%	24%

Source: Tables III-A and III-D.

Manufacturers can effectively boost the power of both gasoline-fueled and diesel engines through turbocharging, though the first cost of the engine suffers somewhat. Because the availability of turbocharged engines is a further consideration of the prospective buyer/user, we have included a brief description.

A turbocharger combines a turbine, driven by engine exhaust gases, with a compressor which increases the air flow into the engine combustion chambers. Increasing the amount of air entering the combustion chambers permits more fuel to be injected and therefore more power is generated per piston stroke. In addition to generating more power than a naturally aspirated engine, turbochargers improve the fuel economy and emission characteristics of the engine. The increased air flow into the combustion chamber increases the inlet air pressure and inlet air temperature. This results in more complete combustion of the air/fuel mixture, particularly under cruise conditions. Fuel economy is improved and emissions of HC and CO are reduced. DOT and EPA have estimated that a 0 to 7 percent fuel economy improvement can be gained by the use of turbochargers on heavy-duty diesel engines.3/ Though turbocharger units can cost from $300 to $1,200, this higher first cost is soon paid back through lower operating costs.4/

C. Manufacturers

Unlike the automobile industry in which the vehicle manufacturer and the engine manufacturer are one and the same, heavy-duty vehicles and the engines used in them are often manufactured by independent companies. A single vehicle manufacturer may, in fact, use engines produced by several different companies. Even vehicle manufacturers that produce their own engines may use another company's engine in the vehicles they produce.

To simplify this discussion of producers of domestically sold heavy-duty trucks, vehicle manufacturers and engine manufacturers will be considered here separately. As an aid to the reader, the list below is provided giving the names of most of the manufacturers in the heavy-duty vehicle industry and their product(s). Summary financial and non-financial information on many of these companies can be found in Table III-Q.

Manufacturers	Engines (G-Gasoline) (D-Diesel)	Vehicles
Chrysler	G	(Chrysler, Dodge)
Ford	G	X
General Motors	G,D	(Chevrolet-GMC)
IHC	G,D	X
Mack Trucks	D	(Mack-Brockway)
Mercedes-Benz	D	X

Manufacturers	Engines	Vehicles
Volvo	D	X
White Engines, Inc.	D	
Caterpillar	D	
Cummins	D	
Deutz	D	
Nissan	D	
Fiat	D	
Hino	D	
Isuzu	D	
Mitsubishi	D	
Scania Vabis	D	
Perkins	D	
Freightliner		X
Peterbilt		X
Kenworth		X
FWD		X
Oshkosh		X
White Motors		X

1. Engine Manufacturers

Manufacturers of engines used in heavy-duty trucks typically fall into one of two categories, those that produce gasoline-fueled engines and those that produce diesel engines. Two companies; General Motors and International Harvester, produce both gasoline-fueled and diesel engines for use in on-road heavy-duty vehicles.

The manufacturers of gasoline-fueled engines and the engines they certified in 1979 are listed in Table III-F. All these manufacturers are domestically based and all produce their own line of heavy-duty trucks or buses. General Motors (GM), Ford, and Chrysler are perhaps most widely known as producers of light-duty passenger cars since it is from that line of business that they derive most of their revenue. However, all produce light-duty trucks and heavy-duty vehicles in addition to gasoline-fueled heavy-duty engines.

A fourth company producing gasoline-fueled engines for trucks sold in the U.S. is the International Harvester Company (IHC). Like the other three, IHC produces complete vehicles as well as gasoline engines — but no passenger cars. Their concentration is in the heavy-duty truck market with some emphasis on light-duty trucks. IHC also makes off-the-road vehicles for construction and industry and farm equipment.

Using past sales data supplied by the manufacturers EPA has estimated each manufacturers market share. Assuming no gasoline-fueled engine sales are made to other manufacturers the following market shares result:

Table III-F

Manufacturers of Gasoline-Fueled Engines
for Use in Heavy-Duty Vehicles

Manufacturer	Engine Families	Displacements Available (CID)
Chrysler	2	360, 440
Ford	6	300, 351, 370, 400 429, 460, 475, 534
GM	4	292, 350, 366, 427, 454
IHC	4	345, 391, 400, 447, 537

Federal Register Vol. 44, No. 140, Part III, July 19, 1979.

GM	43%
Ford	29%
Chrysler	16%
IHC	12%

These market shares are only an estimate since some engines are indeed sold to other manufacturers and also to recreational vehicle manufacturers.

As we turn to a discussion of diesels, it is important to realize that their manufacture and sale is accomplished by a different set of manufacturers than those involved in the production of gasoline engines. Only GM, via its subsidiary Detroit Diesel Allison, and International Harvester manufacture both engine types in significant quantities. Together their production of diesels accounts for something less than 35% of the total produced. The leading producer of diesel engines used in the U.S. trucks is the Cummins Engine Company, followed by Detroit Diesel (GM), Caterpillar, Mack Trucks, and IHC. A list of the engines made by these companies and several others is given in Table III-G. Table III-H presents a distribution by manufacturer of diesel engines used in U.S.-made trucks.

Like gasoline engines, most diesels are produced by domestic companies. Detroit Diesel Allison and Perkins Engine are subsidiaries of GM and Massey-Ferguson, LTD, respectively. Detroit Diesel sells both diesel engines and aircraft engines. In addition to Perkins' sales of diesel engines, Massey-Ferguson also produces agricultural, industrial and construction machinery, and recreation products.

Several of the other manufacturers of diesel engines, like Massey-Ferguson, make off-the-road vehicles. Caterpillar's product line includes construction, warehouse, agricultural, logging and petroleum equipment, accounting for 90% of total sales.

Mack Trucks produces diesel engines and the on-road trucks that use them. Mack is a subsidiary of Signal Companies, Inc., whose business includes aerospace and industrial equipment, petroleum and petrochemical products, and construction and fabricated products.

Cummins Engine Company is the leading producer of heavy-duty diesel engines with about 30% of the market. Cummins is unique in that it does not manufacture any vehicles, either on-road or off-road; nearly all of its sales are engines. Cummins also produces and markets crankshafts, turbochargers, and related components.

Table III-G

Manufacturers of Diesel-Fueled Engines for Use in Heavy-Duty Vehicles

Manufacturer	Engine Families	Displacements Available (CID)
Caterpillar	11	636, 638, 893, 1099
Cummins	10	555, 855, 903, 1150
Deutz	1	288
GM (DDA)	9	212, 426, 552, 568, 736
Hino	1	393
IHC	3	466, 549
Isuzu	2	235, 353
Iveco-Fiat	2	494, 584
Mack	4	672, 998
Mercedes Benz	3	346, 589
Mitsubishi	1	243
Scania Vabis	1	475
Volvo	3	334, 409, 586
White Engines	1	478

Source: Federal Register Vol. 44, No. 140, Part III., July 19, 1979.

2. Vehicle Manufacturers

It is the vehicle manufacturers who combine their own or someone else's engine with a chassis to fabricate the final product needed by the heavy-duty vehicle user. This final product is a bus, a single unit truck, or a tractor for pulling trailer units.

Tables III-I and III-J show the domestic factory sales numbers for trucks and buses respectively during 1978. It is clear that some firms concentrate on producing trucks of a certain weight class while others produce the entire spectrum. In 1978 trucks built by Ford, GM (Chevrolet and GMC), Chrysler (Dodge), and IHC appeared in nearly every class. GM and Ford dominated the market in almost every category and accounted for 39% and 37% respectively of total heavy-duty sales. Along with Chrysler (Dodge) and IHC, they produced all but a few of the vehicles with GVWRs below 26,000 pounds. Most of each of these manufacturer's trucks are gasoline-powered, using their own engines.

International Harvester is the largest producer of Class VII and VIII (26,000 pounds GVW and above) vehicles, and overall is fourth (behind GM, Ford, and Chrysler) in the production of heavy-duty trucks. As noted earlier, IHC also produces both gasoline and diesel engines.

The rest of the heavy-duty vehicle manufacturing industry consists of firms which account for less than five percent of total truck production. These firms concentrate on the production of the "heavy heavies", the Group VIII trucks (33,000 pounds GVW and over) that are used primarily for long haul work. FWD is a privately-owned company specializing in the production of custom built trucks used primarily by owner-operators. FWD produces an expensive truck package that is custom built to the buyer's specifications and produced in limited quantities. Mack, as mentioned in the heavy-duty engine manufacturers description, produces heavy-duty engines and Class VIII heavy-duty trucks. The White Motor Corporation is represented by "White", "Autocar" and "White Western Star" while also producing agricultural and construction equipment. Other manufacturers of Groups VII and VIII heavy trucks include Kenworth (PACCAR) and Peterbilt (PACCAR). These manufacturers specialize in custom-built HDs which are primarily procured by individual owner-operators (as opposed to fleets).

In contrast to the production of heavy-duty trucks, bus manufacturing is limited to only larger companies in the transportation manufacturing industry. As one can see from Table III-J, IHC, GM and Ford are the primary producers of intercity, transit, and school bus chassis in this country. For none of these companies is the sale of buses critical to the financial success of the firm.

Table III-8

Diesel Engines Used In Trucks From U.S. - 1978

Vehicle Mfr.	Diesel Engine Manufacturer: Cat.	Cummins	GM (DDA)	IHC	Mack	Mitsubishi	Nissan	Olds	Perkins	Scania Vabis	Total
Chevrolet	1,236	699	4,329	--	--	--	--	24,084	--	--	30,348
Chrysler	--	446	72	--	--	2,763	--	--	1,404	--	4,685
Ford	22,148	11,805	7,861	--	--	--	--	--	--	--	41,814
Freightliner	709	9,086	2,078	--	--	--	--	--	--	--	11,873
GMC	1,430	5,016	16,312	--	--	--	--	8,172	--	--	30,930
IHC	1,932	25,086	8,190	12,916	--	--	990	--	--	--	49,114
Kenworth	2,360	9,196	2,870	--	--	--	--	--	--	--	14,426
Mack	237	2,472	426	--	30,865	--	--	--	--	596	34,596
Peterbilt	2,166	5,779	1,605	--	--	--	--	--	--	--	9,550
White	935	9,745	3,735	--	--	--	--	--	--	--	14,415
Others	433	748	916	--	--	--	--	--	--	--	2,097
Total	33,586	80,078	48,394	12,916	30,865	2,763	990	32,256	1,404	596	243,848

Source: 1978 MVMA Data.

Table III-1

U.S. Truck Sales by Make and GVW Class, 1978

	6,001-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 & over	Total
Ford	946,934	698	--	137	55,899	15,531	22,293	1,041,492
Chevrolet	801,950	--	--	1,854	34,340	1,662	3,999	843,805
Dodge	322,658	52,643	15,250	85	207	17	--	390,860
IHC	36,065	--	8	--	29,964	16,494	34,051	116,574
GMC	215,185	1,540	--	822	24,898	3,925	14,460	260,830
Mack	--	--	--	--	--		27,390	27,390
Kenworth	--	--	--	--	--	--	14,345	14,345
Freightliner	--	--	--	--	--	--	11,725	11,725
Peterbilt	--	--	--	--	--	--	9,454	9,454
White	--	--	--	--	--	437	10,189	10,626
Jeep	78,326	--	--	--	--	--	--	78,326
Brockway	--	--	--	--	--	--	37	37
Western Star	--	--	--	--	--	--	786	786
Autocar	--	--	--	--	--	--	1,880	1,880
FWD	--	--	--	--	--	--	145	146
Misc.	6	93	--	35	1,705	929	2,087	4,855

Misc. includes Imports, Diamond Reo, Divco, Hendrickson, Oshkosh, etc.
Source: Automotive News Market Data Book, April 25, 1978.

Table III-J

1978 U.S. Bus Sales
(Including School Bus Chassis)

	8,500-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 & Over	Total
Chevrolet	—	—	—	—	4,430	—	—	4,430
GMC	—	—	—	—	2,397	218	1,049	3,664
Ford	—	—	—	—	7,007	—	—	7,007
IHC	—	—	—	—	13,968	62	—	14,030
AM/General	—	—	—	—	—	—	1,036	1,036
Others	—	—	—	—	173	235	803	1,211
TOTAL	—	—	—	—	27,975	515	2,888	31,378

Source: FS-3, 1978 MVMA data.

A brief look at the employment picture in the industry shows that 763 manufacturers of truck and bus bodies (including light-duty trucks) employed 40,796 people in 1976, and the 292 firms building truck trailers employed 20,697. (Table III-Q gives the number of employees in the major vehicle and engine manufacturers.)

D. Users of Heavy-Duty Vehicles

As Section A of this chapter notes, most heavy-duty vehicles are used for commercial puposes. The types of trucks used to meet the transportation needs of various enterprises are as diverse as the needs themselves. Basically, however, these trucks move some commodity from one point to another.

Table III-K lists some of the types of products moved by trucks and other means of transport and the percentage (by weight) that each means of transport carries. Though the data is somewhat outdated, it is interesting to see the fractional distribution of freight and how it is transported. As of 1972 nearly half of the commodities listed were shipped by truck, and in 1977, trucks carried almost 25% of all intercity freight.5/

Trucking can be divided into two types of carriers, local and intercity. The rule of thumb is that local carriers are those who conduct 50% or more of their business in a metropolitan area. The intercity (line haul or over-the-road) carriers conduct local pickup and delivery between metropolitan areas. Local carriers accounted for $67.5 billion in freight transportation expenses and intercity carriers $67.3 billion in 1978.5/

Another way of examining the trucking industry is to distinguish between private ownership and "for hire" trucking. The trucks in "private" fleets are under the control of each particular company for the shipment of their own goods, trucking not being their principle business. Examples of "private" truck owners are the various utility companies (e.g., Bell Telephone System) or retail stores that own their own delivery trucks, and manufacturers of consumer products who make deliveries to retail concerns.

In contrast, "for hire" trucks are used by companies or individual owner/operators whose business it is to transport someone else's freight.5/ Examples of firms in this latter category are United Parcel Service, Roadway Express, Consolidated Freightways, and the various movers of household goods (United Van Lines, North American Van Lines, Allied Van Lines). Some companies, like Hertz and Ryder, are in the business of renting trucks for use by others.

"For hire" trucks accounted for about 4% of the trucks in use in 1975. Over fifty percent of these trucks were combinations (tractor-trailer) most with five or more axles (see Table III-L).6/

Table III-K

Commodities Shipped by Mode of Transport

Group	Tons					Tons/Miles				
	Motor Carrier	Private Truck	Total Truck	Rail	Other	Motor Carrier	Private Truck	Total Truck	Rail	Other
Meat & Dairy Products	41.7%	39.1%	80.8%	18.8%	.4%	54.3%	17.2%	71.5%	27.8%	.6%
Canned, Frozen & Other Food Products	20.3	23.0	43.3	50.7	6.0	18.3	9.5	27.8	66.8	5.4
Candy, Cookies, Beverages Tobacco Products	25.7	58.4	84.1	15.4	.4	28.8	25.8	54.6	43.1	2.2
Basic Textiles & Leather Products	61.4	27.7	89.1	9.7	1.2	61.0	21.0	82.0	16.1	1.8
Apparel & Related Products	69.4	15.6	85.0	8.5	6.5	67.0	9.5	76.5	13.4	10.1
Paper & Allied Products	28.0	17.9	45.9	51.7	2.3	18.9	5.6	24.5	73.8	1.5
Basic Chemicals, Plastics, Synthetic Rubber & Fibers	30.1	12.1	42.2	48.6	9.2	21.6	4.7	26.3	63.1	10.5
Drugs, Paints & Other Chemical Products	38.6	15.7	54.3	37.8	7.9	32.0	8.4	40.4	44.3	15.2
Petroleum & Coal Products	16.0	8.4	24.4	9.7	65.8	3.4	1.6	5.0	7.9	87.1
Rubber & Plastic Products	59.1	15.2	74.3	24.4	1.2	56.8	9.3	66.1	32.1	1.8
Lumber & Wood Products, Except Furniture	16.2	36.3	52.5	45.8	1.6	7.6	10.7	18.3	76.8	4.9
Furniture & Fixtures	41.4	34.7	76.1	22.0	1.9	39.9	20.5	60.4	37.1	2.5
Stone, Clay & Glass Products	47.2	23.7	70.9	21.9	7.2	36.6	11.3	47.9	45.3	6.7
Primary Iron & Steel Products	44.4	6.7	51.1	43.7	5.2	35.9	4.8	40.7	51.6	7.7
Primary Nonferrous Metal Products	31.4	15.1	46.5	51.6	1.9	23.4	7.7	31.1	67.2	1.6
Fabricated Metal Products	55.3	25.1	80.4	17.3	2.3	60.1	13.0	73.1	23.3	3.6
Metal Cans & Misc. Metal Products	44.1	17.8	61.9	36.8	1.3	40.3	7.1	47.4	50.5	2.1
Industrial Machinery, Except Electrical	59.4	18.9	78.3	19.6	2.0	75.7	8.9	84.6	12.3	3.0
Machinery, Except Electrical and Industrial	53.4	17.7	71.1	26.5	2.3	49.7	8.9	58.6	37.7	3.6
Communication Products & Parts	64.5	12.4	76.9	13.0	10.0	59.9	5.6	65.5	18.0	16.5

Table III-K (Cont'd)

<u>Commodities Shipped by Mode of Transport</u>

Group	Tons					Tons/Miles				
	Motor Carrier	Private Truck	Total Truck	Rail	Other	Motor Carrier	Private Truck	Total Truck	Rail	Other
Electrical Products & Supplies	49.3	14.1	63.4	35.0	1.3	46.0	8.4	54.4	43.2	2.6
Motor Vehicles & Equipment	37.3	3.0	40.3	59.3	.4	17.4	1.0	18.4	80.9	.8
Transportation Equipment Except Vehicles	23.9	54.8	78.7	19.5	1.8	30.3	43.1	73.4	24.0	2.7
Instruments, Photo Equipment Watches & Clocks	63.8	10.9	74.7	20.9	4.4	53.9	5.7	59.6	34.4	6.0
TOTAL ALL SHIPPER GROUPS	31.1%	18.3%	49.4%	31.7%	18.8%	20.9%	6.8%	27.7%	42.0%	30.3%
Total all Shipper Groups Except Petroleum and Coal	35.7%	21.3%	57.0%	38.4%	4.5%	28.6%	9.1%	37.7%	56.9%	5.4%

Source: <u>Motor Vehicle Facts and Figures</u>, 1976
Data from 1972 Commodity Transportation Survey - U.S. Bureau of Census.

Table III-L

"For Hire" Trucks In Use (1975)

Single-Unit Trucks		
2 Axles	378,845	39.4
3 Axles	43,276	4.6
Subtotal	422,121	44.0
Combination Trucks		
3 Axles	70,181	7.3
4 Axles	145,899	15.2
5 or more	321,499	33.5
Subtotal	537,579	56.0
Total Trucks for Hire	959,700	100.0
Total Trucks In Use	23,648,008	
% Trucks Used for Hire	4.06%	

Source: Transportation Energy Conservation Data Book, Edition 3, February 1979, Oak Ridge National Laboratory, Table 1.26.

To remain competitive with alternative means of transport, intercity carriers work on a small margin over costs. Costs for drivers are about 30% of the total. Costs of equipment account for another 9.0% of the total and operating costs (fuel/maintenance) about 11%. In 1974 there were approximately 2,800 Class I and II motor carriers. Finally, employment in the trucking industry amounted to 9,052,000 people in 1973 (ATA estimate).

Heavy-duty engine exhaust emission regulations will, of course, also apply to buses. As an example of how this segment of the vehicle population is made up, in 1977 there were about 20,000 buses being operated in the U.S. by 1050 intercity transit bus companies, employing about 44,000 people. There were also 48,700 buses being operated by local transit companies. Most of these transit buses are equipped with diesel engines. School buses, however, account for the overwhelming number of buses on the roads. In 1977 over 298,800 publicly- and privately-owned school buses were in operation. They accounted for over 80 percent of all buses on the road and were nearly all gasoline-powered.5/

E. The Future of Heavy-Duty Vehicles

The next decade is sure to bring changes in the heavy-duty vehicle industry. Changes in GNP and weight and length restrictions may tend to slow the rate of growth of the heavy-duty vehicle fleet. Increasing real fuel costs will certainly lead to further development and utilization of the efficient diesel engines. Although precise predictions are impossible, the discussion which follows addresses some of the major factors which will affect the size and composition of the heavy-duty vehicle fleet in the next decade.

The GNP growth rate is expected to slow in the next decade as compared to the 1970's in which it slowed as compared to the 1960's. The main reason is the energy problem. A corollary of a declining rate of growth in GNP is a declining rate of growth in commercial freight and therefore, a lesser growth rate in sales of heavy-duty vehicles to move that freight.

Another area of change which will affect the sales of heavy-duty vehicles in the next decade is deregulation of the trucking industry. Spurred by the trucking industry, the Federal Government, and the fuel crisis, states should continue to move towards uniform weight and length limitations. This will decrease the number of miles that trucks have to travel since many unnecessary miles are due to the differences in state regulations.7/ Trucks today go around states where regulations are more restrictive since that is cheaper than making two trips through the state to meet weight restrictions or having to reload into a shorter trailer to meet length restrictions.

Along with uniform regulations, less strict weight and length limits may be implemented. Double and triple-trailer rigs can substantially reduce the gallons of fuel used per ton-mile traveled. It is estimated that doubling of gross combination weight results in more than a doubling in fuel efficiency as measured by ton-miles per gallon of fuel. Of course these weight and length restriction changes will continue to be debated in view of safety and environmental concerns.

Restrictions on return trip loads should be eased. This will reduce the number of empty backhauling trips and therefore increase fuel efficiency.

All of the above regulation changes will tend to decrease the rate of growth of the heavy-duty vehicle fleet. Trucks will carry more freight per trip from both a weight and a volume viewpoint. Also, the number of miles per trip should decrease due to less bypassing of overly restrictive states. On the other side of the future heavy-duty vehicle sales equation is the fact that heavy-duty vehicle lifetimes may tend to diminish somewhat since they will be doing more work per hour and per mile. This will place more stress on engines and drivetrains resulting in increased wear and tear. Durability will become increasingly important.

The fuel crisis, while being an underlying cause of all of the above changes, will be a direct cause of the shift from gasoline-fueled engines to diesel engines. As mentioned previously in this chapter, diesel engines are more fuel efficient than gasoline-fueled engines. Coupled with the greater durability of diesels, the fuel efficiency advantage should continue to increase the diesel's market share.

The switch to diesels will not be as fast as the mechanical advantages of diesels would predict. Environmental, social, and economic concerns will prevent the extremely rapid rate of dieselization predicted in some studies.4/,8/ Concern over future particulate and NOx regulations will prevent manufacturers from fully commitng to diesel production until they are confident that such regulations can be met without adversely affecting the economic advantage of the diesel. As more diesels are put into use, the diesel fuel shortages may increase to a greater degree than gasoline fuel shortages. This was demonstrated with the fuel shortages in the spring of 1979. The specter of diesel fuel shortages may dampen demand. Basic economics predicts that as diesel fuel demand increases, its price will increase, which will also remove some of the diesel advantage. Finally, lack of confidence in diesel cold-start capability and maintenance availability is still a concern with many prospective owners.

EPA is projecting that the current growth in heavy-duty vehicle sales will decrease slightly in the mid-eighties. The major change expected is a shift to diesels in the heavier weight classes.

To project total heavy-duty vehicle sales by weight class EPA used several steps.

First, the total heavy-duty vehicle sales by domestic manufacturers for the years 1967-1978 were determined from MVMA data. A linear regression through this data gave a sales growth of 10,903 per year.

The next step in this process was to account for imports, primarily Canadian. The data available to EPA indicated that on a year to year basis, Canadian imports were mathematically about 10 percent of domestic sales by U.S. manufacturers. So the growth rate was increased by 10 percent to about 12,000 per year.

To apportion the sales across the weight classes, historical percentages from the period 1974-1978 were used. These percentages, as shown below, are percentages of total sales in each weight class and have been assumed not to change in the mid-1980's.

Class IIB	8,501 - 10,000#	28.3%
Class III	10,001 - 14,000#	5.3%
Class IV	14,001 - 16,000#	0.9%
Class V	16,001 - 19,500#	2.2%
Class VI	19,501 - 26,000#	32.2%
Class VII	26,001 - 33,000#	5.9%
Class VIII	33,001 and over	25.2%

Table III-M contains the total projected haevy-duty vehicle sales for the period 1984-1988.

To determine how the total heavy-duty sales in each weight class will be divided between gasoline-fueled engines and diesel engines, EPA used several input sources and in a few cases best judgment. This methodology will be discussed on a per class basis in the following paragraphs.

<u>Classes IIB, III, IV, V</u> - Based on data submitted in the light-duty diesel particulate rulemaking action it appears that dieselization in lighter gross vehicle weight will not be as great as in the heavier weight classes. This slower dieselization rate will be caused in part by the larger initial purchase price of the diesel, slightly poorer performance of diesels, and less availability of maintenance for diesels. Based on the light-duty diesel summary and analysis of comments, our projections will allow 20 percent of the sales in each of these classes to be diesel by 1990 <u>9/</u> and the percentage of diesel sales to grow at a steady 2 percent per year for the period 1984-1988 (see Table III-N).

Table III-M

Estimated HDV Sales for
1984 through 1988 by GVWR (pounds)

Year	8,501-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 and over	All HD Vehicles
1988	192,760	36,100	6,130	14,985	219,324	40,187	171,645	681,131
1987	189,366	35,464	6,022	14,721	215,462	39,479	168,623	669,137
1986	185,971	34,829	5,915	14,457	211,600	38,771	165,600	657,142
1985	182,577	34,193	5,806	14,193	207,738	38,064	162,578	645,149
1984	179,183	33,557	5,698	13,929	203,876	37,356	159,555	633,154

Table III-N

Estimated Diesel Sales as a Percentage of Heavy-Duty Sales for 1984 through 1988 by GVWR (pounds)

Year	8,501-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 and over	All HD Vehicles
1988	16%	16%	16%	16%	41%	100%	100%	50%
1987	14%	14%	14%	14%	38%	96%	100%	48%
1986	12%	12%	12%	12%	34%	92%	100%	46%
1985	10%	10%	10%	10%	31%	89%	100%	44%
1984	8%	8%	8%	8%	28%	85%	100%	42%

Class VI - This class is comprised primarily of "medium-duty" trucks and school buses. Historically, school buses are about 18 percent of the sales each year. In an article published in "Fleet Specialist" magazine, several manufacturers estimated Class VI diesel/truck sales in the mid-eighties. The manufacturers estimated that in 1985 between 35 and 50 percent of Class VI truck sales would be diesel.10/ Currently only about 10 percent are diesel. Our analysis will conversatively use the 35 percent figure. Dieselization in school buses is difficult to estimate. Significant growth in school bus sales is not expected due to declining school enrollments and the almost complete implementation of "court ordered busing." Most school buses do not accumulate enough mileage on a daily basis, and thus enough fuel savings, to fully justify the increased initial cost of a diesel engine. Lacking a more specific estimate, best judgment dictates that by 1990 about 10 percent of all school bus sales will have diesel engines.

Class VII - In 1978 Class VII sales were more than 61 percent diesel with dieselization in this class increasing rapidly over the past five years. Sales in this weight class are expected to become mostly diesel in the mid-eighties. Based on historical ratios, this class should be almost all diesel by 1988.

Class VIII - Sales in Class VIII were over 96 percent diesel in 1978. Based on the recent history in this class, these sales will all be diesel by 1984 or earlier. It is reasonable that by 1984 all Class VIII sales will be diesel.

Using the data in Table III-M, and the criteria in the discussions above, Tables III-O and III-P contain the estimated sales split by weight class between gasoline and diesel engines for the period 1984-1988.

Based on this analysis, the major changes expected give an overall heavy-duty sales growth of about 1.8% per year over the 5 year period (1984-1988). The increased dieselization in all classes will actually lead to a decrease of about 2 percent per year in gasoline-fueled engine sales and an increase of about 6.4 percent per year in diesel engine sales over the 5-year period.

Table III-O

Estimated Diesel Usage in Heavy-Duty Vehicles for 1984 through 1988 by GVWR (pounds)

Year	8,501-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 and over	All HD Vehicles
1988	30,841	5,776	981	2,398	89,755	40,187	171,645	341,583
1987	26,511	4,965	843	2,061	80,984	37,979	168,623	321,966
1986	22,316	4,179	710	1,735	72,490	35,824	165,600	302,854
1985	18,258	3,419	581	1,419	64,275	33,725	162,578	284,255
1984	14,335	2,685	456	1,114	56,338	31,678	159,555	266,161

Table III-P

Estimated Gasoline-Fueled Usage in Heavy-Duty Vehicles for 1984 through 1988 by GVWR (pounds)

Year	8,501-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	33,001 and over	All HD Vehicles
1988	161,918	30,324	5,149	12,587	129,569	0	0	339,547
1987	162,855	30,499	5,179	12,660	134,478	1,500	0	347,171
1986	163,654	30,650	5,204	12,722	139,110	2,947	0	354,287
1985	164,313	30,774	5,225	12,774	143,463	4,339	0	360,888
1984	164,848	30,872	5,242	12,815	147,536	5,678	0	366,991

Table III-Q

1978 Vehicle and Engine Manufacturer Information

Company	Total Sales ($)	Net Income ($)	No. of Employees
American Motors	2,585,430,000	36,690,000	27,517
Caterpillar	7,219,200,000	566,300,000	84,004
Chrysler	16,340,700,000	-204,600,000	157,958
Cummins Engine	1,520,750,000	64,400,000	23,298
Ford Motor	42,784,100,000	1,588,900,000	506,531
General Motors	63,221,100,000	3,508,000,000	839,000
International Harvester	6,664,350,000	186,680,000	95,450
Mack Trucks	1,640,010,000	68,800,000	17,100
White Motor	1,095,710,000	330,000	9,232

References

1/ Clean Air Act as Amended, August 1977; 202(b)(3)(C).

2/ Based on 1973 GM and Ford production data.

3/ Panel Report Number 7, Truck and Bus Panel Report, "Study of Potential for Motor Vehicle Fuel Economy Improvement," U.S. DOT and U.S. EPA, January 10, 1975.

4/ Interagency Study of Post-1980 Goals for Commercial Motor Vehicles; U.S. Department of Transportation, Draft Report, June, 1976.

5/ Motor Vehicle Facts and Figures, 1978 MVMA data.

6/ Transportation Energy Conservation Data Book, Edition 3, February 1979, Oak Ridge National Laboratory, Table 1.26.

7/ Trucking in 1995, Motor Vehicle Manufacturers Association, Contract No. LADU 7502-C6.12, June 1975.

8/ The Impact of Future Diesel Emissions on the Air Quality of Large Cities; U.S. EPA, Contract No. 68-02-2585, February, 1979. Also available as EPA 450/5-79-005.

9/ Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Light-Duty Diesel Particulate for 1981 and Later Model Year Vehicles, August 1979, U.S. EPA, OMSAPC, ECTD.

10/ Fleet Specialist May, June 1979, pp. 31-39.

CHAPTER IV

ENVIRONMENTAL IMPACT

A. Background

The Clean Air Act as amended in 1970 contained many provisions aimed at removing harmful pollutants from the air we breathe. Among other things, the 1970 Act called for the establishment of National Ambient Air Quality Standards. These levels were to be set such that there would be no danger to public health and welfare. To date, ambient air quality standards have been set for five pollutants: particulate matter, sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and ozone (of which hydrocarbons (HC) is the main precursor). Of these five pollutants, mobile sources are major contributors to the total pollutants emitted for three: HC, CO, and NOx. This regulation package concerns reduction in HC and CO from heavy-duty vehicles. Therefore, the environmental impact analysis will not involve NOx.

Both HC and CO emission have been related to adverse health effects. Detailed information on the health affects of HC and CO will not be discussed in depth in this Regulatory Analysis since such information is well documented elsewhere.1/ Briefly, HC emissions react with sunlight to form ozone and other photochemical oxidants. Ozone is a pulmonary irritant that affects the respiratory mucous membranes, other lung tissues, and respiratory functions. CO when inhaled replaces oxygen in the blood. The presence of CO adversely affects the carrying and delivering capacity of oxygen by the blood.

Although significant improvements have been made in air quality since 1970, a review of air quality monitoring data makes it clear that additional reductions in HC and CO emissions will be necessary if ambient air quality goals set by Congress in the Clean Air Act are to be achieved. On March 3, 1978, EPA published in the Federal Register a listing on a State-by-State, pollutant-by-pollutant basis, of the attainment status of every area of the Nation (43 FR 8962). This information, compiled by the respective States and reviewed by EPA, was the most accurate picture available of the nation's air quality status as of the adoption of the Clean Air Act Amendments. These data indicated that of 3215 counties or county equivalents covered by those designations, 607 (19 percent) were classified as nonattainment for photochemical oxidant, and 190 (6 percent) were classified as nonattainment for carbon monoxide. Nonattainment status indicates that the given area fails to meet the primary national ambient air quality standard (NAAQS) for the pollutant under consideration based upon either direct air quality monitoring or indirect estimates for areas lacking monitoring data. Current non-attainment data is available to indicate the changes which have occured since 1977. As of July, 1979, the non-attainment designations include 586 (18 percent) counties for ozone and 164 (5 percent) for carbon monoxide.

Since the U.S. population is not uniformly distributed, but rather is concentrated in urbanized areas, the above geographically based figures are not representative of the proportions of population actually exposed to excessive ambient pollutant concentrations. Indeed, it is the very fact of urbanization which has led to many of our air pollution problems. For example, the nonattainment areas for ozone include 103 out of a total of 105 urban areas in the U.S. with populations greater than 200,000 (the exceptions being Honolulu, Hawaii, and Spokane, Washington). The 103 areas represent an exposure of over 100 million people.

Clearly, there is a great need to reduce pollutant (or pollutant precursor in the case of ozone) emissions in the urban areas of the U.S. So long as large numbers of people continue to be exposed to concentrations in excess of the NAAQS, further emission reductions must be sought.

Mobile sources have been recognized for some time as major sources of hydrocarbons (ozone precursors) and carbon monoxide. Light-duty vehicles in particular have been the focus of considerable control work since the late 1960's. However, as light-duty vehicle emissions grow smaller, other source categories such as heavy-duty vehicles grow in proportional significance. The wisdom of controlling heavy duty vehicle emissions is evident when these emissions are placed in the context of other sources of these same pollutants.

In order to properly assess mobile source emissions and their control, it is best to look at urban areas where historically the NAAQS contraventions have occurred. In this way a truer perspective of the air quality impact of mobile sources can be obtained. It is in these urban areas that improvements are most needed. The selection of the areas to analyze will be discussed in detail below in Section 2. The HC analysis will be done on an Air Quality Control Region (AQCR) basis. CO, on the other hand, will be analyzed on a county basis. This is due to the more localized nature of CO problems. Fifty seven AQCRs have been selected for HC, and 52 counties for CO. Hydrocarbons analyzed include only non-methane hydrocarbons since the methane fraction is non-reactive.

Figures IV-A and IV-B present breakdowns of non-methane hydrocarbon (NMHC) and CO emissions into various source categories for the selected regions. These figures give the 1976 emission levels along with projected levels out to 1999. The data presented in these figures represents what is considered the base case. That is, it projects future heavy-duty emissions as if no new regula-

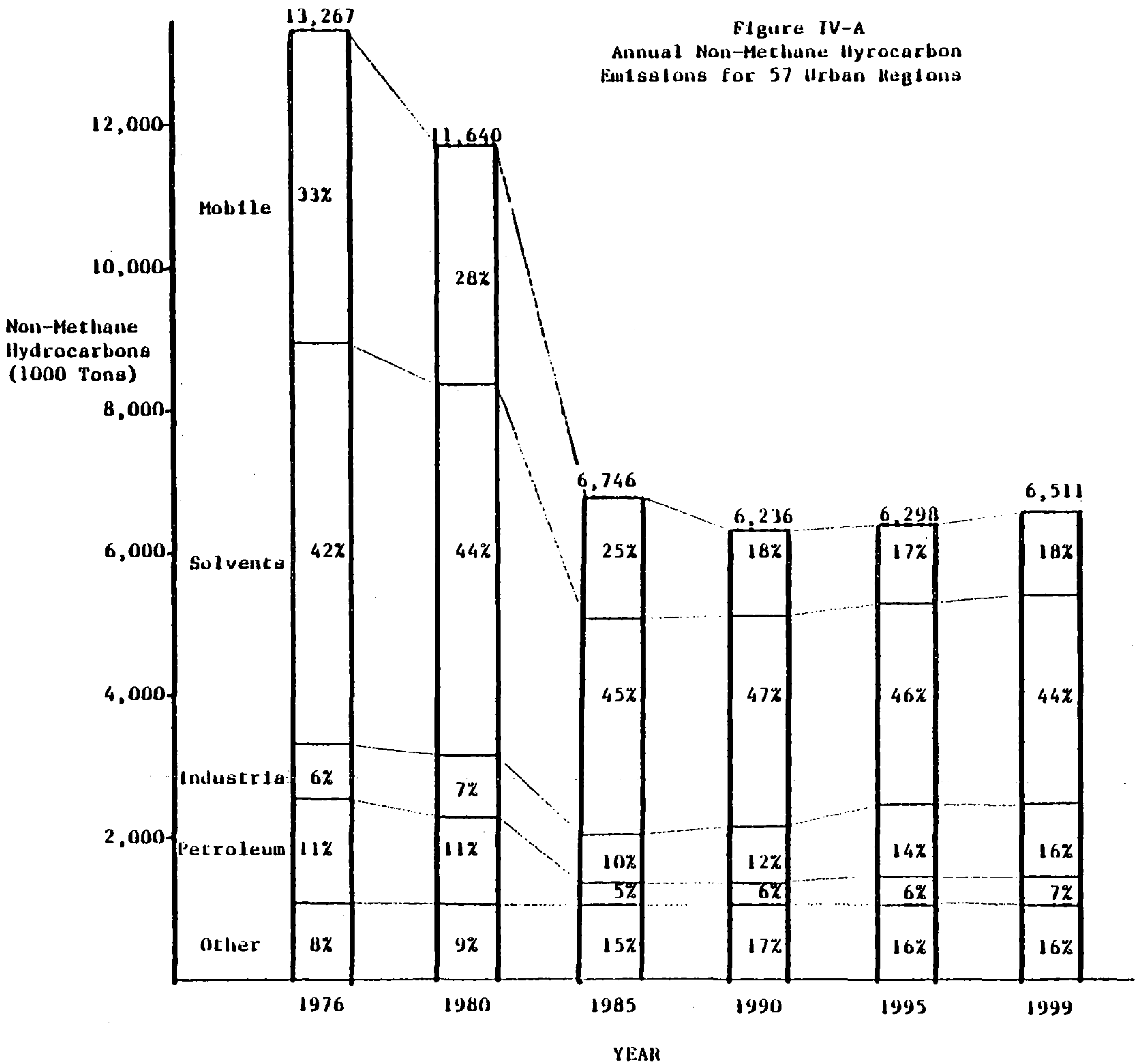


Figure IV-A
Annual Non-Methane Hyrocarbon
Emissions for 57 Urban Regions

3

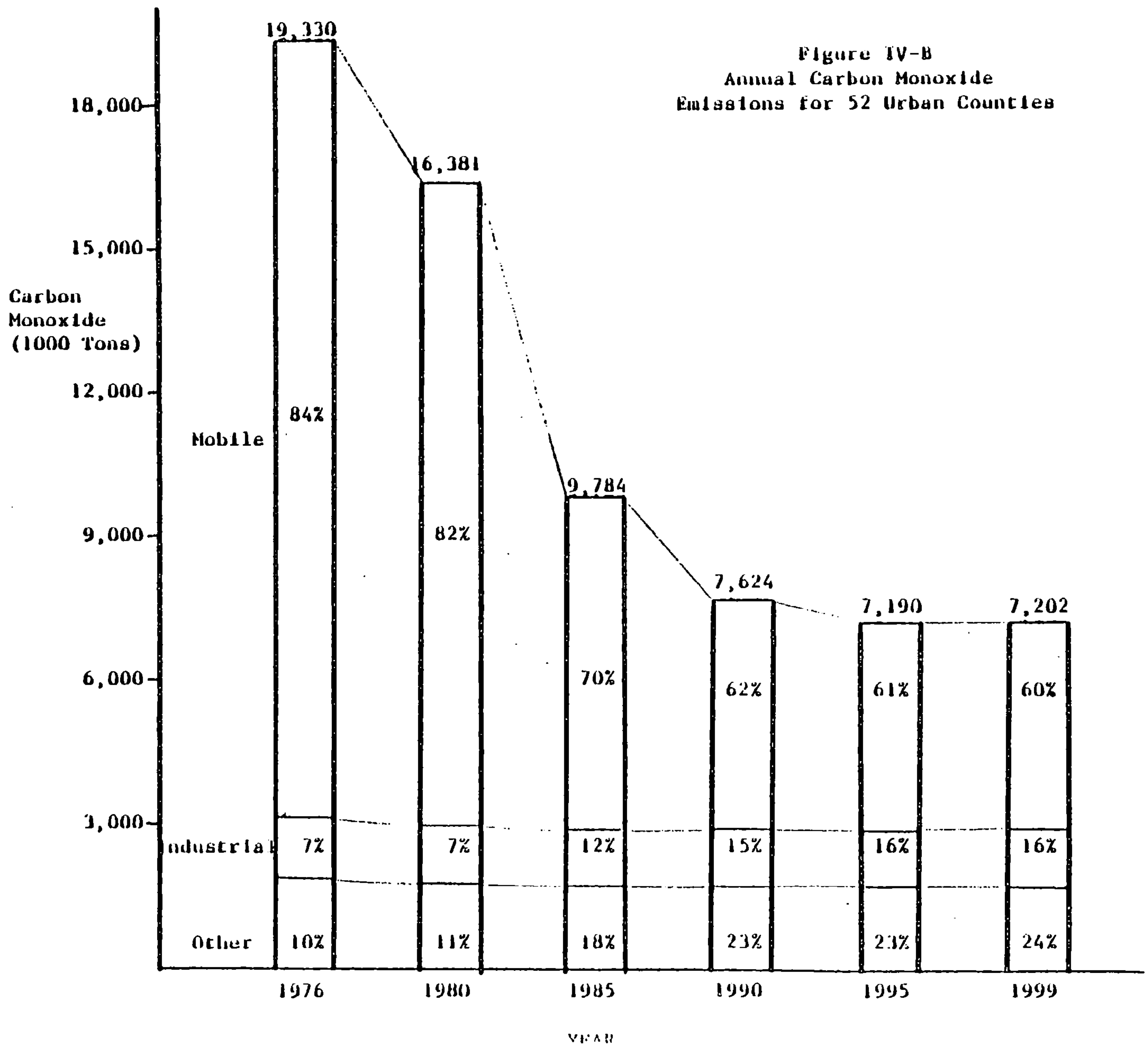


Figure IV-B
Annual Carbon Monoxide
Emissions for 52 Urban Counties
Carbon
Monoxide
(1000 Tons)
18,000
15,000
12,000
9,000
6,000
3,000
19,330
16,381
9,784
7,624
7,190
7,202
Mobile
84%
82%
70%
62%
61%
60%
Industrial
7%
7%
12%
15%
16%
16%
Other
10%
11%
18%
23%
23%
24%
1976
1980
1985
1990
1995
1999
YEAR

tions beyond those already in existence (the 1979 heavy-duty standards) were promulgated. For other source categories, known future control programs are included. For example, light-duty trucks are projected based upon the 1984 implementation of the regulations proposed for light-duty trucks in the July 12, 1979 Federal Register (44FR 40784).2/

For non-methane hydrocarbons, mobile sources currently represent approximately 30 percent of the urban emissions (Fig. IV-A). With current regulations this percentage is expected to decline to 17 percent by 1995. After that time a gradual increase begins to set in.

Mobile source carbon monoxide emissions currently represent over 80 percent of the urban emissions (Figure IV-B). This amount is expected to decline to 60 percent by 1999. No significant change in stationary source emissions is expected for CO. However, since CO problems are often attributed to high localized concentrations during periods of high traffic density, stationary sources have minimal impact on CO air quality problems.

Light-duty vehicles (passenger cars) contribute the major portion of mobile source NMHC and CO emissions. The 1976 emission levels from light-duty vehicle and other mobile sources, and projections of the future urban emissions are given in Figures IV-C and IV-D. Again, these projections are for the base case of no new heavy-duty regulations. The figures give a general overview of the contribution to air pollution that each class of vehicles is expected to make through 1995, and of the distribution of the burden of control of emissions from all mobile sources. From these figures it can be seen that emissions from heavy-duty vehicles will grow in proportion to emissions from light-duty trucks and light-duty vehicles. This apparent inequitable distribution of the burden for reducing mobile source emissions can be in part accounted for by the past need to concentrate control efforts on the primary sources of mobile source pollution where potential gains were the highest.

It is evident from the figures that for both NMHC and CO, heavy-duty vehicles represent a growing proportion of emissions. For hydrocarbons, heavy-duty vehicles go from 12 percent of the total in 1976 to 36 percent in 1999. The increasing share of these emissions going to diesels is also apparent. For carbon monoxide the figures are 15 percent in 1976 and 43 percent in 1999. Thus, control of heavy-duty engines is extremely important in any overall strategy for reducing emissions sufficient to meet ambient air quality standards. The remainder of this chapter will address the environmental impact which would result from imposition of heavy-duty engine emission control strategies considered as part of this rulemaking.

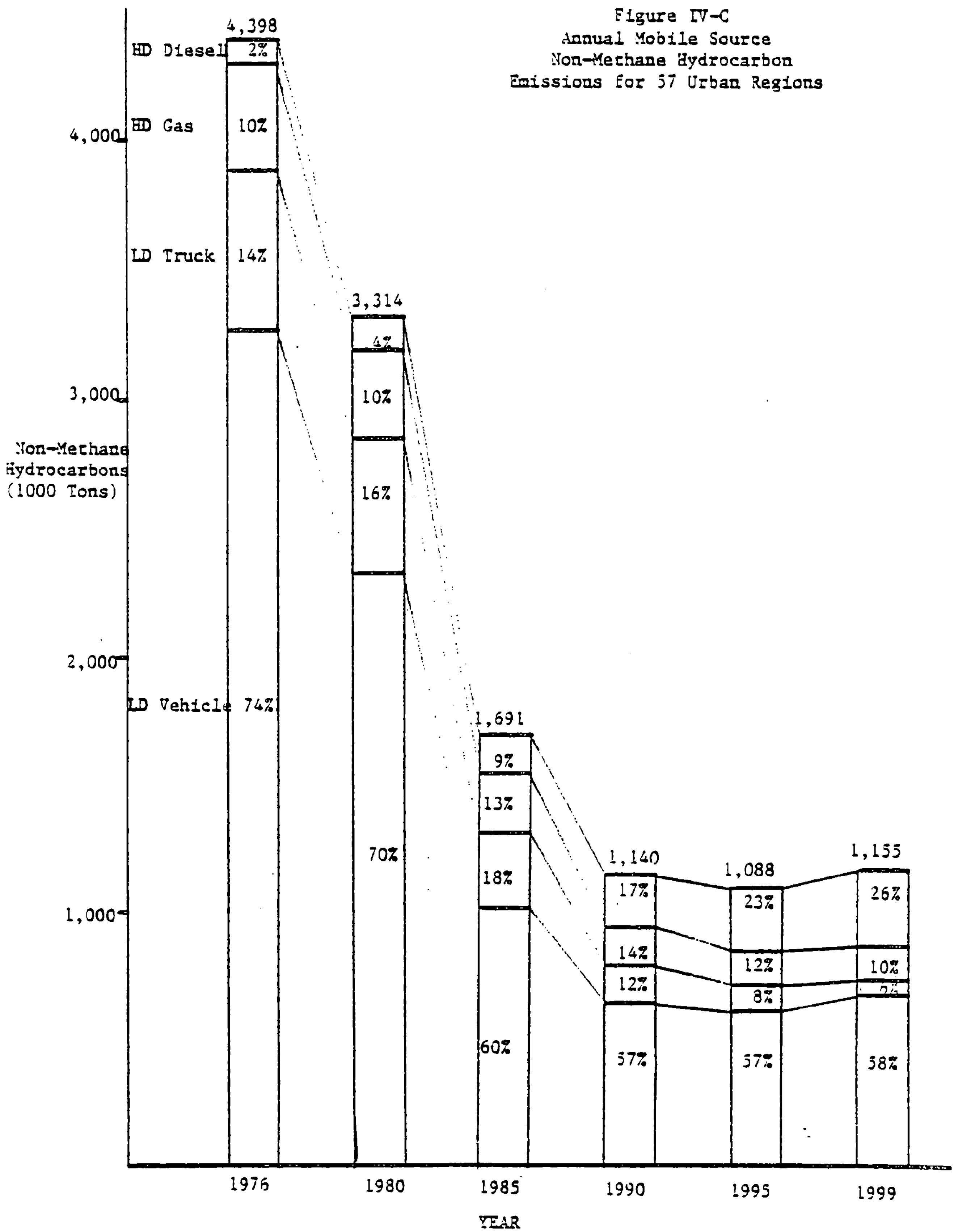
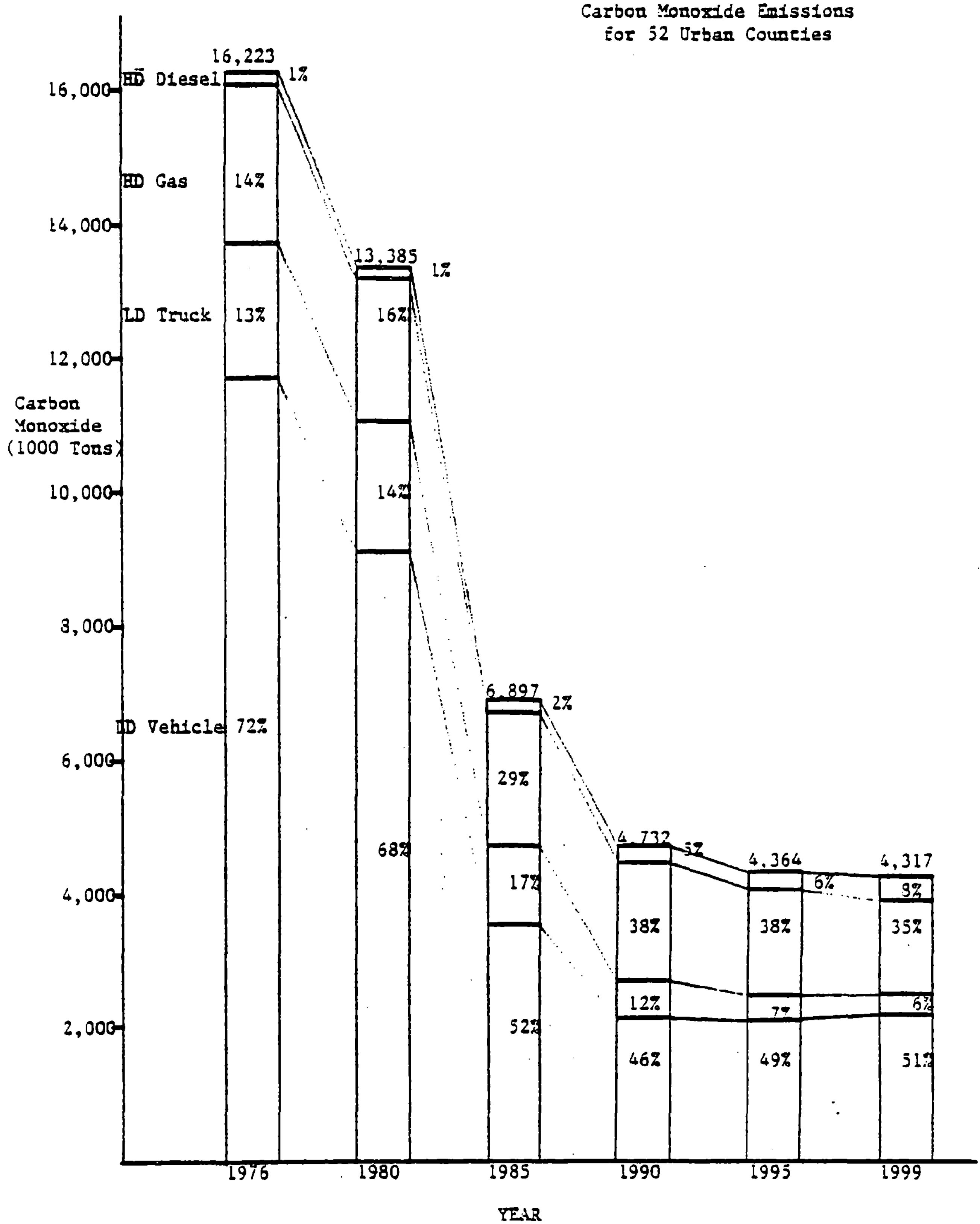


Figure IV-C
Annual Mobile Source
Non-Methane Hydrocarbon
Emissions for 57 Urban Regions
Non-Methane
Hydrocarbons
(1000 Tons)
4,000
3,000
2,000
1,000
4,398
HD Diesel 2%
HD Gas 10%
LD Truck 14%
LD Vehicle 74%
3,314
4%
10%
16%
70%
1,691
9%
13%
18%
60%
1,140
17%
14%
12%
57%
1,088
23%
12%
8%
57%
1,155
26%
10%
58%
1976
1980
1985
1990
1995
1999
YEAR

Figure IV-D
Annual Mobile Source
Carbon Monoxide Emissions
for 52 Urban Counties



B. Primary Impact

1. Heavy-Duty Engine Emission Rates

As was noted in Chapter III, heavy-duty vehicles may be equipped with either gasoline-fueled engines or diesel engines depending on the needs of the user. The use of a diesel engine, as opposed to a gasoline engine, in heavy-duty vehicles is also important from an emissions point of view because the emissions characteristics of the two engines differ. Basically diesel engines have very low levels of HC and CO emissions, below the levels of the current Federal emission standards for heavy-duty engines. NOx emissions on the other hand, for uncontrolled diesel engines are high relative to gasoline engine NOx emissions. Diesels also emit smoke consisting primarily of unburned carbon present in small particles. Gasoline engines do not. But gasoline engines do have higher HC and CO emissions than do diesels.

The primary reason for the different emission characteristics of diesel and gasoline engines is explained by the way each type of engine functions. With gasoline engines, the fuel and air are mixed in the carburetor prior to passing into the engine cylinder. The more or less homogenous air/fuel mixture is admitted into the cylinders via a throttle plate, which is varied in position by the operator to control engine power, before it passes through the intake manifold to the individual cylinders. The air/fuel ratio of the mixture which enters the cylinder tends to vary at different power conditions, with excess fuel under some conditions and excess air under others. In the engine cylinder an ignition source (spark plug) must be provided to get the combustion started, since gasoline air mixtures have high minimum ignition temperatures. The compression ratio must be low enough to avoid detonation (or random auto ignition), which is another basic characteristic of gasoline-air mixtures. The effects of these constraints on pollutant emissions is that carbon monoxide and hydrocarbons tend to be relatively high, being primarily associated with engine operating modes at which the mixtures are somewhat on the excess fuel side. Hydrocarbons also result from "quenching" of the combustion reactions because of contact between the gasoline-air mixture and relatively cool surfaces of the combustion chamber. Nitrogen oxides are relatively high too, because of the high peak combustion chamber temperatures inherent in the relatively rapid combustion process of premixed gasoline and air.

Diesel engine operation differs in many ways from that of the gasoline engine. Fuel and air are not mixed prior to entering the engine cylinder, and there is no spark plug since the type of fuel used has ignition characteristics such that it can be ignited by the heat of compression as long as the compression ratio is high enough. Therefore, unthrottled air alone is inducted into the engine through the intake valve. Engine power is controlled by varying fuel flow only, with the fuel injected under pressure directly into the combustion chamber at the proper time for ignition to begin. Fuel continues to be injected and burned concurrently under highly stratified local air/fuel mixtures. The overall fuel/air mixture, however, is always on the excess air side to assure that enough oxygen is available near the fuel spray to support combustion. Compression ratios to achieve spontaneous ignition tend to be much higher than for gasoline engines, roughly 16 to 21. Because of these high compression ratios, diesel engines have higher thermal efficiencies than gasoline engines which, combined with the fact that there are no pressure losses associated with having a throttle valve in the inlet system, give them superior fuel consumption characteristics. As to emissions, the excess air conditions result inherently in relatively low carbon monoxide and hydrocarbon emissions, but the high compression ratio tends to cause diesel engines to have nitrogen oxide emission characteristics of roughly the same magnitude as gasoline engines. The smoke from diesel engines is caused by the initially unmixed nature of the fuel and air in the diesel combustion process. This may also result in objectionable odors in diesel exhaust that are not found in gasoline engine exhaust.

Considerable work has been done within EPA in an attempt to determine accurate emission factors for mobile sources. This work depends heavily on in-use vehicle testing under EPA's Emission Factor Program. To answer the question of how well vehicles perform in actual use, EPA has administered a series of exhaust emission surveillance programs. Test fleets of consumer-owned vehicles within various major cities are 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.

The data collected in these programs are analyzed to provide mean emissions by model-year vehicle in each calendar year, change in emissions with the accumulation of mileage, change in emissions with the accumulation of age, percentage of vehicles complying with standards, and effect on emissions of vehicle parameters (engine displacment, vehicle weight, etc.). These surveillance data, along with prototype vehicle test data, assembly line test data, and technical judgment, form the basis for the existing and projected mobile source emission factors. 3/

For this regulatory analysis, changes have been made to the emission factors for heavy-duty and light-duty trucks. The emission factors found in the mobile source emission factors document for heavy-duty vehicles are based upon steady-state data gathered on the 9-mode and 13-mode test procedures. In the course of developing these current regulations, EPA has accumulated substancial data on the transient emissions of heavy-duty engines. Both the CAPE-21 data gathering program and resultant transient test procedure were designed to accurately characterize in-use operation and therefore in-use emission. Therefore, the available transient test data has been used to revise the heavy-duty truck emission factors which are currently being used. The emission factors for future heavy-duty engines as well as for future light-duty trucks have also been revised to reflect accurately the final standards and the implementation of Selective Enforcement Auditing with a 10 percent acceptable quality level. Refer to Appendix A for details of the methodology and the calculations.

The general form of all the emission factors for mobile sources is an equation with some starting new vehicle emission rate plus a mileage dependent deterioration rate (see Tables 1 and 2 of Appendix A). This means that to determine the emissions from a given vehicle one must know the accumulated mileage. To determine the average emission rate for the fleet made up by a given class of vehicles (for example, heavy-duty gasoline-fueled trucks), it is necessary to account for the fact that the on-the-road fleet consists of a mix of vehicles of varying ages and model years. The appropriate emission rate is applied to each fraction of the fleet and the fractions are summed into a composite.

When vehicles meeting a new emission standard are introduced into the on-the-road fleet, they at first represent only a small fraction of the whole fleet. As time passes, the newer technology vehicles come to represent a larger and larger share of the entire fleet. This means that the composite emission rate for the entire fleet will show a gradual change in response to new standards, rather than a sudden change. As an illustration, the composite emission rate for heavy-duty gasoline-fueled vehicles for CO changes as follows:4/

Year :	1980	1985	1990	1995	1999
Composite CO (g/mi):	256	222	106	57	40

Although the new standard is introduced in 1984, composite rates do not show substantial drops until 1990 and beyond.

One way to examine the effect of the rulemaking action is to compare the emissions of engines built to meet the requirements of the rulemaking with the emissions of earlier engines. Using the emission factor equation of Table 1,2 and 4, of Appendix A, the total lifetime emissions of a given model year engine may be estimated. This will be done for 1969 (the "baseline" model year for deriviation of the standard), 1979 (representing engines built to current standards), and 1984 (year of implementation for this rulemaking) model year vehicles. The calculations will use average vehicle lifetimes of 114,000 miles for heavy-duty gasoline-fueled vehicles, and 475,000 miles for heavy-duty diesel vehicles.5/ Lifetime per-vehicle average emissions are given in Table IV-A.

Table IV-A

Lifetime Emissions for Heavy-Duty Vehicles (Tons)

Class + Pollutant	Model Year 1969	1979	1984
Gasoline fueled			
HC	2.71	1.17	0.17
CO	31	31	2.4
Diesel			
HC	2.18	2.18	1.41
CO	5.9	5.9	5.9

The impact of the new standards on vehicles produced for 1984 (or later) is clearly evident in this data. Compared to emissions from 1979 engines, 1984 engines are reduced 85 percent for HC and 92 percent for CO in the case of gasoline-fueled engines. For diesel engines, HC is reduced 35 percent while CO remains unchanged.

2. Reduction in Urban Emissions From Heavy-Duty Vehicles

We have seen that as new heavy-duty vehicles are put into use and older ones retired, the emissions of the average heavy-duty vehicle on the road will decrease. The resulting composite emission factors can be used to project changes in annual emissions from the entire fleet. The same can be done for other mobile source categories as well. To make the projections, the changes in composite emission rates are used along with estimated growth rates in total vehicle miles traveled to modify the baseline emission inventory for future years. Projections are also made of changes in stationary source emission rates depending on present and anticipated stationary source control programs.2/

For hydrocarbons, the exhaust emissions themselves are an indirect rather than a direct problem. That is, the principal harmful effect of HC emissions stems from the photo-chemical reactions leading to ozone formation. The reaction process can take several hours, by which time the pollutants involved are transported and dispersed over broad areas. Therefore, the hydrocarbon emissions have been analyzed on an Air Quality Control Region (AQCR) basis. The AQCR's selected were those non-California, non-high-altitude regions violating the ozone standard (or estimated to be violating where actual sampling data is missing) in a 1975-1977 base period. California regions were excluded since California has its own emission standards. High altitude regions were excluded because the emissions data used in the analysis is not considered representative of high altitude conditions. A separate detailed analysis would have to be done to assess the impact of these regulations on high-altitude areas. This selection process led to a set consisting of 57 AQCRs to be analyzed for hydrocarbons. In addition, because methane emissions are non-reactive and do not contribute to ozone formation, the emission inventories compiled for analysis will be based upon non-methane hydrocarbons (NMHC).

Carbon monoxide emissions, in contrast to hydrocarbons, frequently create localized problems of high concentrations. These are often associated with urban core areas experiencing high traffic densities. It is desirable, therefore, to analyze CO on a more localized basis than AQCRs. This has been done by using a county based inventory. As for HC, only non-California non-high-altitude areas were selected. The result is 52 counties exceeding the CO standard for a 1975-1977 base period.

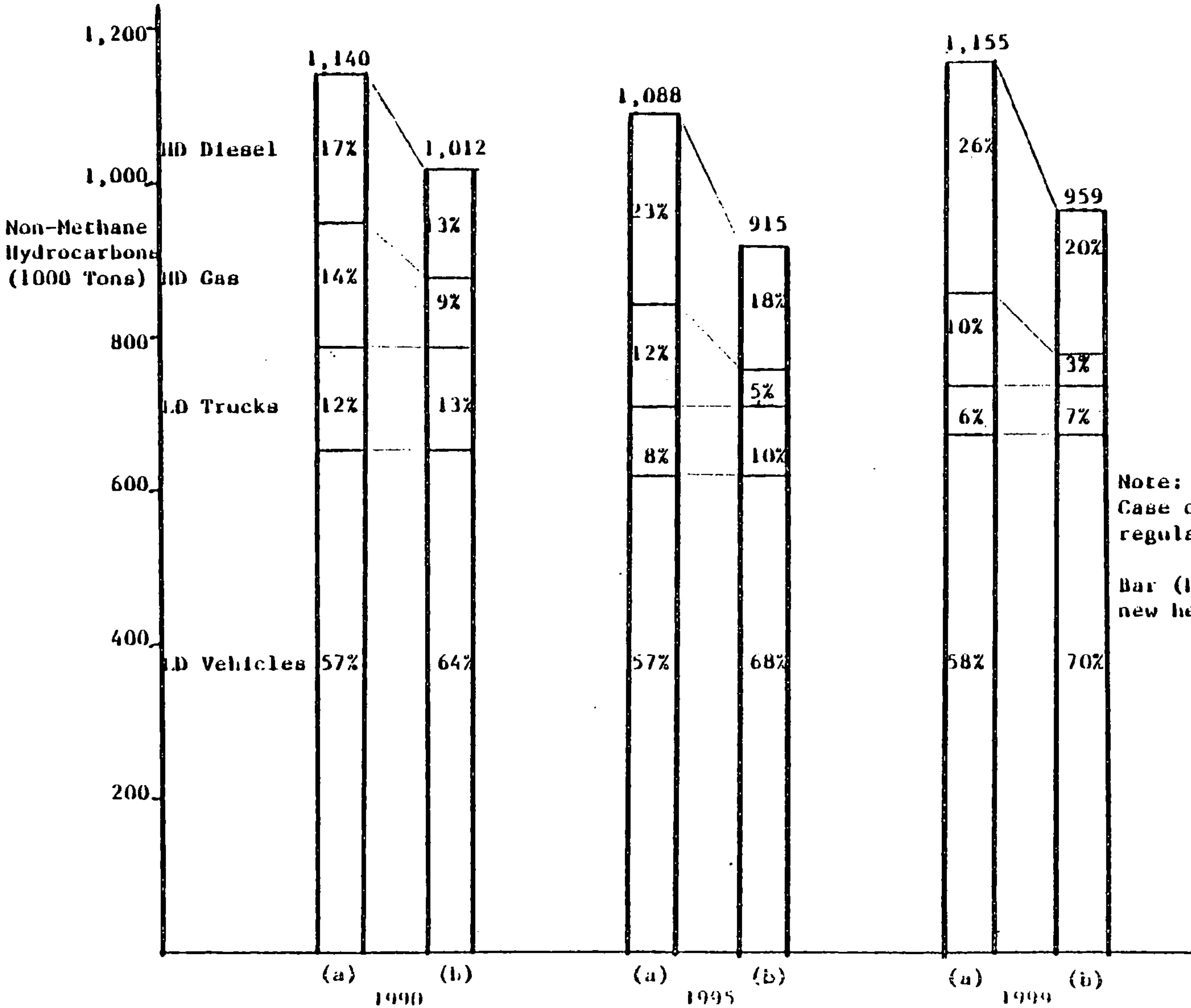
Following the selection of areas to be analyzed, an emission inventory for each region was compiled. The most recent year for which complete information could be obtained was 1976. This data then forms the basis for future projections. Compilation of the baseline and projection for future years is an involved process entailing a number of assumptions. These are discussed in detail in supporting documents.6/7/ Two assumptions are important to highlight here. The first is the assumption that light-duty vehicle and light-duty truck I/M programs will be implemented in all the areas analyzed by 1982. Since all the areas chosen are areas exceeding the HC and CO standards, such programs are expected.

The second assumption concerns projected growth rates for various source categories in future years. For non-methane hydrocarbons, rollback projections were made for a range of growth rates. The high and low end of these ranges differ by one or two percent. For this analysis we will use the growth rates of the low growth option. For mobile sources these rates appear most consistent with what appears likely because of energy costs and related matters. The high growth assumptions would increase the absolute levels of emissions and decrease the absolute levels of air quality benefits projected by the models somewhat. They would, however, make little difference in the relative change from the base case to the control case. The maximum air quality benefits would peak in 1995 rather than in 1999 if the high growth case were chosen. For heavy-duty vehicles, other specific adjustments in growth rates are also required. Based upon the results found in Section D of Appendix A, annual vehicle miles traveled (VMT) are expected to decline for gasoline-fueled engines by about 2 percent per year, while diesel VMTs will increase by about 5 percent per year. These rates reflect increased use of diesel engines in the heavy-duty industry, largely because of energy considerations.

Projections for both emission data and air quality data are made on a AQCR by AQCR basis (or county by county for CO). However, the underlying assumptions on emission factors are not region specific. Rather, they represent typical nationwide values. Because of this, only average results for all regions will be used for analysis.

Figure IV-E and IV-F provide a comparison of the projected mobile source emissions for the base case presented in Section A of no new heavy-duty regulations with the projected emissions for the final regulations. They cover the years from 1990-1999. Without further controls, heavy-duty emissions become a major fraction of mobile source emissions. By 1995, heavy-duty emissions would account for 35 percent of mobile source NMHC and 44 percent of mobile source CO emissions. The substantial reductions in heavy-duty emissions expected are clearly indicated. For HC, in 1999 the

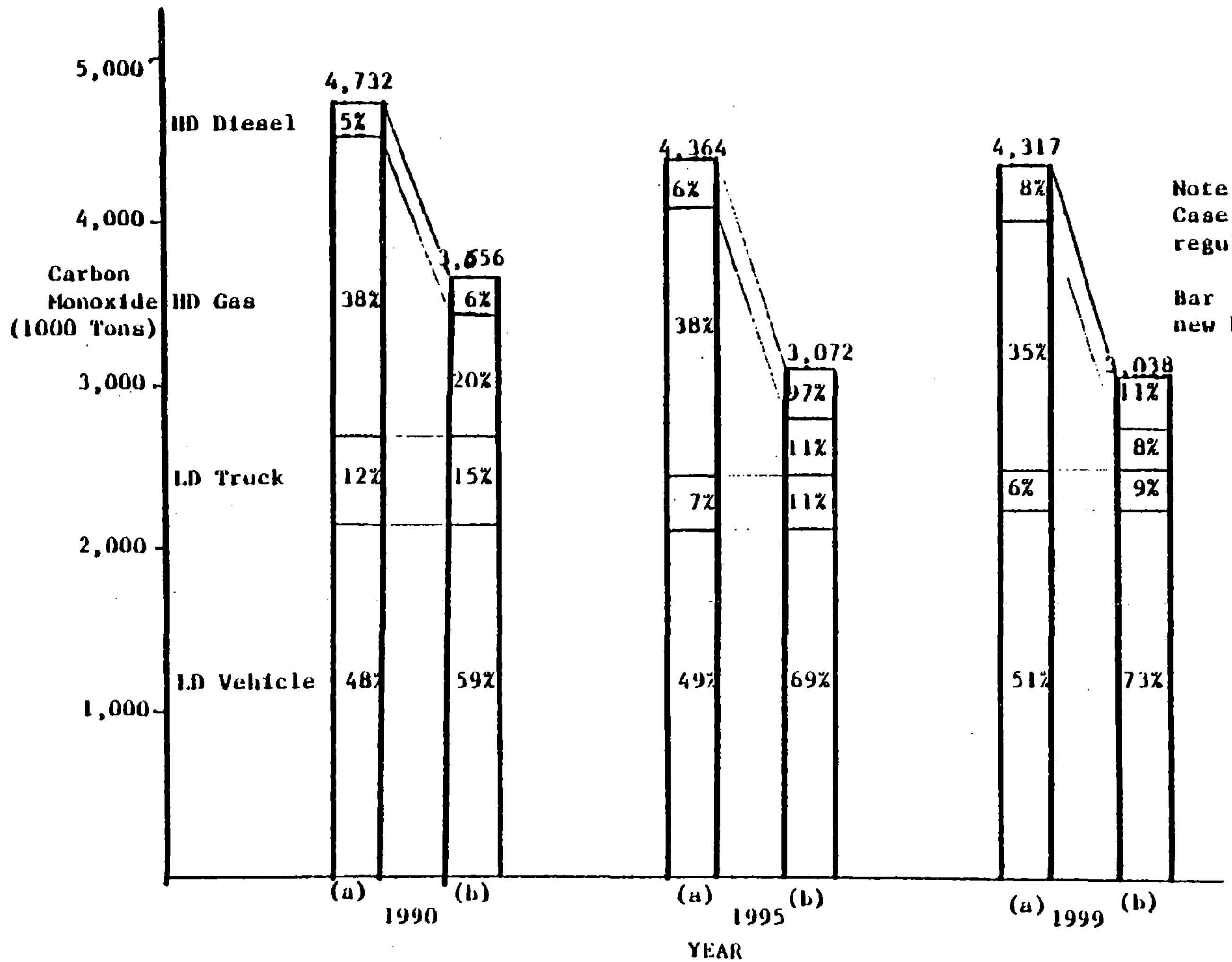
Figure IV-E
Annual Non-Methane Hydrocarbon
Emissions for Baseline Case
and Control Case



Note: Bar (a) = Baseline Case of no new heavy-duty regulations.

Bar (b) = Control Case with new heavy-duty regulations.

Figure IV-F
Annual Carbon Monoxide
Emissions for Baseline Case
and Control Case



Note: Bar (a) = Baseline Case of no new heavy-duty regulations.

Bar (b) = Control Case with new heavy-duty regulations.

reduction reaches 75 percent for gasoline-fueled engines and 36 percent for diesels. For CO, in 1999 the reduction for gasoline-fueled engines is 84 percent. Diesel CO is unaffected by the new regulations. These percentages are measured in comparison to the base-case emissions for the same year, 1999.

Expressed as a percentage of all mobile source emissions, the impact of the final rulemaking is as follows. Hydrocarbons are reduced 17 percent in 1995 and 1999. Carbon monoxide is reduced 30 percent in 1995 and 1999.

3. Ambient Air Quality Impact of Regulation

Using the emission rates previously discussed, an analysis was done of the air quality impact in each of the selected regions.7/ The Modified Rollback method was used for oxidant and CO to project future air quality improvements for each region. In addition, the Empirical Kinetic Modeling Approach (EKMA) was also used for oxidant. The EKMA procedure has been developed by EPA in an attempt to provide an improved analysis of the relationship between oxidant and precursor emissions while avoiding the complexity of photochemical dispersion models.7/ There is uncertainty over the applicability of EKMA, so that both EKMA and rollback were used to provide a range of possible air quality impacts.

In preparing the air quality projections, baseline emission rates for various source categories were taken from the National Emissions Data System (NEDS), and projections for future control strategies plus growth rates were made. In combination with the mobile source projections, this data allowed an evaluation of air quality improvements to be expected. With both Modified Rollback and the EKMA approach, the relative changes from strategy to strategy are more reliable than predictions of absolute levels of air quality. Therefore, the results will be expressed as percentage gains over baseline between various strategies. In addition, although the individual regions used in the analysis can be identified, the results are not considered accurate enough to be used for a region by region review of the regulations. Rather, averages over all areas analyzed will be used. The average air quality improvements are given in Table IV-B.

The modified linear rollback and EKMA models differ by a factor of nearly 2 to 1 for ozone reductions. However, they each indicate nearly the same percentage gain from implementing the new standards. For example, both methods indicate an improvement of 1 percent in ozone in 1995 when the 1984 regulations are implemented. This reduction becomes 2 percent in 1999.

Table IV-B indicates that carbon monoxide will be improved 5 percent in 1990, and 7 percent in both 1995 and 1999.

Table IV-8

Average Air Quality Percent Reductions
From 1976 Base Year

Ozone
(Modified Linear Rollback/EKMA)

Strategy	1980	1985	1990	1995	1999
Base Case	13/7	49/25	54/30	54/31	52/29
Implement HD Regs	13/7	49/25	55/32	55/32	54/31

Carbon Monoxide

Strategy	1980	1985	1990	1995	1999
Base Case	16	53	65	67	67
Implement HD	16	54	70	74	74

The significance of a percentage gain in air quality in terms of progress toward attainment of standards depends upon the original levels. For example, a 2 percent improvement in air quality may be sufficient to bring a region that is already close to the standard into compliance, whereas in a region experiencing very high levels (relative to the standard) that 2 percent would represent a totally inadequate reduction. In a region already meeting the standards, such a further gain would increase the margin for compliance. The question could then be posed: "How many areas originally exceeding air quality standards are brought into compliance by implementing the new emission standards?" In Table IV-C the air quality improvements are analyzed in this fashion.

Considering the ozone results first, the marked difference in absolute reductions predicted by modified rollback versus EKMA noted in Table IV-B are again readily apparent. While modified rollback indicates that 96-98 percent of the regions originally violating the ozone standard will come into compliance in the 1990's, EKMA puts that percentage at 68-72 percent. Therefore, as noted earlier, caution must be used in interpreting results from either model in absolute terms. For example, the indication from modified rollback that nearly all violating regions will meet the ambient ozone standard by 1999 should not be considered reliable. Rather, the relative change attributable to implementation of the new regulations is the item of maximum accuracy. The table indicates that implementation of the heavy-duty regulations will result in approximately a 2 percent (rollback) to 4 percent (EKMA) reduction in the number of violating regions.

The cautions noted for ozone are equally important in interpreting the CO results in Table IV-C. Only rollback applies to this case, and that model indicates that with either strategy, all regions analyzed will attain the CO standard by 1990. However, it has already been noted that it is not within the ability of this model to accurately predict absolute air quality levels. Therefore, the indication of all regions meeting the standard is inconclusive. As an illustration of the accuracy required to accept the absolute projections, in the final rollback projections for 1999 only 87 percent of the regions are in compliance with the standard by a margin of greater than 20 percent for the base case. For the control case, that result changes by 5 percent to a value of 92 percent. Inaccuracies on the order of 20 percent or greater are more than possible in the present air quality analysis, and would markedly change the absolute levels of predictions. However, such inaccuracy would probably be relatively constant from strategy to strategy and lead to consistent relative effects. Unfortunately, since changes in air quality produced by the new regulations do not become significant prior to 1990, no clear conclusions can be drawn about the effect these regulations will have on attainment status. As noted, based upon the number of regions within 20 percent of the standard, implementing the heavy-duty regulations produces a 5 percent improvement.

Table IV-C

Percentage of Regions Originally Violating
Air Quality Standards Brought Into Compliance

Ozone
(Modified Linear Rollback/EKMA)

Strategy	1980	1985	1990	1995	1999
Base Case	35/14	96/56	98/68	98/72	96/68
Implement HD Regs	35/14	96/56	98/72	98/72	98/72

Carbon Monoxide

Strategy	1980	1985	1990	1995	1999
Base Case	2	88	100	100	100
Implement HD	2	88	100	100	100

C. Potential Secondary Environmental Impacts

1. Sulfuric Acid Emissions

A recent EPA report (8/) provides an in-depth review of the current status of sulfate emissions from mobile sources. On a nationwide basis, mobile sources represent less than 2% of the total man-made sulfur oxides. However, with the introduction of the catalyst/air pump technology to control HC and CO emissions from mobile sources, there exists the potential for a significant source of mobile related sulfate emissions in the form of sulfuric acid aerosol. While of negligible magnitude on a regional basis, mobile source sulfuric acid emissions could produce a significant localized urban sulfate concentration in urban street canyons, or congested urban freeway situations. Moreover, mobile source sulfates differ from stationary source sulfates in that they are emitted in the form of a fine sulfuric acid mist and the particles tend to remain near ground level.

The increase in sulfate emissions due to the use of oxidation catalyst/air pump control systems on passenger cars and light-duty trucks has been of considerable concern to EPA. In pre-model year 1975 non-catalyst systems, most of the fuel sulfur leaves the vehicle after combustion as SO_2. In oxidation catalyst/air pump systems used on recent model year automobiles and light-duty trucks, a small amount (less than 10 percent) (8/) of the sulfur is converted by the catalyst to SO_3. The SO_3 combines with water in the exhaust to form sulfuric acid aerosol. Heavy-duty catalyst technology has not yet been used on in-use vehicles, and so little is known about sulfate emissions from these systems.

Extensive efforts have been made within government and industry to improve the information about mobile source sulfate emission factors, sulfate air quality modeling techniques and sulfate health effects as a function of exposure level. In addition, technology assessment work is proceeding to identify how sulfates are formed in catalyst/air pump systems, and to develop other low sulfate producing catalytic control systems such as the three-way catalyst. According to current data, the extent of sulfate emissions is much less than early concerns had anticipated. Major adverse health and welfare effects from mobile source sulfates are unlikely.8/ Table IV-D indicates sulfuric acid emission rates for several mobile source categories.

The use of catalysts on heavy-duty gasoline engines resulting from implementing the new gaseous standards is not expected to increase present mobile source sulfate emissions significantly or to present a future problem. Considering the much larger sulfate emissions already associated with diesel trucks, plus the fact that equipping HD gasoline vehicles with catalysts would increase the number of all catalyst equipped vehicles by only approximately 2

Table IV-D

Approximate Mobile Source
Sulfuric Acid Emission Rates 8/

Source Category	H_2SO_4 Conversion Rate (%)	H_2SO_4 (mg/mile)
Non-catalyst car	1	1
Oxidation catalyst car	10	10-15
3-way catalyst car	5	4
Light-duty diesel car	2	9
Heavy-duty diesel truck	2	50
Aircraft gas turbine	0.03	N/A

percent, there appears to be no reason to expect a significant change in roadside sulfate levels.

2. Lead

The introduction of catalyst technology for heavy-duty engines will require use of unleaded gasoline to replace the leaded gasoline used in current heavy-duty gasoline fueled engines. This change will have a positive environmental effect as regards the emission of lead particulate in engine exhausts. Reduction of mobile source lead emissions is an important means of reducing U.S. urban population exposures to high ambient air lead concentrations.

Emission data for light-duty vehicles shows that approximately 80 percent of the lead content of leaded gasoline is eventually emitted from the tailpipe. Applying this to a typical lead content for leaded gasoline of 1.5 grams per gallon gives an emission of 1.2 grams per gallon. With an average heavy-duty mileage of 9.9 miles per gallon, and a 114,000 mile life, total lead emission over the life of a heavy-duty gasoline-fueled vehicle would be approximately 30 pounds. That is, converting to unleaded fuel will result in a reduction of lead emissions for gasoline-fueled heavy-duty vehicles of approximately 30 pounds per vehicle over the vehicle life.

3. Water Pollution, Noise Control, Energy Consumption

Complying with the heavy-duty engine regulations is expected to have negligible impact on water pollution, or on the ability of the heavy-duty vehicle manufacturers to meet present and future noise emission regulations. Implementing catalyst technology can be done with no fuel economy penalty. In fact, the analysis of fuel economy impact done in the Summary and Analysis of Comments indicates the possibility of up to a 9 percent fuel economy benefit.

D. Irreversible and Irretriavable Commitment of Resources

Assuming that catalytic converters are used to meet the 1984 standards, an additional committment of platinum and palladium would be required over and above that needed for light-duty vehicles and light-duty trucks which already employ catalysts. The incremental demand in 1985 from equipping all HD gasoline vehicles with catalytic converters would be approximately 72,423 troy ounces of plantinum and 36,212 troy ounces of palladium. These figures are based upon vehicle sales, catalyst loadings and catalyst sizes developed in Chapter V.

E. Relationship of Short-Term Uses of the Environment to Maintenance and Enhancement of Long-Term Productivity

More stringent control of heavy-duty engine emissions than that currently imposed will result in substantial decreases in hydrocarbon and carbon monoxide emissions from this source. This reduction will be beneficial and aid in the long-term attainment and maintenance of acceptable air quality.

Footnotes

1/ For a current review of this data, as well as citations to other reports on health effects of HC and CO, see "Health Effects of Exposure to Low Levels of Regulated Air Pollutants - A Critical Review," Benjamin A. Ferris, Jr., M.D., Journal of the Air Pollution Control Association, Vol. 28, No. 5, May 1978.

2/ For details on assumed future strategies for other source categories see "Data Assumptions and Methodology for Assessing the Air Quality Impact of Proposed Emission Standards for Heavy-Duty Vehicles," EPA Air Management Technology Branch, Office of Air Quality Planning and Standards, November 1979.

3/ A complete presentation of mobile source emission factors, including future use projections, can be found in EPA-400/9-78-005, "Mobile Source Emission Factors - Final Document," March 1978.

4/ "Air Quality Impact of Proposed HDV Emission Standards - Summary of Results," EPA Report TAEB 80-07, December 1979.

5/ "Average Lifetime Periods for Light-Duty Trucks and Heavy-Duty Vehicles," EPA Report SDSB 79-24, G. Passavant, November 1979.

6/ "Data Assumptions and Methodology for Assessing the Air Quality Impact of Proposed Emission Standards for Heavy-Duty Vehicles," EPA Air Management Technology Branch, Office of Air Quality Planning and Standards, November 1979.

7/ "Uses, Limitations and Technical Basis of Procedures for Quantifying Relationships Between Photochemical Oxidants and Precursors," EPA-450/2-77-021a, US EPA, Research Triangle Park, NC, November 1977.

8/ "Emissions of Sulfur-Bearing Compounds From Motor Vehicles and Aircraft Engines," Report to the United States Congress, EPA-600/9-78-028, August 1978.

Chapter V

ECONOMIC IMPACT

This chapter will examine the costs of complying with the gaseous emission standards and control strategy for 1984 and later model year heavy-duty engines. Costs of compliance are in four main areas: 1) purchase, installation, and check-out of new test facilities designed for use with the transient test procedures; 2) development, production, and installation of redesigned engines and new or redesigned emission control systems; 3) certification testing to assure the emission standards are being met; and, 4) the purchase and installation of new SEA facilities, self audits, and annual SEA testing. For gasoline-fueled engines, the primary cost is that for emission control systems. For diesel engines, the primary costs are equally shared by necessary test facility modifications and engine development and redesign aimed at lowering emissions. Also, there are costs associated with the anticipated need for unleaded fuel for use in catalyst-equipped heavy-duty gasoline-fueled engines.

The engine manufacturer must bear the initial costs for engine modifications, emission control hardware, certification, test facility modifications, and SEA facilities and tests. These costs will be added to the price of the engines it sells to vehicle manufacturers or uses in its own trucks if it also produces vehicles. These costs in turn will be passed on to its customers, the truck and bus owners and operators. These operators must also bear the costs, if any, of increased operating (fuel/maintenance) costs which may be caused by the emission control technology.

A. Cost to Engine Manufacturers

The emission control system cost estimates discussed in the following paragraphs inherently include costs to cover the allowable maintenance provisions, the lower target emission levels with the 10% AQL, the useful life redefinition, and the idle emission standard for gasoline-fueled engines in addition to the revised emission standards.

1. Emission Control System Costs: Gasoline-Fueled Engines

The actual cost of complying with the emission standards can be divided into two main areas: pre-production catalyst development and testing and the actual emission control hardware installed on each engine produced.

Development and testing costs are difficult to estimate when considering the magnitude of the task. Catalyst technology is well developed, which would tend to make this cost minimal, but the application of catalytic converter technology to heavy-duty engines presents some unique problems. Prolonged operation at high speed and high load, as well as high speed motoring, presents catalyst durability problems which must be closely studied. EPA has estimated a development and testing cost of $5.00 per catalyst sold. This estimate is based on a rough equivalence with the research and development cost per catalyst applied in light-duty vehicle and light-duty truck applications.

EPA expects that manufacturers of gasoline-fueled engines will adopt oxidation catalyst/EGR based emission control systems to comply with the 1984 standards. The components EPA expects will be used are shown in Table V-A, and are discussed separately below:

a. Two Monolithic Oxidation Catalysts

This analysis assumes that manufacturers will use one monolithic oxidation catalyst for each exhaust bank. A total catalyst volume to engine CID ratio of 1:1 is used to increase catalyst durability and efficiency. This volume is at least 20% larger that that used in light-duty applications. A loading of 45 g/cubic foot of platinum and palladium in a 2:1 ratio is used to allow maximum catalyst durability and efficiency. The catalyst manufacturing cost was computed using the data and methodology in a cost estimation report prepared under contract for EPA.1/ The methodology was altered by using 1979 noble metal prices and allowing for the effects of inflation on other costs.2/ The use of these catalysts will inherently yield compliance with the idle emission standards at no extra cost.

b. Chassis Heat Shields

Chassis heat shields may be required to protect the vehicle chassis from heat damage by the catalytic converter. These will likely be simple stamped steel parts weighing two to three pounds a piece. The use of brush shields is not expected because of the need to maximize converter cooling and the inherently higher running clearance of heavy-duty vehicles. Chassis heat shield costs were estimated using the Rath & Strong report cited earlier and allowing for the effects of inflation.

c. Stainless Steel Exhaust Pipes

Stainless steel exhaust pipes between the exhaust manifold and the catalyst will be necessary to insure the proper functioning of the catalyst for the full useful life. The actual cost of the pipes is dependent upon the distance between the exhaust manifold and the catalytic converter. EPA has estimated the cost of these pipes using the Rath & Strong report and taking a credit for the standard steel exhaust pipes being replaced.

Table V-A

Emission Control Component Manufacturing Costs for Gasoline-Fueled Engines

Component	EPA Estimate
2 Monolithic Oxidation Catalysts	$175
Chassis Heat Shields	6
Stainless Steel Exhaust	14
Air Pump Upgrade	26
Air Modulation System	7
Deceleration Fuel Shut-off	11
Parameter Adjustment	4
Unleaded Fuel Engine Modifications	10
High Energy Ignition	0
	$253

1/ Assumes total catalyst volume equals expected average engine CID (360), noble metal loading of 45 g/cu.ft. using platinum and palladium in a 2:1 ratio. Sized and loaded for full useful life.

d. Air Pump Upgrade

Although all heavy-duty gasoline-fueled engines currently use air pumps, they do not provide the air volume necessary to maximize oxidation in the exhaust manifold, the exhaust pipe, and the catalytic converter. The cost of this upgrade has been estimated by assuming that current air pumps will be modified to provide approximately a factor of two to three increase in the air volume. These costs were estimated using the manufacturing cost estimates presented in the Rath & Strong report as an indication of the increased material costs and labor necessary to upgrade the air pump. The cost estimate is in close agreement with a GM estimate submitted in their comments.

e. Air Modulation

Air modulation is necessary to provide the optimum air/exhaust gas ratio at different operating loads, thus maximizing HC and CO oxidation. The manufacturing cost used is a GM estimate.

f. Deceleration Fuel Shut-off

To aid in prolonging catalyst durability during high speed motoring, some form of fuel shut-off may be required. The manufacturing costs used here are taken from a GM estimate.

g. Unleaded Fuel Restrictor, Decal and Engine Label

These minor components will be necessary to deter misfueling and comply with useful life regulations.

h. Parameter Adjustment

These modifications will be necessary due to the parameter adjustment regulations. Since most heavy-duty engines are also sold in light-duty trucks, and light-duty truck parameter adjustment provisions will be implemented prior to 1984, the cost of applying the parameter adjustment provisions to heavy-duty engines should not exceed minor hardware modifications. Based on manufacturer comment, a manufacturing cost of $4.00 per engine is assumed.

i. Unleaded Fuel Engine Modifications

Unleaded fuel will require exhaust seat inserts, valve guides and valve seals to maximize engine lifetime. The cost per engine estimate is taken from GM data.

j. High Energy Ignition

This item is already standard equipment on heavy-duty gasoline-fueled engines.

The component manufacturing (vendor) costs shown in Table V-A are in close agreement with confidential figures received by EPA in other waiver and rulemaking actions.3/ Corporate and dealer overhead and profit will be considered in a separate section of this chapter.4/

2. Emission Control Costs: Diesel Engines

a. Gaseous Emissions

Even with the increased stringency of the HC and CO emission standards, few heavy-duty diesel engine manufacturers are expected to employ add-on devices solely to reduce emissions. Diesel engine CO emissions are inherently so low that no engine family will require further reductions to meet the target emission levels.

However, this is not the case for HC emissions. An EPA analysis of diesel transient test emission data currently available5/ shows that 14 of the current domestic engine families (36.3 percent of sales) already meet the target emission levels for HC and CO.

Another 14 of the current engine families (38 percent of sales) are within easy range of meeting the target emission levels with relatively minor changes to injector timing, injector redesign, or, in a few cases, combustion chamber redesign. EPA estimates injector timing changes to cost not more than $5 per engine, injector redesign $20 per engine, and combustion chamber redesign $50-$300 depending on production volume. Of these 14 families, two will not be certified in 1984 but will be replaced by other families which are not yet certified.

The remaining 10 engine families, about 26 percent of current sales, are not within range of meeting the target HC levels without major design changes or add-on hardware. Based on the data available in the analysis mentioned previously, the remaining engine families seem to have one or more of the following characteristics:

-high rated speed, low rated BHp
-naturally aspirated
-turbocharged, but not intercooled or aftercooled
-two stroke engine
-high surface to volume (S/V) ratio
-larger than average sac volume

EPA expects the manufacturers of these engine families will take several steps to reduce the HC emissions.

The first steps taken will be similar to those used to bring other engine families into compliance. These include changes to the fuel injection timing and rate as well as modifications to the fuel injector design aimed at decreasing sac volume or optimizing the injector spray pattern.

Other more costly and sophisticated HC control techniques which may be used include combustion chamber redesign to reduce the S/V ratio, pre-chamber injection, variable injection timing, turbocharging, aftercooling, and EGR. Cost estimates for each of these possible strategies are found in Table V-B.

Of the 10 families which will need major work to meet the HC target levels, EPA has learned that at least five will not be certified in 1984. Of these five families, one is simply being dropped, and four are being redesigned primarily due to the 1982 noise standards, with emissions and fuel economy as secondary considerations. Based on the diesel transient test data analysis mentioned previously, EPA has used engineering judgment in determining how the manufacturers of the remaining engine families may reduce HC emissions to the target levels required. This is shown in Table V-C, together with EPA's manufacturing cost estimate for each engine family.

It should be noted that the injector and combustion chamber redesign work discussed above gives the manufacturers an excellent opportunity to perform design research and development aimed at lowering NOx and particulate emissions, while at the same time improving fuel economy.

b. <u>Crankcase Emissions: Naturally Aspirated Engines</u>

The percentage of engines which will be naturally aspirated (non-turbocharged) in 1984 is difficult to estimate. Current certification data shows that about 25 percent of all new diesel engines sold are naturally aspirated. These 25 percent are engines primarily produced for use in either buses or inner-city class VI trucks (also known as medium-duty).

It is well known that turbochargers are not as effective in inner-city and suburban applications as they are in rural and linehaul applications. However, as diesel fuel prices continue to increase, the fuel saved by turbocharging for these applications will begin to offset the increased initial purchase price and maintenance cost of turbochargers.

With the expected influx of diesels into the predominately gasoline-fueled engine market, classes IIB-VI (8,500-26,000 lb. GVWR), it is inevitable that a substantial portion of these diesels will remain naturally aspirated.6/ Chapter III shows that in 1986, the mid year of this analysis, classes IIB-VI will account for 34 percent of total diesel sales. For purposes of this analysis, EPA shall assume that half of these engines remain non-turbocharged.

Table V-B

Manufacturing Cost for Diesel HC Control Techniques 1/

	Component/Technique	EPA Estimate Cost per Engine
1.	Optimize Injection Timing 2/	$ 5
2.	Injector Redesign 2/4/	$ 20
3.	Combustion Chamber Redesign 2/4/	$ 50-300
4.	Pre-Chamber Injection 2/3/	$100-300
5.	Variable Injection Timing	$120-450
6.	Turbocharging 4/	$300-1,200
7.	Aftercooling 4/	$200-400
8.	Exhaust Gas Recirculation 3/	$ 40-160

1/ Source: Interagency Study of Post-1980 Goals for Commercial Motor Vehicles, June 1976, and EPA estimates.
2/ Estimates include short-term research, development and cooling costs, but do not include additional hardware which is not inherently necessary.
3/ Slight fuel economy penalty.
4/ Slight fuel economy increase.

Table V-C

Emission Control Techniques and Costs for Heavy-Duty Diesel Engines

Engine Family	Estimated % of Total Sales	Control Technique	Estimated Manufacturing Cost Per Engine 1/
1	.044%	Injector redesign, combustion chamber redesign	$320
2	6.6%	Aftercool	$200
3	0.66%	Optimize injection timing, combustion chamber redesign	$305
4	0.22%	Injector redesign, aftercool	$420
5	11%	Redesign combustion chamber, add EGR	$225

1/ Manufacturing cost estimate is based on production volume affected.

A per-engine manufacturing cost of $10.00 will be used as the hardware cost to close the crankcase. This estimate was provided by Caterpillar Tractor Co.

c. Summary of Diesel Control Costs

The actual costs incurred to reduce gaseous emissions can be divided into three main areas: research and development, tooling changes, and hardware.

Research and Development (R&D) costs will be incurred in 1981 and 1982 as modifications and redesigns are made to engines and engine components. Tooling costs will occur primarily in 1983 as changes are made to prepare for 1984 production. Hardware costs will be incurred in the actual year of production.

The major design changes which are expected: optimized injection timing, redesigned injectors, and redesigned combustion chambers, are primarily short term R&D and tooling costs. The redesigned or modified hardware should not be inherently more expensive than that which was previously used. It is reasonable that the costs attributable to R&D and tooling would be divided evenly over the period 1981-1983.

The actual manufacturing cost to make any hardware modifications or add any additional hardware to an engine would be primarily dependent on the production volume affected. For example, the cost per engine for combustion chamber redesign would be much larger for 500 engines than for 10,000 engines. For this cost analysis, small production volume will be considered as 2,000 or less per year, medium production volume 2,000-10,000 per year and large production volume greater than 10,000 per year.

The final emission control cost will be discussed according to the small, medium, and large volume criteria described above and estimating costs based on production volumes.

Of the 63.7 percent of current sales which will require some work to meet the standard, 2.8 percent comes from families with a small sales volume, 6.6 percent comes from medium sales volume families, and 46.6 percent comes from families with large sales volumes. The remaining 7.7 percent of the sales will not be produced in their current families in 1984.

Table V-D shows the control strategies which may be used in the small, medium, and large volume sales families. The control strategies used are based on EPA's analysis of the diesel transient test data mentioned previously. The cost estimates are taken from Table V-B. However, the final cost estimate used is based, in addition, on the sales volume affected. Small volume families would incur manufacturing costs near the high end of the range

Table V-D

Engine Family Control Cost Estimates 1/

Volume Class	Control Technique	Percent of Total Sales	EPA Cost Estimate
Small	Optimize Injection Timing	0.88	$ 5
	Injector Redesign	2.1	$ 20
	Combustion Chamber Redesign	1.45	$300
	Aftercooling	0.22	$400
Medium	Optimize Injection Timing	2.0	$ 5
	Injector Redesign	3.0	$ 20
Large	Optimize Injection Timing	20	$ 5
	Injector Redesign	13.4	$ 20
	Combustion Chamber Redesign	26.6	$ 50
	Aftercooling	6.6	$200
	Exhaust Gas Recirculation	11.0	$160 2/

1/ Cost estimates are linked to production volume expected.
2/ Based on engine family specific data.

shown in Table V-8, medium volume sales families near the mid point of the range, and high volume sales families near the low end of the manufacturing cost estimates.

The final average cost per engine can now be computed by using the sales percentage and cost estimate data shown in these tables and the data presented above on sales already in compliance, discontinued engine families, and diesel crankcase control cost. This final computation is shown below:

Category	Fraction of Total	Manufacturing Cost Estimate	
		R&D	Hardware
In Compliance	.363	0	0
Discontinued	.113	0	0
Small Volume Sales	.028	4.80	.88
Medium Volume Sales	.030	.70	0
Large Volume Sales	.466	17.00	30.80
Diesel Crankcase	.170	0	1.70
Average Cost Per Engine		$22.50	$33.38

Corporate, vehicle manufacturer, and dealer overhead and profit on this investment and hardware will be discussed in a separate section in this chapter.4/

3. Certification Costs

Certification is the process in which EPA determines whether a manufacturer's engines conform to applicable regulations. The engine manufacturer must prove to EPA that its engines are designed and will be built such that they are capable of complying with the emission standards over their full useful life. The certification process begins by a manufacturer submitting to EPA an application for certification. Subsequently, two steps occur.

The first step involves the determination of preliminary deterioration factors for the regulated pollutants. These deterioration factors must be multiplicative in nature for both gasoline-fueled and diesel heavy-duty engines. The engine manufacturer may determine these preliminary deterioration factors in any manner it deems necessary to insure that the preliminary deterioration factors it submits to EPA for certification purposes are accurate for the full useful life. Manufacturers must state that their procedures follow sound engineering practices and specifically account for the deterioration of EGR, air pumps, and catalysts as well as other critical deterioration processes which the manufacturer may identify. In addition, when applicable, the manufacturers must state that the allowable maintenance intervals were followed in determining the preliminary deterioration factors. The manufacturers would submit preliminary deterioration factors, based on the definition of useful life, in each case where current certification procedures require testing of a durability-data engine. Beyond these requirements, EPA would not approve or disapprove the durability test procedures used by the manufacturers.

Step two involves emission data engines. One to four engines will be chosen for each engine family. These engines would be operated for 125 hours in a procedure designed by the manufacturers before the emission test. The preliminary deterioration factor will be multiplied by the 125 hour emission test results to predict whether the emission data engines would meet the standards for their full useful life. If the emission data engines are predicted to pass the standards over the full useful life, then the engine family is granted certification.

For the purpose of this cost analysis, the following assumptions are reasonable based on past practice. In 1984, manufacturers will certify one emission control system per engine family resulting in the need for one set of preliminary deterioration factors per family. EPA will select three emission data engines for each gasoline-fueled family and two for each diesel family7/, since each manufacturer will develop its own preliminary deterioration factors. As a base estimate, EPA has assumed that a manufacturer will follow the current procedures established by EPA. For a gasoline-fueled engine, this is a 1500 hour period with a test each 125 hours plus tests associated with scheduled maintenance. For a diesel engine, this covers 1,000 hours with a test each 125 hours plus tests associated with scheduled maintenance.

In order to estimate certification costs, unit costs must be known for each of the following: an emission data engine test including the required 125 hours of service accumulation plus the prototype engine and, preliminary deterioration factor assessment, which EPA believes will be conducted in a manner similar to the current pre-production durability testing procedure. All certification test costs include transient and idle emissions for gasoline-fueled engines and transient and smoke emissions for diesel engines.

Table V-E gives EPA estimates of these costs for both types of engines.8/ Estimates are in 1979 dollars.

Tables V-F and V-G show the calculation of initial certification costs for each manufacturer. The number of test operations of each kind required by each manufacturer depends on the number of engine families it will certify in 1984. Some manufacturers have provided EPA estimates of how many families they will certify in the mid 1980's. These estimates have been used when possible. In all other cases, the number of engine families certified in 1979 has been used.9/ It should be noted that the preliminary deterioration factor assessment costs will only be incurred for those

Table V-E

Unit Costs of Certification Tests

Test		Gasoline-fueled	Diesel 1/
1.	Preliminary deterioration factor assessment. 2/	$122K	$106K
2.	125-hour emission data engine. 3/	$13K	$20K

1/ Includes transient, idle, and smoke emissions.

2/ Assumes manufacturers follow current EPA procedures, but this is not mandatory.

3/ The manner in which the 125-hour break-in period is carried out is at the manufacturers' discretion.

Table V-F

Gasoline-Fueled Engine Certification Costs
for Model Year 1984 and Following

Mfr.	(a) Number of Engine Families	(b) Total Preliminary Deterioration Factor Assessment Costs	(c) Number of Emission Data Engines	(d) Total Emission Data Engine Costs	(e) Total Initial Certification Costs
IHC	4	$ 488K	12	$ 156K	$ 644K
Ford	8	$ 976K	24	$ 312K	$1288K
Chrysler	3	$ 366K	9	$ 117K	$ 483K
GM	4	$ 488K	12	$ 156K	$ 644K
Total		$2318K		$ 741K	$3059K

(b) = (a) x ($ 122K/engine family).

(c) = (a) x 3.

(d) = (c) x ($13K/emission data engine).

(e) = (b) + (d).

Table V-G

Diesel Engine Certification Costs
for Model Year 1984 and Following

Mfr.	(a) Number of Engine Families	(b) Total Preliminary Deterioration Factor Assessment Costs	(c) Number of Emission Data Engines	(d) Total Emission Data Engine Costs	(e) Total Initial Certification Costs
GM	9	$ 954K	18	$360K	$1314K
Cummins	19	1178K 1/	38	760K	1938K
Caterpillar	9	954K	18	360K	1314K
Mack	4	424K	8	160K	584K
IHC	5	530K	10	200K	730K
Deutz	2	-	2	40K	40K
Isuzu	2	-	2	40K	40K
White Engines	1	-	1	20K	20K
Fiat	2	-	2	40K	40K
Mercedes	3	318K	6	120K	438K
Mitsubishi	1	-	1	20K	20K
Scania Vabis	1	-	1	20K	20K
Volvo	3	-	3	60K	60K
Hino	1	-	1	20K	20K
Total		$4358K		$2220K	$6578K

(b) = (a) x ($106K/engine family).

(d) = (c) x ($20K/emission data engine), assumes two per engine family for large volume manufacturers and one for small volume manufacturers.

(e) = (b) + (d).

1/ Cummins stated their preliminary deterioration factor assessment costs at $62,000/family.

engine families certified by large volume manufacturers. For small volume manufacturers this cost is virtually zero.

4. Test Facilities Modification

These regulations will require that manufacturers remodel and/or purchase new engine dynamometers, dynamometer controls, constant volume sampling systems, and analytical systems. Some manufacturers will have to remodel or build new test cells, as well, to accommodate the new test equipment. There will also be costs for developing testing software and computer hook-ups. These requirements are the result of the revisions in the test procedures and the increased certification load anticipated for the mid-1980's. Of all the manufacturers which are affected by these test facility modifications, only GM and Chrysler commented in sufficient detail for analysis.

EPA's analysis of these comments, given in the Summary and Analysis of Comments10/, shows that GM's modifications for gasoline-fueled engines facilities would not exceed $1,673,000 and Chrysler's costs would not exceed $3,334,000. In either case, EPA believes these amounts to be the absolute maximum that either manufacturer would have to spend on new facilities and equipment to comply with these regulations.

Based on EPA's analysis of GM's comments, heavy-duty diesel facility and equipment modifications for GM should not exceed, at most, $6,015,000.10/

Since GM and Chrysler test facility and equipment costs have been mentioned above and discussed in more detail in other supporting documentation, GM and Chrysler costs will not be discussed in any further detail here but will be directly carried through to the summary tables which follow.

a. Dynamometers and Control Systems

Manufacturers will need engine dynamometers for two purposes: pre-production testing and emissions testing. Dynamometers used for emission testing using the new transient test procedure will likely have to be DC-electric dynamometers with sophisticated control systems. Dynamometers used for pre-production testing can be substantially simpler in terms of their control systems, and can be either DC-electric or eddy-current modified by the addition of a motor to permit constant-speed motoring. It will be possible to use an emission test dynamometer to accumulate service, but not vice versa. This difference in required capabilities and cost leads EPA to anticipate that manufacturers will dedicate dynamometers for each purpose, rather than perform both operations on the same set of dynamometers.

The number of dynamometers of each type needed by each manufacturer has been estimated by starting with the number of engine families estimated for the mid 1980's or, lacking a non-confidential estimate, with the number of 1979 diesel families and gasoline-fueled families. Based on conversations with manufacturers or on historical ratios between number of families and number of development-plus-certification dynamometers, the total number of dynamometers needed for 1984 was estimated. This total was split between emission test and pre-production testing dynamometers by allowing one emission test dynamometer per engine family plus one, unless a manufacturer indicated it planned to make do with fewer. The remaining dynamometers were taken to be pre-production testing dynamometers. EPA believes this method is conservative in that it over estimates the number of the more expensive emission test dynamometers.

EPA then inventoried the dynamometers now owned by the major manufacturers, to identify where modifications or additions will be required to meet their 1984 needs. Small volume manufacturers were treated by assuming worst-case needs for new equipment. Unit costs for modifications and additions were also estimated based on EPA experience, manufacturers' comment, and vendor estimates received by EPA.

Tables V-H and V-I show the resulting pre-production testing dynamometers costs by manufacturer. No manufacturer will need to buy completely new pre-production testing dynamometers, but most will have to make modifications.

Tables V-J and V-K present EPA's estimates of the need for and cost of new and modified dynamometers for emission testing. Manufacturers now using DC-electric dynamometers will have to remodel these in either of two ways, depending on the dynamometer models. EPA assumes that all manufacturers with a shortage of DC-electric dynamometers will purchase new DC-electric dynamometers and new control systems to fill the shortage. However, it is likely that some manufacturers will be able to avoid the cost of new DC-electric dynamometers by finding a way to remodel old eddy-current dynamometers. Two types of electric dynamometers which are suitable for emissions testing will be considered: motor-generator based and thyristor based. There is a considerable cost difference between these two types of dynamometers, but the more expensive motor generator based system is much more established. For the sake of this analysis, EPA shall assume that half of the manufacturers purchase the more expensive motor-generator based dynamometer and half purchase the newer, less expensive thyristor based dynamometers.

Table V-H

Pre-Production Dynamometer Costs, Gasoline-Fueled Engines

Manufacturer	No. of Engine Families in 1984	No. of Dynos Needed	No. Available Without Remodeling	No. Remodeled 1/	Total Cost
IHC	4	2	0	2	$170K
Ford	8	4	4	0	0
Chrysler	3	-	-	-	-
GM	4	-	-	-	-

1/ Cost each = $85K. Includes new control system and motoring capability on all eddy-current dynamometers, EPA estimate.

2/ GM & Chrysler costs are included in the total cost estimates cited previously.

Table V-I

Pre-Production Dynamometer Costs, Diesel Engines

Manufacturer	No. of Engine Families in 1984	No. of Dynos Needed	No. Available Without Remodeling	No. Remodeled 1/	Total Cost
GM 2/	9	-	-	-	-
Cummins	19	10	0	10	850K
Caterpillar	9	5	0	6	510K
Mack	4	2	0	2	170K
IHC	5	3	0	3	255K
Deutz	2	1	0	1	85K
Isuzu	2	1	0	1	85K
White Engines	1	1	0	1	85K
Fiat	2	1	0	1	85K
Mercedes	3	2	0	2	170K
Mitsubishi	1	1	0	1	85K
Scania-Vabis	1	1	0	1	85K
Volvo	3	2	0	2	170K
Hino	1	1	0	1	85K

1/ Cost each = $85K. Includes new control system and motoring capability on old eddy-current dynamometers, EPA estimate.
2/ GM costs are included in the total cost estimate cited earlier.

Table V-J

Emission Test Dynamometers and Control System Cost, Gasoline-Fueled Engines

Manufacturer	No. of Engine Families in 1984	No. of Emission Test Dynos Needed	No. Remodeled 1/ By Adding Computer Control System	No. Remodeled 2/ By Adding Computer Control and New Control Cabinet	Total Cost
IHC	4	5	2	3	$580K
Ford	8	9	8	1	450K
Chrysler 3/	3	-	-	-	-
GM 3/	4	-	-	-	-

1/ Cost each = $35K.
2/ Cost each = $170K.
3/ GM & Chrysler costs are included in the total costs cited previously.

Table V-K

Emission Test Dynamometers and Control System Costs, Diesel Engines

Manufacturer	No. of Engine Families in 1984	No. of Emission Test Dynos Needed	No. Remodeled 1/ By Adding Computer Control System	No. Remodeled 2/ By Adding Computer Control and New Control Cabinet	No. New 3/	Total Cost
GM 4/	9	-	-	-	-	-
Cummins	19	20	0	0	20	$5800K
Caterpillar	9	10	0	0	10	2900K
Mack	4	2	0	0	2	580K
IHC	5	5	0	0	5	1450K
Deutz	2	2	0	0	2	580K
Isuzu	2	2	0	0	2	580K
White Engines	1	1	0	0	1	290K
Fiat	2	2	0	0	2	580K
Mercedes	3	4	0	0	4	1160K
Mitsubishi	1	1	0	0	1	290K
Scania-Vabis	1	1	0	0	1	290K
Volvo	3	4	0	0	4	1160K
Hino	1	1	0	0	1	290K

1/ Cost each = $85K
2/ Cost each = $170K
3/ Cost each = $290K, with a range of $175K - $405K.
4/ GM costs are included in the total diesel cots for GM cited previously.

b. Constant Volume Sampling Systems

No engine manufacturer presently owns any constant volume sampling (CVS) systems suitable for use in testing heavy-duty engines with the transient test procedure. CVS systems will be used only for emission testing. Since one CVS unit can serve more than one emission test dynamometer, manufacturers will need fewer CVS units than they do emission test dynamometers. Tables V-L and V-M gives EPA's estimates of the number and cost of CVS systems that will be required by each manufacturer. This analysis will assume a 2:1 dynamometer-to-CVS ratio and will use cost estimates consistent with manufacturers' comment and EPA experience.

c. Analytical Systems

Current analytical systems used by engine manufacturers are designed for measuring pollutant concentrations in hot, raw exhaust. Under the transient test procedure, CO, NOx, and gasoline-fueled engine HC will be measured after being diluted with cool air and collected in a sample bag. EPA anticipates that an existing system can be converted to the new requirements at less than the cost of a new system. The cost depends on the type of NOx analyzer in the existing system. Also, because of the idle emission standard, manufacturers will need an additional raw exhaust CO_2 analyzer for use in the idle emission test. One new raw CO_2 analyzer will be required with each analytical system. Tables V-N and V-O give the number of systems requiring conversion and the total cost for each manufacturer. Costs are EPA estimates.

d. New Structures and Remodeling of Existing Structures

Some manufacturers indicated during conversations with EPA that new dynamometers and CVS systems could not be accommodated without new or remodeled buildings. Table V-P and V-Q list the cost of new or remodeled structures. The costs used are EPA estimates, which on a manufacturer-to-manufacturer basis are conservatively high. These costs are estimated on a square footage basis for the CVS modifications. Dynamometer-related costs depend upon the type of dynamometer purchased. For manufacturers who purchase the more expensive DC-electric dynamometers with motor-generator sets, facility modifications will also be required to accommodate the motor-generator sets. No facility modifications will be required if the manufacturer purchases electric dynamometers which do not require motor-generator sets. As before, EPA shall assume that one-half purchase electric dynamometers which require facility modifications and one-half purchase electric dynamometers which require no substantial modifications.

e. Software and Computer Hook-up

Manufacturers will need to develop new computer software for

Table V-L

Constant Volume Sampling System Cost
Gasoline-Fueled Engines

Manufacturer	Number of Emission Test Dynos	Number of 1/ CVS Systems Required	Total CVS Cost
IHC	5	3	$450K
Ford	9	5	750K
Chrysler 2/	4	-	-
GM 2/	5	-	-

1/ Cost each = $150K, includes installation.
2/ GM and Chrysler costs are included in the total costs cited previously.

Table V-M

Constant Volume Sampling System Costs
Diesel Engines

Manufacturer	Number of Emission Test Dynos	Number of 1/ CVS Systems Required	Total CVS Cost
GM 2/	-	-	-
Cummins	20	10	$1800K
Caterpillar	10	5	900K
Mack	2	2	360K
IHC	5	3	540K
Deutz	2	1	180K
Isuzu	2	1	180K
White Engines	1	1	180K
Fiat	2	1	180K
Mercedes	4	2	360K
Mitsubishi	1	1	180K
Scania-Vabis	1	1	180K
Volvo	4	2	360K
Hino	1	1	180K

1/ Cost each = $180K, includes installation.
2/ GM costs are included in diesel total costs for GM cited previously.

Table V-N

Analytical System Costs
Gasoline-Fueled Engines

Manufacturer	Number of Chemiluminescence Equipped 1/4/ Systems to be Converted	Number of NDIR- 2/4/ Equipped Systems to be Converted	Number of 3/4/ New Systems	Total Analytical System Cost
IHC	5	0	0	$105
Ford	8	0	1	238K
Chrysler 5/	–	–	–	–
GM 5/	–	–	–	–

1/ Cost each = $21K
2/ Cost each = $29K
3/ Cost each = $70K
4/ Cost includes $5K for a new raw CO_2 analyzer.
5/ GM and Chrysler costs are included in the total cost estimates cited previously.

Table V-O

Analytical System Conversion Costs
Diesel Engines

Manufacturer	Number of Chemiluminescence Equipped 1/ Systems to be Converted	Number of NDIR- 2/ Equipped Systems to be Converted	Number of 3/ New Systems	Total Analytical System Cost
GM	-	-	-	-
Cummins	0	0	10	810K
Caterpillar	0	3	2	264K
Mack	1	0	1	107K
IHC	0	2	1	149K
Deutz	0	0	1	81K
Isuzu	0	0	1	81K
White Engines	0	0	1	81K
Fiat	0	0	1	81K
Mercedes	0	0	2	162K
Mitsubishi	0	0	1	81K
Scania-Vabis	0	0	1	81K
Volvo	0	0	2	162K
Hino	0	0	1	81K

1/ Cost each = $26K
2/ Cost each = $34K
3/ Cost each = $81K

Table V-P

New or Remodeled Structures Costs 1/
Gasoline-Fueled Engines

Manufacturer	Costs to Accommodate CVS Systems 2/	Costs to Accommodate Dynamometers	Total Cost
IHC	$240K	0	$240K
Ford	400K	0	400K
Chrysler 3/	-	-	-
GM 3/	-	-	-

1/ Based on conversation with manufacturers.
2/ Assumes 400 sq. ft. at $200 per sq.ft., per CVS.
3/ GM and Chrysler costs are included in the total costs cited previously.

Table V-Q

New or Remodeled Structures Costs 1/
Diesel Engines

Manufacturer	Costs to Accommodate CVS Systems 3/	Costs to Accommodate Dynamometers 4/	Total Cost
GM 2/	-	-	-
Cummins	800K	0	800K
Caterpillar	400K	1500K	1900K
Mack	160K	300K	460K
IHC	240K	750K	990K
Deutz	80K	300K	380K
Isuzu	80K	300K	380K
White Engines	80K	150K	230K
Fiat	80K	300K	380K
Mercedes	160K	600K	760K
Mitsubishi	80K	150K	230K
Scania-Vabis	80K	150K	230K
Volvo	160K	600K	760K
Hino	80K	150K	230K

1/ Based on conversations with larger-volume manufacturer, and on worst-case assumptions for smaller-volume manufacturers.
2/ GM costs are included in the total diesel cost cited previously.
3/ Assumes an average of 400 sq.ft. at $200 per sq.ft.
4/ Assumes an average of $150K per emission dynamometer, with a range of $50K-$250K.

use in unnormalizing engine operating cycles, validating test runs, and calculating test results. Most of the manufacturers now have suitable computers at their facilities for this purpose, and others can arrange for commercial time-sharing service. In either case, there are costs associated with computer hook-up to the test area. Tables V-R and V-S give EPA's estimates of these software and hook-up costs. Cost estimates are in close agreement with comments by GM.

5. Selective Enforcement Auditing Costs (SEA)

In addition to the revised emission standards for 1984, EPA is implementing a production line testing program for gasoline-fueled and diesel engines. This program, known as Selective Enforcement Auditing, is designed to ensure that production-line engines will meet at least the applicable emission standards after adjustment for projected useful life deterioration. The costs associated with the SEA program can be broken into three main categories for both gasoline-fueled and diesel engines: SEA test facilities, SEA test costs, and costs associated with a 10% Acceptable Quality Level (AQL).

a. Test Facilities and Equipment for Formal SEA

The number of test facilities required for formal SEA is dictated by the audit rate prescribed in the regulations. Presently this requirement is two tests per day. For small volume manufacturers this requirement is decreased to one test per day. Based on a statistical analysis an average sample size of twelve engines per audit is expected.11/ This average sample size assumes that 10 percent of the engines tested are not in compliance.

Based on the comments received, it appears that manufacturers will use less expensive eddy-current dynamometers for engine "break-in" and will then move the engines to another test site for formal emissions testing on a DC-electric dynamometer. Using the SEA regulations and EPA testing experience as guidelines, EPA has determined that two "break-in" sites and one emissions testing site could provide six engines per week.12/ Thus, doubling these facilities to four "break-in" sites and two emission testing sites would provide the two engines per day necessary to fulfill the requirements.

In calculating the costs for these facilities, EPA has assumed all new facilities and equipment for gasoline-fueled engine manufacturers. An outline of these facilities and their total cost is shown in Table V-T.12/

For diesel manufacturers, EPA has assumed all new facilities and equipment with two exceptions. First, EPA believes the large volume diesel manufacturers will use the eddy-current dynamometers

Table V-R

Software and Computer Hook-Up Costs
Gasoline-Fueled

Manufacturer	Software and Hook-Up Costs
IHC	$125K
Ford	$150K
Chrysler 1/	-
GM 1/	-

1/ GM and Chrysler cost estimates are included in totals cited previously.

Table V-S

Software and Computer Hook-Up Costs
Diesel

Manufacturer	Software and Hook-Up Costs
GM 1/	$ -
Cummins	175K
Caterpillar	150K
Mack	125K
IHC	125K
Deutz	100K
Isuzu	100K
White Engines	100K
Fiat	100K
Mercedes	125K
Mitsubishi	100K
Scania-Vabis	100K
Volvo	125K
Hino	100K

1/ GM costs are included in estimates cited previously.

Table V-T

SEA Testing Facilities and Costs
Gasoline-Fueled Engines

Mfr.	Number of Break-in Sites	Cost per Break-in Site 1/	Number of Emission Testing Sites	Cost per Emission Testing Site 2/	TOTAL
GM	4	$530K	2	$1.015M	$4.15M
Ford	4	530K	2	1.015M	4.15M
Chrysler 3/	4	-	2	-	1.60M
IHC	4	530K	2	1.015M	4.15M
					$14.05M

1/ Includes new facility, supporting functions and equipment, eddy current dynamometer, dynamometer control, transporters, and receivers.
2/ Includes new facility, supporting functions and equipment, electric dynamometer, computer control, CVS, analytical system, and computer interface.
3/ Chrysler estimated their costs lower because they would be able to use existing facilities and equipment.

displaced from their certification facilities as their "break-in" dynamometers. Secondly, EPA does not believe that small volume manufacturers will purchase facilities dedicated to SEA, but instead, would use their certification facilities for SEA testing. In the final cost analysis, EPA shall assume one-half of the certification facility costs are attributable to SEA. Table V-U contains an outline of the facilities and cost per manufacturer.

The facilities for SEA will, in most cases, be built near the engine assembly point to decrease testing costs and allow the common usage of some support facilities. The costs allowed for facilities in this analysis are ample to allow the construction of a test cell which has all the essential equipment and supporting functions necessary for an efficient and safe testing program.

b. SEA Testing Costs

The actual testing costs incurred by a manufacturer are dependent on some testing decisions made by the manufacturer and on the number of SEAs a manufacturer undergoes. For example, the manufacturer decides, in advance, how many times (1-3) he will test each engine and the length of the break-in period prior to testing (0 to 125 hours). The number of SEAs to which a manufacturer is susceptible is primarily dependent on the annual sales volume. For each 30,000 engines sold, the manufacturer is susceptible to one SEA. The minimum number of SEAs to which a manufacturer is susceptible is one, regardless of sales volume. The possible number of SEAs per gasoline-fueled engine manufacturer is shown in Table V-V, and the possible number for diesel engine manufacturers is shown in Table V-W.

The actual cost per audit is based on the formula:

Cost/Audit = (Cost/Test)(Tests/Engine)(Engines/Audit)

This cost analysis will be based on the following set of assumptions:

(1) all audits are passed (12 engines tested);
(2) each engine is tested only once;
(3) each gasoline-fueled engine SEA test costs $1,750 and each diesel test costs $1,750 (these costs cover engine selection and transport, a 24 hour break-in period, emissions testing, and miscellaneous);
(4) each test in the audit is completed in 24 hours or less (excluding the break-in period, which is assumed to occur on the "break-in" dynamometer);
(5) two full SEA tests are completed each 24 hour day (thus, two SEA test cells are used for testing and four other dynamometers are used for break-in).

Table V-U

SEA Testing Facilities and Costs
Diesel Engines

Mfr.	Number of Break-in Sites	Cost per Break-in Site 1/	Number of Emission Testing Sites	Cost per Emission Testing Site 2/	TOTAL
Cummins	4	$480K	2	$1.045M	$4.01M
GM	4	480K	2	1.045M	4.01M
Cater-pillar	4	480K	2	1.045M	4.01M
Mack	4	480K	2	1.045M	4.01M
IHC	2	480K	1	1.045M	2.01M
Others(9)3/	2 each	-	1 each		6.78M

1/ Includes new facility, supporting functions and equipment, dynamometer installation, dynamometer control, transporters and receivers.
2/ Includes new facility, supporting functions and equipment, dynamometer, CVS, computer control, analytical system, and computer interface.
3/ Includes Isuzu, Mitsubishi, Hino, Mercedes, White Engines, Fiat, Scanis Vabis, Volvo, and Deutz.
4/ One half of certification facility costs as shown in preceding tables.

Table V-V

Number of "Possible SEAs" 1984-1988 1/ 2/
Gasoline-Fueled

Manufacturer	1984	1985	1986	1987	1988	Total per Manufacturer
GM	6	6	6	5	5	28
Ford	4	4	4	4	4	20
Chrysler	2	2	2	2	2	10
IHC	2	2	2	2	2	10
Total per year	14	14	14	13	13	68

1/ Based on projected sales (see Table V-Z) and allowing one audit for each 30,000 sold. Rounding of "possible audits" is up to the next whole number. Assumes no change in market shares of each manufacturer.

2/ The term "possible SEAs" includes only audits which are prompted by sales volume, and does not include those for failure of an SEA or other reason.

Table V-W

Number of "Possible SEAs" 1984-1988 1/ 2/
Diesel

Manufacturer	1984	1985	1986	1987	1988	Total per Manufacturer
Cummins	3	3	4	4	4	18
GM	3	3	3	3	3	15
Caterpillar	2	2	2	2	3	11
Mack	2	2	2	2	2	10
IHC	1	1	1	1	1	5
Others 3/	9	9	9	9	9	45
Total per year	20	20	21	21	22	104

1/ Based on projected sales (see Table V-Z) and allowing one audit for each 30,000 sold. Rounding of "possible audits" is up to the next whole number. Assumes no change in market shares of each manufacturer.
2/ The term "possible SEAs" includes only audits which are prompted by sales volume, and does not include those for failure of an SEA or other reason.
3/ Includes one each for Isuzu, Mitsubishi, Hino, Mercedes, White Engines, Fiat, Scania Vabis, Volvo and Deutz.

Cost/Audit = ($1,750/engine test)(12 engines tested/audit) = $21,000.

Using the cost per audit figure above and the total number of possible SEAs per manufacturer shown in Tables V-Y and V-W, the SEA testing costs for gasoline-fueled and diesel heavy-duty engine manufacturers are shown in Tables V-X and V-Y.

c. <u>10% Acceptable Quality Level (AQL) Costs</u>

The goal of passing formal SEA at a 10% AQL and, in essence, producing all engines to pass the emission standards at production, can be achieved through at least three means: research and development aimed at reaching lower target emission levels, production line quality control procedures to reduce variability, and post-production emissions testing aimed at providing the manufacturer with confidence in its efforts at passing SEA and the 10% AQL. The lower target emission levels associated with a 10% AQL were considered when the emission control system costs, shown in Sections A-1 and A-2, were computed. These costs are higher than those which would be necessary for a 40% AQL. Therefore, no further costs for research and development and hardware will be discussed here.

EPA expects that as a response to the implementation of SEA and, in addition, a 10% AQL, the manufacturers will institute a production quality control program to reduce engine-to-engine variability. Specifically, this program will be aimed at ensuring that emission-related parts are manufactured and installed correctly and that emission-related calibrations are the same as those of the emission data engines. EPA has estimated a cost of $10 per engine for this program. This assumes one-third of a man hour.

Finally, in response to SEA and the 10% AQL, EPA expects that all manufacturers will institute a manufacturer operated production line audit program to measure the effectiveness of their compliance efforts and provide themselves assurance of their ability to pass a formal EPA audit.

EPA believes that in the first year of SEA, 1984, the manufacturers may, on the average, audit as much as 0.6 percent of their production. However, as they gain greater confidence in their SEA compliance efforts and build engines to achieve the same emission standards for several years, this percentage will decline. EPA has assumed that by 1986 the audit fraction will have dropped from 0.6 percent to 0.4 percent and will remain at 0.4 percent through 1988.

The costs of this production line testing program potentially lie in two main areas: facilities and testing.

Table V-X

Costs per Year for SEA Testing 1984-1988 1/ 2/
Gasoline-Fueled

Manufacturer	1984	1985	1986	1987	1988	Total per Manufacturer
GM	$126K	$126K	$126K	$105K	$105K	$588K
Ford	84K	84K	84K	84K	84K	420K
Chrysler	42K	42K	42K	42K	42K	210K
IHC	42K	42K	42K	42K	42K	210K
TOTAL PER YEAR	$294K	$294K	$294K	$273K	$273K	$1428K

1/ Assumes that all "possible SEAs" are performed.
2/ (12 engines/audit) x ($1,750/engine) x (possible audits from Table V-V).

Table V-Y

Costs per Year for SEA Testing 1984-1988 1/ 2/
Diesel

Manufacturer	1984	1985	1986	1987	1988	Total per Manufacturer
Cummins	$ 63K	$ 63K	$ 84K	$ 84K	$ 84K	$ 378K
GM	63K	63K	63K	63K	63K	315K
Caterpillar	42K	42K	42K	42K	63K	231K
Mack	42K	42K	42K	42K	42K	210K
IHC	21K	21K	21K	21K	21K	105K
Others 3/	189K	189K	189K	189K	189K	945K
TOTAL PER YEAR	$420K	$420K	$441K	$441K	$462K	$2184K

1/ Assumes that all "possible SEAs" are performed.
2/ (12 engines/audit) x ($1750/engine) x ("possible audits" from Table V-W).
3/ Aggregate of the costs if Isuzu, Mitsubishi, Hino, Mercedes, White Engines, Fiat, Scania-Vabis, Volvo and Deutz are each audited once.

The facilities which the manufacturers will purchase for formal SEA will provide each large volume manufacturer the capabilities to test 1,000 engines per year, which at a 0.6 percent audit rate would support a production volume of 166,000 engines. For small volume manufacturers, the SEA facilities would support a production of 83,000 per year.

The sales projections shown in Chapter III and repeated in Table V-Z are EPA's projections for the heavy-duty class as a whole and are independent of the manufacturers involved. To determine the need for additional SEA testing facilities and the per manufacturer cost of production line audits, EPA shall assume that the manufacturers' market shares remain unchanged from current percentages. These percentages are shown as part of Tables V-AA and V-BB.

Based on these market percentages and EPA's sales projections, none of the diesel or gasoline-fueled manufacturers will require additional facilities for their own production line audit program.

The cost of a production self audit may vary quite substantially from that for a formal SEA audit test. Manufacturers would minimize the length of the "break-in" period to protect the engine resale value. In addition, there would be no substantial cost associated with engine and component selection and transport since the engines will be removed from the production line at random, and pipes, catalysts, etc., will be used many times. It is reasonable that manufacturers would design their "break-in" programs such that one engine per 16 hour day is "broken-in" and gasoline-fueled engine selection and transport costs would be cut to about the same as for diesels. This would be possible in self auditing because pipes and catalysts can be used over again, and testing facilities are located near either the vehicle or engine assembly point. So, the cost per test would be $1,072 for gasoline-fueled engines and $1,274 for diesel engines.12/ These costs include labor and fuel for "break-in" and emissions testing plus overhead and supervisory costs. Using the total sales figures shown in Table V-Z, and the self-audit fractions and audit test costs described above, the self-auditing costs per manufacturer are shown in Tables V-AA and V-BB.

5. Total Cost to Manufacturers

The four parts of the costs to manufacturers (emission control system costs, certification costs, test facility modification costs, and SEA associated costs) are summarized in Tables V-CC and V-DD. Costs are in 1979 dollars.

B. Costs to Users of Heavy-Duty Vehicles

1. Overhead and Profit

Table V-2

Heavy-Duty Engine Sales 1/
1984-1988

Year	Gasoline-Fueled	Diesel
1984	366,991	266,161
1985	360,888	284,255
1986	354,287	302,854
1987	347,171	321,966
1988	339,547	341,583
Total	1,768,884	1,516,819

1/ Domestic sales plus imports.

Table V-AA

Self Audit Testing Costs
Gasoline-Fueled 1/2/

Mfr.	Market Share % 3/	1984	1985	1986	1987	1988	Total Per Mfr.
IHC	12	$283K	$232K	$182K	$179K	$175K	$1051K
Ford	29	685K	561K	441K	432K	422K	2541K
Chrysler	16	378K	309K	243K	238K	233K	1401K
GM	43	1015K	832K	653K	640K	626K	3766K
Total per year		$2361K	$1934K	$1519K	$1489K	$1456K	$8759K

1/ Assumes a per test cost of $1072.
2/ Assumes audit percentages of: 1984, 0.6 percent; 1985, 0.5 percent; 1986 to 1988, 0.4 percent.
3/ Market share is an EPA estimate based on past sales data.

Table V-8B

Self Audit Testing Costs
Diesel 1/2/

Mfr.	Market Share % 3/	1984	1985	1986	1987	1988	Total Per Mfr.
Cummins	30	$610K	$543K	$463K	$492K	$522K	$2630K
GM	25	509K	453K	386K	410K	435K	2193K
Caterpillar	18	366K	326K	278K	295K	313K	1578K
Mack	14	285K	254K	216K	230K	244K	1229K
IHC	7	142K	127K	108K	115K	122K	614K
Deutz	0.8	16K	14K	12K	13K	14K	69K
Isuzu	0.7	14K	13K	11K	11K	12K	61K
White Engines	0.8	16K	14K	12K	13K	14K	69K
Fiat	0.8	16K	14K	12K	13K	14K	69K
Mercedes	1.8	37K	33K	28K	30K	31K	159K
Mitsubishi	0.2	4K	4K	3K	3K	3K	17K
Scania Vabis	0.2	4K	4K	3K	3K	3K	17K
Volvo	0.5	10K	9K	8K	8K	9K	44K
Hino	0.2	4K	4K	3K	3K	3K	17K
Total per year		$2033K	$1812K	$1543K	$1639K	$1739K	$8766K

1/ Assumes a per test cost of $1274.
2/ Assumes audit percentages of: 1984, 0.6 percent; 1985, 0.5 percent; 1986 to 1988, 0.40 percent.
3/ Market share is an EPA estimate based on past sales data.

Table V-CC

Total Cost to Manufacturers: Gasoline-Fueled Engines 1/

Manufacturer	Average R & D Cost per Engine	Emission Control System Cost per Engine	Initial Certification Cost	Test Facility Modification Costs For Certification
IHC	$10	$253	$ 644K	$1670K
Ford	10	253	1288K	1988K
Chrysler	10	253	483K	3334K
GM	10	253	644K	1673K

Manufacturer	Test Facilities for SEA	Formal SEA Testing (1984-1988)	Self Audit Testing (1984-1988)	Quality Control Program Cost per Engine	Total per Manufacturer 2/
IHC	$4150K	$210K	$1051K	$10	$ 7725K
Ford	4150K	420K	2541K	10	10387K
Chrysler	1600K	210K	1401K	10	7028K
GM	4150K	588K	3766K	10	10821K

1/ All Costs are undiscounted.
2/ Does not include R & D, emission control system, and quality control program cost per engine.

Table V-DD

Total Costs to Manufacturers:
Diesel Engines

Manufacturer	Average R & D Cost per Engine	Emission Control System Cost per Engine	Initial Certification Cost	Test Facility Modification Costs for Certification
GM	$23	$33	$1314K	$ 6015K
Cummins	23	33	1938K	10235K
Caterpillar	23	33	1314K	6284K
Mack	23	33	584K	1802K
IHC	23	33	730K	3509K
Deutz	23	33	40K	.703K
Isuzu	23	33	40K	703K
White Engines	23	33	20K	483K
Fiat	23	33	40K	703K
Mercedes	23	33	438K	1369K
Mitsubishi	23	33	20K	483K
Scania Vabis	23	33	20K	483K
Volvo	23	33	60K	1369K
Hino	23	33	20K	483K

Table V-DD

Total Costs to Manufacturers:
Diesel Engines (cont'd.)

Manufacturer	Test Facilities For SEA 2/	Formal SEA Testing (1984-1988)	Self-Auditing Testing (1984-1988)	Quality Control Program Cost per Engine	Total per Manufacturer 3/
GM	$4010K	$315K	$2193K	$10	$13847K
Cummins	4010K	378K	2630K	10	19191K
Caterpillar	4010K	231K	1578K	10	13417K
Mack	4010K	210K	1229K	10	7835K
IHC	2005K	105K	614K	10	6963K
Deutz	703K	105K	69K	10	1620K
Isuzu	703K	105K	61K	10	1612K
White Engines	483K	105K	69K	10	1160K
Fiat	703K	105K	69K	10	1620K
Mercedes	1368K	105K	159K	10	3439K
Mitsubishi	483K	105K	17K	10	1108K
Scania Vabis	483K	105K	17K	10	1108K
Volvo	1368K	105K	44K	10	2946K
Hino	483K	105K	17K	10	1108K

1/ All costs are undiscounted.

2/ Assumes small volume manufacturers would use certification facilities for SEA, thus, facility costs are shared equally by certification and SEA.

3/ Does not include R & D, emission control system, and quality control cost per engine.

In addition to the direct costs of manufacturing discussed in the previous sections and summarized in Tables V-CC and V-DD, the manufacturers involved have increased general overhead costs which must be recovered and an average profit which should be returned on the corporate resources invested. To a lesser degree this is also true for the vehicle dealer.

To determine what these corporate overhead and profit figures should be, EPA turned to the 1979 edition of Moody's Industrial Manual. In addition to general financial information on each corporation listed, this publication gives data on corporate costs as a function of net sales. Included in these corporate cost figures are several categories which EPA has found useful in estimating the overhead and profit figures discussed above. These include: cost of sales, general expenses, administration expenses, selling expenses, miscellaneous expenses, interest, other income, and income before taxes. Using the other income and expense related categories, EPA was able to closely estimate corporate ovehead as a percentage of cost of sales. Using the income before taxes figure, EPA computed the profit as a percentage of cost of sales.

(a) Gasoline-Fueled Engines

For gasoline-fueled heavy-duty engines, EPA studied the financial figures for General Motors, Ford, Chrysler, and International Harvester for 1976, 1977, and 1978. The corporate overhead percentages on a per manufacturer basis over the 3 year period ranged from 6.7 percent to 19.3 percent, with an average of 12.2 percent. The corporate profit figures range from 0 percent to 14.5 percent , with an average of 7.9 percent.

The range on these figures is too large to establish a meaningful average, so EPA instead has chosen to make a conservative assumption. The clear leader in heavy-duty gasoline-fueled engine sales is General Motors, with more than 40 percent of the market. In addition, General Motors is also the sales and profit leader motor vehicle industry wide. To be conservative then, EPA has applied General Motors 1976-1978 average overhead and markup percentages to sales for all manufacturers. EPA considers the use of GM figures to be conservative because GM profits are the largest percentage of the four and GM overhead is second largest of the four manufacturers considered. Using these assumptions, overhead as a percentage of cost of sales is 11.4 percent and profit before taxes as a percentage of cost of sales is 13.8 percent.

The close out of the portion of this discussion related to gasoline-fueled heavy-duty engines dealer overhead and profit should be addressed. Selling a vehicle with a larger AIR pump, catalytic converter, or any other modification caused by these regulations would not increase dealer overhead. No additional personnel or vehicle servicing would be necessary. Dealer profit after all taxes has been estimated at 1.5 percent of the dealer purchase price.13/ To account for the effect of taxes, this profit margin will be doubled to estimate the effect of dealer's profit on the first price increase.

Therefore, the total markup on the manufacturing cost becomes 1.29. This markup is applied on a per vehicle basis to all costs incurred including hardware, research and development, certification, SEA, etc.

The retail price equivalent (RPE) can now be computed as:

RPE = (All Vendor/Manufacturing Cost per Vehicle)(1.252)(1.03)

(b) Diesel Engines

For diesel engines, EPA studied the aforementioned 1976, 1977, and 1978 financial data for five manufacturers: General Motors, Cummins, Caterpillar, Mack, and International Harvester. The corporate overhead as a percentage of cost of sales on a per manufacturer basis over the 3 year period ranged from 8.5 percent to 33.6 percent with an average of 16.7 percent. The before tax corporate profit as a percentage of cost of sales ranged from 5.5 percent to 17.2 percent, with an average of about 11.9 percent. Although there is once again a very large range on these percentages, more reason is available to allow an analysis. The five major manufacturers mentioned above build a wide variety of engines and motor vehicles as well as engine and motor vehicle related products. This diversification will obviously impact the corporate financial figures. In addition, this gives EPA some reasons for the wide range in corporate overhead and profit percentages. Of the five manufacturers mentioned, two make only engines (Cummins and Caterpillar), and three make vehicles and engines (GM, IHC, and Mack). In terms of sales, this is roughly a 50/50 split. Therefore, using the industry wide average corporate overhead and markup percentages cited previously (16.7 percent and 11.9 percent respectively) would certainly be a representative, if not a conservatively high, estimate for the heavy-duty diesel industry as a whole.

Turning finally to dealer overhead and profit, EPA once again sees no incremental increase in dealer or franchise overhead as a result of these regulations. No additional personnel or engine servicing will be necessary. Most heavy-duty diesel engines sold in the United States are not sold through conventional dealers as are automobiles and light-duty trucks, but instead, are sold through either dealer franchises which specialize in only trucks or through manufacturers' representatives. The individual retail price of a diesel truck or bus may exceed $50,000, and multiple unit sales to city transit systems, inter-city bus companies, or large trucking companies are quite common. Admittedly, dealers would try to get a small profit on their increased investment in the engine, but this could easily be very small or nothing after the final price negotiations on the sale of the vehicle(s). The amount of any profit will be very small, so EPA shall assume it is small enough to fall within other possible errors in estimating manufacturing costs or corporate overhead and profit.

Therefore, EPA shall use a profit and overhead markup figure of 1.29 to determine the retail price equivalent. Once again this markup will be applied to all the per engine costs associated with this rulemaking action.

These overhead and profit markups which, coincidentally, are both 29 percent, will be applied to the total manufacturing costs to determine the first price increase.

2. Increases in First Costs

The added costs to engine manufacturers for emission control system research, development, hardware, certification and durability testing, test facility modifications, and SEA related costs will be passed on to the purchasers and users of heavy-duty vehicles. Assuming the average R&D and hardware cost per engine, the amount a manufacturer must increase the price of its engines in order to recover its expenses depends on the timing of costs and revenues from sales and on the cost of capital to the manufacturers. Tables V-EE and V-FF show the timing of costs which has been used to estimate the average first price increase.

EPA has assumed that over the long run, manufacturers face a 10 percent cost of capital and that they price their engines so as to recover their investment in five model years, 1984-1988.

Table V-GG presents the expected average first cost increases for the 1984-1988 period for both types together with a restatement of the critical assumptions used.

The remainder of the costs discussed in this Costs to Users section are discounted at 10 percent to January 1 of the model year in which the engine is produced unless stated otherwise.

3. Maintenance Costs

The use of 1984 control technology is not expected to increase maintenance costs, but conversely is expected to actually decrease maintenance costs in at least two areas: exhaust systems and spark plugs. The use of unleaded gasoline combined with material improvements in the exhaust system will reduce maintenance costs associated with exhaust system replacement. EPA estimates that at the minimum one entire exhaust system replacement will be saved over the vehicle lifetime. Spark plug life will be lengthened

Table V-EE

Fixed Cost to Manufacturers by Period: Gasoline-Fueled

Mfr.	1980 1/	1981 2/	1982 3/	1983 4/	1984 5/	1985 5/	1986 5/	1987 5/	1988 5/	Total 6/
IHC	$ 557K	$1113K	$2536K	$2231K	$ 325K	$ 274K	$ 224K	$ 221K	$ 217K	$ 7725K
Ford	663K	1325K	3051K	2387K	769K	645K	525K	516K	506K	10,387K
Chrysler	1111K	2223K	1166K	917K	420K	351K	285K	280K	275K	7028K
GM	558K	1115K	2563K	2231K	1141K	958K	779K	745K	731K	10,821K
Total	$2889K	$5776K	$9343K	$7766K	$2655K	$2228K	$1813K	$1762K	$1729K	$35,961K

1/ One-third of certification facility modifications.
2/ Two-thirds of certification facility modifications.
3/ Preliminary deterioration factor assessment costs plus one-half of SEA facility costs.
4/ Emission data engine costs plus one-half of SEA facility costs.
5/ Formal SEA plus self-auditing costs.
6/ Does not include R & D, emission control hardware, or quality control program costs per engine.

Table V-FF

Fixed Cost to Manufacturers by Period:
Diesel Engines

Mfr.	1980 1/	1981 1/	1982 2/	1983 3/	1984 4/	1985 4/	1986 4/	1987 4/	1988 4/	Total 5/
GM	$3007K	$3008K	$2959K	$2365K	$ 572K	$ 516K	$ 449K	$ 473K	$ 498K	$13847K
Cummins	5117K	5118K	3183K	2765K	673K	606K	547K	576K	606K	19191K
Caterpillar	3142K	3142K	2959K	2365K	408K	368K	320K	337K	376K	13417K
Mack	901K	901K	2429K	2165K	327K	296K	258K	272K	286K	7835K
IHC	1754K	1755K	1533K	1202K	163K	148K	129K	136K	143K	6963K
Deutz	-	703K	703K	40K	37K	35K	33K	34K	35K	1620K
Isuzu	-	703K	703K	40K	35K	34K	32K	32K	33K	1612K
White Engines	-	483K	483K	20K	37K	35K	33K	34K	35K	1160K
Mercedes	-	1369K	1686K	120K	58K	54K	49K	51K	52K	3439K
Mitsubishi	-	483K	483K	20K	25K	25K	24K	24K	24K	1108K
Scania Vabis	-	483K	483K	20K	25K	25K	24K	24K	24K	1108K
Volvo	-	1369K	1368K	60K	31K	30K	29K	29K	30K	2946K
Hino	-	483K	483K	20K	25K	25K	24K	24K	24K	1108K
Fiat	-	703K	703K	40K	37K	35K	33K	34K	35K	1620K
Total	$13921K	$20703K	$20158K	$11242K	$2453K	$2232K	$1984K	$2080K	$2201K	$76,974K

1/ One-half of certification facility modification costs.
2/ One-half of SEA facility costs plus preliminary deterioration factor assessment costs.
3/ One-half of SEA facility costs plus emission data engine costs.
4/ Formal SEA audits plus self-audit testing costs.
5/ Does not include R & D, emission control hardware, and quality control program costs.

Table V-GG

Average Increases in First Cost of 1984-1988 Model Year Engines

Engine Type	Increase in First Cost 1/2/
Gasoline-fueled	$ 394
Diesel	$ 195

1/ Assumes: equal first cost increases for all engines of a type produced during 1984-1988 model years; amortization of all costs from Tables V-HH and V-II during 1984-1988 at 10 percent interest; 1984-1988 sales from Table V-CC.

2/ Cost includes all overhead and profit at all levels.

substantially over the current intervals as a result of the use of unleaded fuel.

To estimate these cost savings, exhaust system and spark plug replacement costs, the current and future spark plug replacement intervals, and a mileage accumulation rate for heavy-duty gasoline-fueled engines must be known.

EPA ascertained exhaust system and spark plug replacement costs using parts plus labor replacement cost estimates received from several retail dealers. For a set of 8 spark plugs, estimates ranged from $9.50 to $20.00. EPA used the mid-range in these estimates, approximately $14 per set. Exhaust system replacement costs ranged from $180 to $200 for parts and labor. Since at least one complete exhaust system will not have to be replaced, EPA conservatively estimates a cost savings of $180 over the vehicle lifetime.

The current heavy-duty spark plug replacement interval lies in the 12,000 to 16,000 mile range. The new maintenance interval is 25,000 miles. For exhaust systems, EPA has estimated that without the use of unleaded gasoline, only one replacement, probably late in the fourth year, would be required, and the second replacement could be eliminated.

Finally, to compute the discounted values of these savings, the average mileage accumulation rate for heavy-duty gasoline-fueled vehicles must be known. This was taken from an EPA technical report14/ and is shown in Table V-HH together with the exhaust system and spark plug computations.

Using the data in Table V-HH and a standard 10 percent discount rate, the average spark plug and exhaust system savings can be computed to be $176 per vehicle. EPA believes this figure to be a minimum that can be expected over the 8 year, 114,000 mile average useful life.14/

4. Fuel Economy and Fuel Costs

EPA does not expect an increase in overall fuel consumption for either gasoline-fueled or diesel heavy-duty engines.

Some diesel engines which use EGR to control HC may incur a slight fuel economy penalty. However, diesel engines which add aftercoolers, or redesign injectors or combustion chambers will have a fuel economy increase which, in the aggregate, will more than offset any possible penalty.

For gasoline-fueled engines, the addition of a larger AIR pump will cause a 4-8 percent fuel economy penalty. However, the addition of a catalyst will allow engine tuning for fuel economy.

Table V-III

Exhaust System and Spark Plug Savings

Year 1/	Average Annual Mileage 2/	Cumulative Mileage 2/	Number of Spark Plug Replacements Based on Intervals 12,000 miles	25,000 miles	Exhaust System Replacement With and Without Unleaded Gasoline Without	With
1	9,500	9,500	0	0	-	-
2	19,000	28,500	2	1	-	-
3	18,450	46,950	1	0	1	-
4	17,200	64,150	2	1	-	1
5	15,750	79,900	1	1	-	-
6	14,250	94,150	1	0	1	-
7	12,750	106,900	1	1	-	-
8	7,100	114,000	1	0	-	-
			9	4	2	1

1/ Year of vehicle usage.
2/ Average Lifetime Periods for Light-Duty Trucks and Heavy-Duty Vechiles, US EPA, ECTD, SDSB 79-20 Glenn W. Passavant, November 1979.

which could yield a 12 percent to 17 percent fuel economy improvement. Thus, considering the AIR pump losses to be 8 percent, the worst case assumption, the fuel economy improvement expected ranges from 4 percent - 9 percent.15/

Using a 1979 fuel economy of 5.4 miles per gallon16/ and a retail unleaded fuel cost of $1.10 per gallon this could yield savings per vehicle over a useful life of 8 years and 114,000 miles in the amounts shown in Table V-II. Table V-II gives discounted fuel economy benefits and fuel economy increases.

Catalyst equipped gasoline-fueled engines will require unleaded gasoline which can be expected to cost more than leaded gasoline. The current average nationwide differential between leaded and unleaded gasoline is roughly 4 cents per gallon, 3 cents of which is the current refinery gate cost differential.17/

In the long run, as increased quantities of unleaded fuel are produced, this differential is predicted to shrink to about 2.5 cents per gallon at the refinery gate and 3 cents per gallon retail.18/ This 3 cents would include about 0.5 cents per gallon to cover the need for modified or increased unleaded gasoline pumping facilities.

Using an average fuel economy in the 1984-1988 time frame of 9.9 miles per gallon19/ a lifetime of 114,000 miles and a differential of 3 cents per gallon lifetime fuel costs will increase by $259 (discounted). Including this cost ignores the real likelihood that by 1984 lead tolerant catalysts will have been developed to the point that they will be commercially available on motor vehicles.

5. Total Costs to Users

To summarize, users of heavy-duty vehicles equipped with diesel engines can, as a result of the statutory emission standards and accompanying procedure changes, expect to pay about $195 more for 1984 model year vehicles than for comparable models bought in 1983, in 1979 dollars. No increase in operating costs for these vehicles will occur. Assuming a 475,000 mile total life, the first cost increase translates to an increase in operating costs of 0.041 cents per mile (undiscounted).

For vehicles powered by gasoline engines, the first cost will increase by $394. Added unleaded fuel costs, less savings on spark plug and exhaust system replacement, will total $83 (discounted) over the useful life. The sum of first costs plus operating costs is equivalent to about 0.42 cents per mile (undiscounted). This does not include a fuel economy benefit which would actually lead to decreased operating costs.

Table V-II

Fuel Economy Benefits

Fuel Economy Increase	Gallons Saved	Discounted Savings at $1.10 per gallon at 5% discount rate 1/
1 Percent	209	$ 197
3 Percent	627	$ 591
4 Percent	836	$ 788
5 Percent	1045	$ 985
7 Percent	1463	$1379
9 Percent	1881	$1773

1/ Use of a 5 percent discount rate is a more realistic reflection of the actual benefits because it accounts for fuel prices which are expected to rise at a greater rate than other prices. This discount rate was suggested by the Council on Wage and Price Stability in their Comments on the Proposed Light-Duty Diesel Particulate Regulations. See Summary and Analysis of Comments, Section V for the Light-Duty Diesel Particulate Regulations for further discussion.

C. Aggregate Costs - 1984-1988

The aggregate cost to the nation of complying with the 1984 Federal heavy-duty engine emission regulations and the new SEA program consist of the sum of increased costs for new emission control technology and hardware; new and modified test equipment and facilities; additional certification costs; SEA facilities and testing; and unleaded fuel, for gasoline-fueled engines. These costs will be calculated for a five year period (1984-1988) of compliance, but will include operating costs incurred after 1988 by engines produced in the five year period.

It must be noted that calculating aggregate costs based on a five-year period distorts the cost impact of the regulations. At the end of that five year period, part of the initial investment in new engine designs, new certification, and new or remodeled test facilities will still exist and be productive. As just one example, the new dynamometers required by manufacturers have an expected life of about 20 years. The "salvage value" of the 1984 investment could reasonably be subtracted from the five-year aggregate costs. It will not be, since the exact value of the still-intact investment at the end of 1988 will depend on the manufacturers' product plans at that time, which are uncertain now.

It must also be noted that aggregate costs will be calculated without considering the more stringent NOx and particulate standards expected to be promulgated for 1985. These standards will likely force redesign and recertification of at least some engines. The cost of this has not been considered here. When the 1985 NOx and particulate standards are proposed, their cost impact will be taken to be the cost increase they cause over the costs calculated here.

The five year costs of compliance are dependent, of course, on the number of heavy-duty vehicles sold during that period with either gasoline or diesel engines, and also on the mix of sales between gasoline engine or diesel engine-equipped vehicles. The accuracy and validity of projecting vehicle sales as far into the future as 1988 is problematical, so cost estimates based on such projections are also subject to some qualification. The engine sales scenario which EPA used to make these cost calculations is discussed in detail in Chapter III of this analysis. They are also shown in Table V-Z and reflect roughly a 6.4 percent growth in diesel sales, a 2 percent decrease in gasoline-fueled engine sales, and a 1.85 percent overall growth rate in heavy-duty engine sales over the 5 year period 1984-1988.

The various costs associated with the regulations will occur in different periods. In order to make all costs comparable, the present value at the start of 1984 of the aggregate costs has been calculated, based on a discount rate of 10 percent.

Use of a discount rate emphasizes that because of the time value of money, a cost incurred today is worth more to the nation than a cost incurred in the future.

The calculation of the present value in 1984 of the aggregate costs is shown in Table V-JJ. The timing assumptions used in Tables V-EE and V-FF were used in computing the aggregate costs. It is estimated that the aggregate cost of complying with the new regulations for the 5 years period is the equivalent of a lump-sum investment of about $988 million dollars (1979 dollars) made at the start of 1984. Expressed in other terms, the aggregate cost of compliance is equivalent to investments of $195 per diesel engine made at the start of the year the engine is produced and $477 per gasoline-fueled engine also made at the start of the year the engine is produced. Overall the aggregate cost is equivalent to $288 per heavy-duty engine.

For ease of reference the components of the cost of compliance and the different ways of expressing it are shown in Tables V-KK, V-LL, and V-MM.

The effect of the fuel economy benefit on the aggregate cost of this package is substantial.

The data from Table V-II together with the total heavy-duty gasoline-fueled engine production estimated for the 5 year period (1,768,884) can be used to estimate the affect of the fuel economy benefit on the aggregate cost. This is shown in Figure V-A.

It is very obvious that the minimum fuel economy improvement determined in EPA's analysis (4 percent) would reduce the aggregate cost of these regulations to below zero. The fuel savings would be so large that any increase in the purchase price of heavy-duty gasoline-fueled vehicles would be more than offset by decreased operating costs.

D. Socio - Economic Impact

1. Impact on Heavy-Duty Engine and Vehicle Producers

The promulgation of the 1984 heavy-duty engine emission regulations will cause the manufacturers of these engines to spend about $71 million dollars for test facilities modifications and engine certification, an additional average $83 million a year for production of emission control systems and $90 million for the SEA program over and above those required to meet current standards. These costs will be initially paid by individuals or companies that buy heavy-duty vehicles and ultimately by the consumers of the products carried by those vehicles. SEA and self-audit testing costs are an exception, but most of the compliance costs are incurred by engine manufacturers before they

Table V-JJ

Present Value in 1984 of Aggregate Cost of Compliance For 1984-1988 Model Years

Year	Cost	Present Value in 1984
Diesel (1,516,819 Engines)		
1980	$13,921K	$ 20,382K
1981	32,054K	42,664K
1982	24,732K	29,925K
1983	29,371K	32,308K
1984	25,669K	25,669K
1985	26,933K	24,485K
1986	28,277K	23,369K
1987	30,068K	22,591K
1988	31,996K	21,854K
		$243,247K
Gasoline-Fueled (1,768,884)		
1980	2,889K	4,230K
1981	14,605K	19,439K
1982	18,172K	21,988K
1983	7,766K	8,543K
1984	142,243K	142,243K
1985	155,113K	141,012K
1986	167,135K	138,128K
1987	116,756K	87,721K
1988	131,855K	90,059K
1989	11,593K	7,198K
1990	11,072K	6,250K
1991	-119K	-61K
1992	42,639K	19,892K
1993	25,926K	10,995K
1994	15,704K	6,055K
1995	2,551K	894K
		$704,586K

1984 Pesent Value of Aggregate Cost: $947,833K

Table V-KK

Undiscounted Costs of Compliance Per Engine for Engines Produced 1984-1988

Cost Affecting Selling Price	Gasoline-Fueled	Diesel
Certification Facilities	$ 4.91	$22.88
Research and Development	10.00	22.50
SEA Facilities	7.96	16.40
Certification Testing	1.73	4.35
SEA Testing	.81	1.44
Self Audits	4.95	5.78
Manufacturing	253.00	33.38
Quality Control	10.00	10.00
Overhead and Profit	88.61	43.84
Operating Cost		
Unleaded Fuel	$345.40	-
Exhaust System and Spark Plugs	-237.00	-
Undiscounted Cost per Engine	$490.37	$160.57
Potential Fuel Savings (low estimate)	-$920	0

Table V-LL

Discounted Costs of Compliance Per Engine for Engines Produced 1984-1988 1/

Cost Affecting Selling Price	Gasoline-Fueled	Diesel
Certification Facilities	$ 8.06	$38.43
Research and Development	15.18	33.13
SEA Facilities	10.98	22.69
Certification Testing	2.45	6.19
SEA Testing	.81	1.45
Self Audits	5.06	5.90
Manufacturing	253.00	33.38
Quality Control	10.00	10.00
Overhead and Profit	88.61	43.84
Operating Cost		
Unleaded Fuel	$258.72	-
Exhaust System and Spark Plugs	-176.13	-
Cost of Engine at Start of Production Necessary to Pay Cost of Compliance	$476.74	$195.01
Potential Fuel Savings (low estimate)2/	-$788	0

1/ 10 Percent Discount to January 1 of the model year.
2/ See Table V-II.

Table V-MM

Aggregate Cost of Compliance
for Engines Produced 1984-1988
(10% Discount to January 1, 1984)

	Gasoline-Fueled	Diesel
Certification Facilities	$ 11,918K	$ 47,937K
Research and Development	22,435K	41,330K
SEA Facilities	16,228K	28,297K
Certification Testing	3,620K	7,715K
SEA Testing	1,196K	1,813K
Self Audits	7,475K	7,363K
Manufacturing	373,924K	41,635K
Quality Control	14,780K	12,473K
Overhead and Profit	130,957K	54,683K
Unleaded Fuel	382,373K	-
Exhaust System and Spark Plugs	-260,319K	-
Total	$704,587K	$243,246K

Grand Total: $947.833 Million Dollars

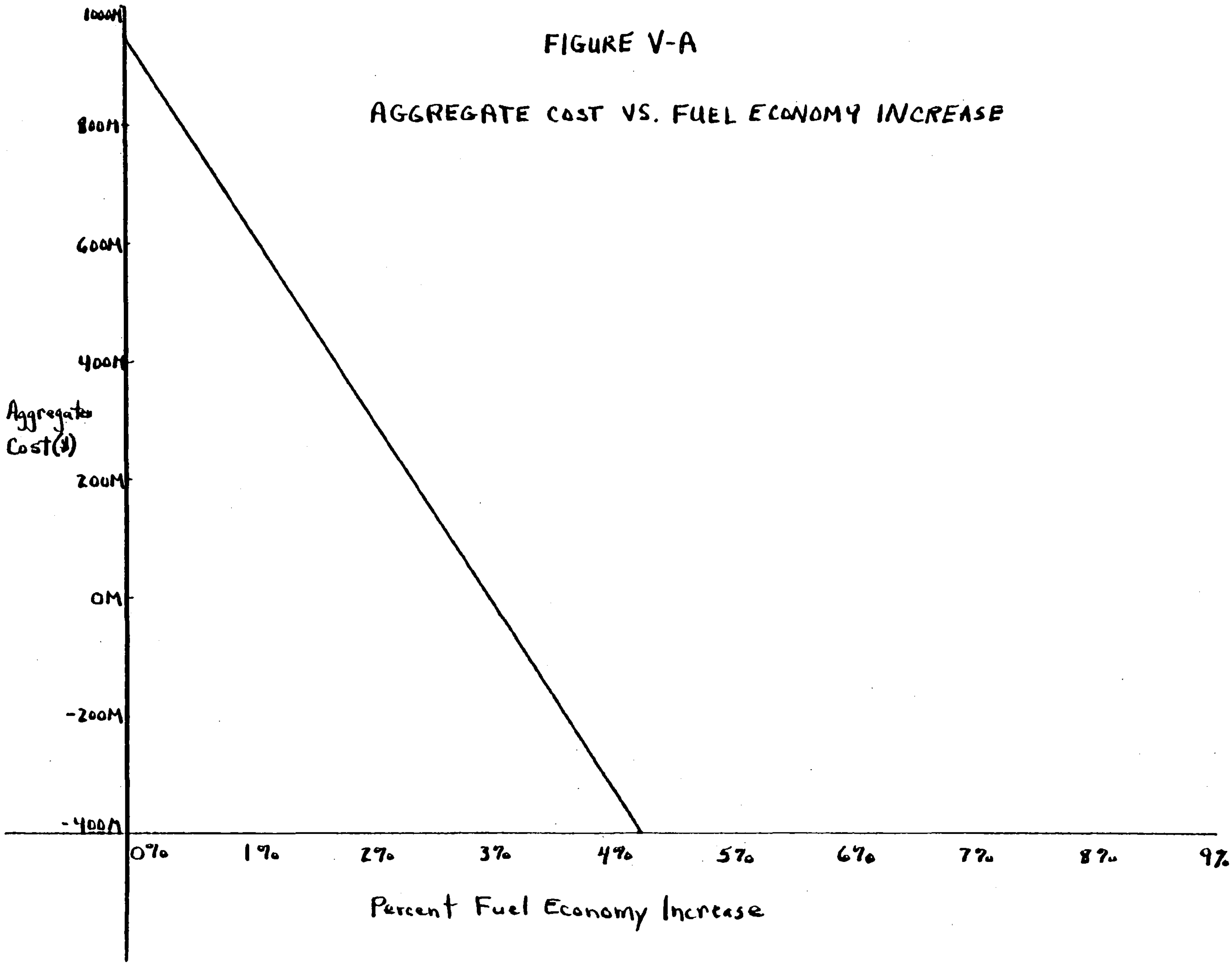


FIGURE V-A

AGGREGATE COST VS. FUEL ECONOMY INCREASE realize any revenue from sales of engines for which this money is expended. This regulation, therefore, will require manufacturers to generate additional capital between promulgation of the final rule and 1984 either internally or from the capital markets, sufficient to meet each year's costs.

Tables V-CC and V-DD show the costs of test facility modifications certification and SEA by company. (GM and IHC are the only companies appearing in both tables.) Tables V-EE and V-FF show their total costs including control system production costs, by year. Costs are first incurred in 1980 as facility modifications begin on a large scale. The first opportunity to recover costs via price increases will be in 1984, assuming that competitive pressures keep manufacturers from raising prices on earlier engines beyond what they would do without these regulations.

Most engine manufacturers should have little difficulty financing the required investment, barring a post 1980 recession. Cummins, Chrysler and White Engines can be expected to have the most difficulty. For Cummins the 1980-1983 investment represents about 40 percent of its 1978 corporate profits. Chrysler will have severe trouble financing any capital investment without government loan guarantees. White Engines will require several years profits to finance their investment and may choose to seek another means of certification to reduce their initial capital investments. For Mack, Caterpillar and IHC the investment ranges from 3 percent to 16 percent. For GM and Ford the investment required is less than one percent of 1978 profits. The foreign manufacturers should also have little problem financing the required investment which will likely be below the worst case estimate presented here.

Payments on recurring costs (emission control system production, SEA related testing) will occur closer to the time revenues are received (via sales of controlled engines) than do the payments required before 1984 production begins. Assuming manufacturers can pass on the largest fraction of their costs, then they should be able to finance most of production and installation of control equipment from current revenues.

Changing the prices and operating costs of heavy-duty engines may, of course, impact the sales of engine manufacturers. Both total sales and sales mix between diesel and gasoline-fueled engines may be affected. EPA knows of no estimate of the cross-elasticities of demand20/ for gasoline-fueled and diesel engines. When considering the change in sales mix, the cost of ownership, as well as the increased first cost, may cause a demand shift. Based on the average first cost increase ($394 gasoline-fueled, $195 diesel) and the increased costs of ownership ($83 gasoline-fueled, $0 diesel) the demand shift would appear to be toward diesel engines. However, fuel economy improvement expected for heavy-duty gasoline-fueled vehicles will offset the increased operating cost associated with unleaded fuel. Therefore, in the long run the demand shift would be caused only by the first price increase. This could occur when the larger first price increase for gasoline-fueled engines, coupled with their inherently larger operating and maintenance costs offsets the greater initial purchase price of a diesel engine for a given vehicle. However, the existing price difference between comparable diesel and gasoline-fueled engines (as much as a factor of three) will allow this demand shift to occur for only a small fraction of total heavy-duty sales. In addition to first costs and operating costs, other factors are considered by purchasers of heavy-duty engines. Gasoline-fueled engines usually give better overall performance and are better suited to multi-stop applications. Diesel engines have lower maintenance and fuel costs, a longer useful life, and give better fuel economy especially in over the road applications.

The pending heavy-duty particulate and NOx regulations may have an effect on the gasoline-fueled and diesel sales mix. In the long run, fuel economy considerations will be the primary reason for the sales mix change which is generally expected by both industry and EPA. The impact of these regulations on the selling price and operating costs of each type of engine should not cause any further increase in the changes in the heavy-duty market split.

EPA's Office of Noise Abatement Control has estimated the overall price elasticity of demand for new trucks to be in the range of -0.9 to -0.5.21/ Assuming a mid-range elasticity of -0.7, and a range of $15,000 to $50,000 for the selling price of heavy-duty vehicles, the added cost of compliance with the 1984 regulations may reduce sales by 0.3 percent to 1.8 percent.22/ Manufacturers of heavy-duty engines and vehicles withstood a much larger drop in sales around 1975 due to general economic conditions, but sales are now recovering well. The small decrease in total industry sales from the regulations will be more than overcome by normal sales growth, and thus can be expected to have no noticeable effect on any manufacturer's growth.

EPA does not expect heavy-duty vehicle sales or the trucking industry in general to suffer because of a shift in the mode of freight transportation used. Rail and air are not reasonable alternatives for intracity freight movement. The vast majority of "over-the-road" freight movement is done by heavy-duty diesel trucks. The purchase price and operating costs of heavy-duty diesels are not affected by a sufficient amount to warrant anything but a slight increase in intracity freight hauling costs.

Total bus sales and the bus transportation industry as a whole should suffer no loss in sales or ridership. The cost increases due to these regulations will not offset the fact that buses are the best option for the transportation of school children and intracity transport. The intercity bus ridership should show no decrease because the per passenger cost of these regulations is a negligible amount when compared to other factors in the total ticket price.

Sales by some individual manufacturers of heavy-duty diesel engines may decline more than predicted by overall demand price elasticity. This could result from small volume manufacturers having to spread their costs for test facility modifications and certification over their smaller sales. These costs depend primarily on the number of engine families certified, not on the sales of engines within those families. Thus smaller volume, primarily foreign manufacturers like Deutz, Volvo, Hino, Fiat, Scania Vabis, and others will have larger price rises than larger volume, domestic manufacturers like Mack, Detroit Diesel (GM), Cummins, and Caterpillar. Smaller volume diesel engine manufacturers may find the diesel engine market less profitable as a result.

EPA cannot present manufacturer-specific estimates of how serious this reduction in profitability will be. Such estimates would require accurate projections of each manufactuers's sales through 1988. EPA does have available manufacturer's own sales for recent model years and these are shown as fractions of the total market in Table V-BB. EPA has used these market shares and the cost figures from Table V-FF to estimate the increase in engine price needed to recover each diesel manufacturer's costs. These estimates are shown in Table V-NN, in scrambled order and without manufacturer identification. Generally, the higher increases are for manufacturers with low U.S. sales. It should be emphasized that this cost analysis has assumed the worst case (i.e., higher costs) for small volume manufacturers. Therefore, the cost figures in Table V-NN will probably exceed the actual cost increases for these manufacturers. The spread in the estimates is considerable, and in a few cases represents a sizable fraction of total engine cost. It should be noted, however, that the manufacturers with the highest increases produce heavy-duty diesel engines for use in motor vehicles sold in the U.S. as only one small part of their large, and often multinational, operations. Some presently enjoy a price advantage over the larger manufacturers, which will offset part of all of the differential in price increases. Based on corporate size, product diversification, assets, and total worldwide sales, each of the manufacturers with the larger price increases could absorb the cost of these regulations without any threat to its corporate survival. Any or all could withdraw from the market without any threat to its survival and with little impact on the remaining manufacturers or on competition in the market. If any or all of the small volume manufacturers were to withdraw from the heavy-duty diesel market, engine availability would be unaffected and no significant cost increase would occur as a result of less competition. This is true becuase the U.S. sales market is heavily dominated by the large volume domestic pro-

Table V-NN

Estimated Increase in Price Needed for Individual Diesel Engine Manufacturers to Recover Their Costs of Compliance

Manufacturer	Price Increase
1	$ 519
2	492
3	492
4	492
5	243
6	221
7	221
8	213
9	177
10	142
11	123
12	115
13	108
14	108

1/ The order of the manufacturers has been changed from that in Table V-FF and the names omitted.

2/ Approximated by dividing the non-recurring costs of Table V-FF by 5 times the manufacturers share of 1986 projected sales and adding the recurring 1984-1988 costs per engine per year. Effect of interest and profit has not been included as it would not significantly affect manufacturer to manufacturer comparisions.

ducers. The annual U.S. sales of the first 8 corporations in Table V-NN comprise about 5 percent of the total U.S. heavy-duty diesel sales per year.

Although White appears in the list of smaller-volume manufacturers, it is not in competition with the larger-volume engine manufacturers in the same way as the others in the list. In the past several years White has usually certified only military engines, which do not compete in the civilian engine market.

Small volume truck and bus manufacturers should not experience any disadvantage, since most use engines produced by several engine manufacturers.

It is not expected that the promulgation of these regulations will have any long term impact on employment or productivity in the heavy-duty engine or vehicle industries, since industry-wide sales will be affected little.

2. Impact on Users of Heavy-Duty Vehicles

Users of heavy-duty vehicles will be affected by the higher costs for the vehicles they use to transport goods, and this in turn will affect the prices consumers pay for the products transported by trucks.

The expected first cost increases of $195 for vehicles equipped with diesel engines and $394 for those with gasoline engines should not substantially impact either fleet owners' or an individual owner operator's ability to pay for new heavy-duty vehicles, since these costs represent at most 3 percent of a vehicle's sales price.

The regulations will add less than one cent per mile of gasoline-fueled vehicle operation (undiscounted operating cost increases divided by total life mileage). All operators of gasoline-fueled vehicles will incur these cost increases, so no subgroup will be at a disadvantage. This does not consider the anticipated increase in fuel economy for gasoline-fueled vehicles/engines. To vehicle operators as a group, this cost should not add significantly to their current vehicle operating costs, and therefore should not significantly impact either the demand for their transport services or their profit margins.

3. Impact on Fuel Costs to Users of Other Vehicles

The need for unleaded fuel by gasoline-fueled heavy-duty vehicles will increase the demand for that fuel. However, the increase will be relatively small, since these vehicles presently consume less than 10% as much gasoline as vehicles used for personal transportion.23/ Also, the increase will come slowly.

The price difference between leaded and unleaded fuel should not be changed significantly since by 1984 most light-duty vehicles and trucks will use unleaded fuel and heavy-duty gasoline-fueled vehicles use only 3 percent of all gasoline consumed.24/ Consequently, there will be no significant impact on fuel costs to users of other vehicles.

4. Balance of Trade

The implementation of these regulations will not have a substantial impact on the U.S. balance of trade.

American manufacturers who sell gasoline-fueled and diesel heavy-duty engines overseas will build these engines to comply with the emission standards of the importing country. Therefore, no loss in foreign sales is expected as a result of these regulations.

As can be seen in Table V-NN, the difference in the per engine first price increase is not so great as to preclude foreign manufacturers from the U.S. heavy-duty diesel market. Currently, all heavy-duty gasoline-fueled engines sold in the U.S. are manufactured domestically.

The use of oxidation catalysts on heavy-duty gasoline-fueled vehicles will cause an increase in the imports of noble metals to the U.S. The noble metals, primarily platinum and palladium will amount to 6.25 grams of platinum and 3.125 grams of palladium per engine sold. In 1979 dollars this is approximately $63 per engine.

However, the predicted fuel economy increase (at least 4%) for gasoline-fueled engines will allow a savings of at least 836 gallons per vehicle over its lifetime. Using 42 gallons per barrel and a per barrel price of $20, this fuel import savings ($398 undiscounted) more than offsets the increase noble metal imports.

References

1/ "Cost Estimations for Emission Control Related Components/Systems and Cost Methodology Description," LeRoy H. Lindgren, Rath & Strong, Inc., March 1978, EPA-460/3-78-002.

2/ All Rath & Strong estimates used were adjusted for inflation.

3/ These figures include vendor overhead and profit.

4/ See section B-1 in this chapter.

5/ See the Test Procedure issue in the Summary and Analysis of Comments.

6/ Class IIB represents 8,500-10,000 lb. GVWR.

7/ Larger-volume manufacturers only. It will be assumed that some smaller-volume manufacturers of diesel engines will have only one emission-data engine selected per engine family, in accordance with past experience.

8/ For a more detailed description on how these costs were computed, see the economic impact issue in the Summary and Analysis of Comments.

9/ Based on data gathered from EPA's Certification Division.

10/ See Economic Impact issue in Summary and Analysis of Comments.

11/ Analytical Development of Sampling Plans for Selective Enforcement Auditing, Sylvia G. Leaver, MSED, December 1978.

12/ See economic impact issue in the Summary and Analysis of Comments for a more in-depth discussion.

13/ Dun's Review, November 1978, Vol. 112, No. 5, pp. 119-121.

14/ Average Lifetime Periods for Light-Duty Trucks and Heavy-Duty Vehicles, US EPA, ECTD, SDSB 79-24, Glenn W. Passavant, November 1979.

15/ See the fuel economy issue in the Summary and Analysis of Comments for a more detailed discussion.

16/ 1979 Baseline Engine Data available in the public docket supporting this rulemaking action.

17/ Conversation with Chuck Boehl, US. Department of Energy, Economic Regulatory Administration, September 28, 1979.

18/ Phone communication with Willard Smith, Economic Analysis Division, OPM, EPA - Based on consultant working papers from Sobotka and Company, Inc. regarding the analysis of the retail price differential between leaded and unleaded gasoline. Final report is under preparation.

19/ EPA memo, "Estimated Heavy-Duty Gasoline Fueled Engine Fuel Economy for the Mid Eighties." Glenn Passavant, November 12, 1979.

20/ The price cross elasticity of demand is a measure of the proportional change in the quantity of one product (e.g., gasoline-fueled engines) demanded resulting from a given relative change in the price of a related product (e.g., diesel engines).

21/ Background Document for Medium and Heavy Truck Noise. Emission Regulations, Appendix C, EPA Office of Noise Abatement Control, March 1976, EPA-550/9-76-008.

22/ The price elasticity of demand used here considers only the average first cost increase and does not consider the effect of the cost of ownership of gasoline-fueled vehicles. EPA knows of no elasticity of demand model for trucks which incorporates both increased first costs and increased costs of ownership.

23/ Comparing Table VM-1 of 1975 Highway Statistics with Table 39 of "Trucking Activity and Fuel Consumption - 1973, 1980, 1985, and 1990," FEA, July 1976, PB-263035.

24/ Transportation Energy Conservation Data Book, Edition 3, February 1979, Oak Ridge National Laboratory. Table 2.8. About 6 percent of 2 axles single unit trucks were considered as heavy-duty gasoline-fueled engines (Table 1.26). Calculated for 1975.

CHAPTER VI

ALTERNATIVE ACTIONS

A. Introduction

As EPA has proceeded with the development of a final rulemaking based upon analysis of comments received in response to the February 1979 proposal, alternatives and options in essentially all aspects of the rulemaking have been evaluated. Most of the comments received from manufacturers either explicitly or implicitly involved alternatives to items which EPA had proposed. That is, EPA was requested to evaluate eliminating, modifying or replacing elements of the rulemaking proposal in a wide variety of ways based upon what manufacturers preceived as defects in the proposal, or more desireable alternatives. Some of the alternatives raised during the comment period had already been analyzed by EPA, while some had not.

In the Summary and Analysis of Comments detailed analysis of all identified alternatives are developed. This document is available in the public docket (OMSAPC-78-4) and the material it contains will not be repeated in this chapter beyond the level of a brief review of major alternatives considered. In addition the Summary and Analysis of Comments, Chapter VII (Cost Effectiveness) of this Regulatory Analysis considers the emission benefits and costs associated with each basic element of the rulemaking and determines the resulting cost effectiveness.

The alternatives evaluated by EPA fall into three broad areas: 1) alternatives to specific elements of the rulemaking, 2) alternative timing for implementation of the rulemaking, 3) alternative levels of stringency for the emission standards. Each of these will be reviewed separately.

B. Alternatives to Specific Elements of the Rulemaking

1. Test Procedure

The question of test procedure was one of the most controversial aspects of the proposal. The Summary and Analysis of Comments considers the issue of the new test procedure in great depth in the "Test Procedure" section of that document. The basic alternative consists of promulgating emission standards based upon either the existing 9-mode and 13-mode steady-state tests, or using the transient test procedure. Between those two extremes lie a number of variations consisting of modifications to the original proposal, such as different approaches to deriving the test cycle from the CAPE-21 data base, field validation programs, alternative cycles, etc.

The fundamental question relating to choice of test procedure is the ability of the current procedures to adequately characterize in-use emissions of heavy-duty vehicles. All available data continues to indicate to EPA that steady-state tests are fatally defective in this ability, and that the desired 90 percent emission reductions in HC and CO could not be obtained through their use. Chapter VII estimates the additional emission reductions expected from use of the transient test. The results, summarized in Tables VII-1 for gasoline-fueled engines and VII-2 for diesel engines, indicate that the incremental benefit from changing test procedures is substantial and cost effective. Approximately 40 percent of the overall benefit for gasoline-fueled engines and 60 percent of the overall benefit for diesel engines is attributable to implementation of the transient test. The related costs are low enough to make that incremental benefit more cost effective than the steady-state test option. Cost effectiveness numbers for these options are reproduced below from Tables VII-1 and VII-2.

Option	Cost Effectiveness ($/ton) Gasoline Fueled HC	Gasoline Fueled CO	Diesel HC
Steady-state test	349	13	304
Transient test	65	2	224

The need for the transient test procedure had been a fundamental decision included in the proposed rulemaking. Nothing submitted during the comment period has raised substantial challenge to that need. In fact, as the data just summarized indicates, the need for the transient test for gasoline-fueled and diesel engines has become even more clearly established. EPA has therefore concluded that the transient test should be retained for both gasoline and diesel engines. In the case of diesel engines, there is a possiblity that existing eddy current dynamometers could be made to perform adequately on the transient test. In recognition of the significant cost savings that could result from this possibility, EPA has chosen to allow for diesels an optional certification procedure on the existing test cycle for the first year of implementation of the new regulations. This delay would allow diesel manufacturers additional time to explore the feasibility of using existing dynamometers.

2. Other Elements

Alternatives relating to the following elements of the rulemaking in addition to the choice of test procedure have been analyzed: redefinition of useful life, in-use durability tesing, parameter adjustment, allowable maintenance regulations, assembly line testing with a 10 percent Acceptable Quality Level, diesel crankcase control. For each, there is an appropriate portion of the Summary and Analysis of Comments which can be consulted. In addition, the cost effectiveness of each element is estimated in Chapter VII of this Regulatory Analysis. It is important to realize that Chapter VII is actually an analysis of alternative rulemaking packages. Each cost versus benefit ratio is derived from a comparison of the final rulemaking with a rulemaking package not having the item being evaluated. Thus, each constitutes a unique combination package, and each combination represents an alternative approach to the rulemaking.

For the case of in-use durability testing, this review process indicated that the proposal should not be promulgated at the present time. For each of the remaining elements, the basic approach originally proposed by EPA remains the best alternative. However, modifications have been made in several of them to improve their practicability or clarity.

C. Alternative Timing for Implementation of the Rulemaking

The timing for introduction of new regulations can have very important consequences. From the manufacturers point of view it affects the rate at which resources must be expended to attain compliance, and possibly the very ability to comply. Environmentally, timing defines the point at which desired emission reductions will begin to be realized.

The proposal had called for implementation of the new regulations in 1983. A great deal of comment was received from manufacturers on the feasibility of that deadline. All comments indicated that the regulations as proposed were not feasible in 1983. EPA's analysis of these comments and the alternatives which were suggested is contained in the Summary and Analysis of Comments under the "Leadtime" issue. The conclusion of that analysis was that gasoline-fueled engines might be able to meet a 1983 timetable, but the risk of missing the deadline would be high. For diesel engines, some families could meet a 1983 deadline, but those requiring significant emission reduction could not. Therefore, EPA has chosen to delay implementation of these regulations until 1984.

D. Alternative Levels of Stringency for the Emission Standards

Section 202(a)(3)(E)(i) of the 1977 Amendments to the Clean Air Act required that EPA "shall conduct a continuing pollutant specific study concerning the effects of each air pollutant emitted from heavy-duty vehicles or engines and from other sources of mobile source related pollutants on the public health and welfare." The intent of requiring these reports was to provide a portion of the framework needed to evaluate the statutory standards for heavy-duty vehicles (HDV) provided in those same amendments.

Subparagraph (ii) of the above section indicates that on the basis of such studies, and other information available, EPA may change the statutory standards for heavy-duty engines or vehicles.

Chapter IV of the Regulatory Analysis assesses the impact of the statutory standards on emissions of HC and CO and on air quality. That chapter, combined with the remaining portions of this Regulatory Analysis provides a comprehensive review of the statutory standards. However, in order to make the judgement just indicated concerning whether the standard should be changed, evaluation of alternative stringency levels is required. Since EPA's evaluation of alternative stringency levels is not reported elsewhere, that analysis will be done here.

The statutory standard provides for emission standards for both gasoline-fueled and diesel engines derived from a 90 percent reduction from a 1969 gasoline-fueled engine baseline. To examine the appropriateness of that 90 percent reduction, two alternatives will be considered. One is an 85 percent reduction and is less stringent than the 90 percent statutory standard. The second is a 95 percent reduction from baseline and is more stringent than the statutory standard. These standards correspond to the following numerical values (g/BHP-hr):

	HC	CO
85% standard	1.9	23.3
95% standard	0.64	7.7

These alternatives will be evaluated in terms of lifetime emission reductions per vehicle (and cost effectiveness), changes in mobile source emissions, and changes in air quality.

1. Lifetime Emission Reductions and Cost

Table IV-A presents lifetime emissions for engines representative of 1969 baseline levels, 1979 engines, and the final regulations. Similar results can be computed for the alternative standards. Emission factors corresponding to the alternative standards are given in Table 4 of Appendix A. They were derived in the same fashion as those for the statutory standards. The corresponding lifetime emission rates, compared to the statutory standards, are as follows:

Lifetime Emissions for Heavy-Duty Vehicles (Tons)

Engine Class and Pollutant	Optional 85% Standard	Statutory 90% Standard	Optional 95% Standard
Gasoline-fueled			
HC	0.24	0.17	0.10
CO	3.2	2.4	1.5
Diesel			
HC	2.07	1.41	0.71
CO	5.9	5.9	5.9

The effect of changing the stringency of the standard is significant over the average life of a heavy-duty vehicle. For example, relaxing the standard to the 85 percent level would increase HC emissions from gasoline-fueled engines by a factor of 1.4. On the other hand, increasing the stringency would reduce HC emissions by a factor of 1.7. A similar change occurs for CO. Relaxing the standard increases diesel HC emissions by a factor of 1.5, while tightening the standard would reduce diesel HC by a factor of 2.0. Diesel CO emissions are unaffected by a change in the standard because they are inherently lower than even the 95 percent standard level.

In Chapter VII, lifetime emission rates are used to evaluated the cost effectiveness of the rulemaking. To do this for the alternative standards necessitates assigning costs to these levels. A prime consideration in evaluating cost variations is the change in production target levels associated with the standards. Target levels are as follows:

Production Target Levels (g/BHP-hr)

Engine Class and Pollutant	85% Standard	90% Standard	95% Standard
Gasoline-fueled			
HC	0.73	0.50	0.24
CO	8.9	5.9	2.9
Diesel			
HC	1.32	0.89	0.42

Considering gasoline-fueled engines first, the 85 percent standard will allow some reduction in hardware costs. R&D costs would be unchanged since most of the R&D effort is expected to be directed toward system durability. Likewise, other components of the per engine cost are not directly tied to the level of the standard and would remain unchanged. Hardware cost would include savings on air pump requirements and catalyst loading. Air pump cost has been estimated at $26 in Chapter V (before markup for overhead and profit). This was the cost of increasing air pump capacity the equivalent of two additional air pumps. At the 85 percent standard only one air pump would be required, and the cost would be reduced $13. At the 85 percent standard, catalyst loading will be reduced from 45 g/ft^3 to 40 g/ft^3 with a net savings of $11. Total cost change, including markup, is (13 + 11) 1.29 = $30.96. Applied to the cost per engine from Chapter V of $477, the 85 percent standard would cost $446.

For the case of the 95 percent standard for gasoline-fueled engines, the target level for CO is sufficiently low as to make the feasibility of this option questionable. There is insufficient data at this time to determine how low-optimized heavy-duty catalyst systems will be able to operate. Therefore, no costs will be estimated for this case.

Turning next to diesel engines, a somewhat different situation exists. Much of the cost of reducing engine emissions is in R&D rather than in add-on hardware. Hardware costs relate largely to those few engine families which exceed the standards by substantial amounts. These are largely unaffected by the change of target values. Most engine families can attain the desired targets by design changes or calibration changes (e.g., injector design or injection timing). These actions are included in the R&D costs. In evaluating the cost for diesels associated with the AQL level (Chapter VII, Section E6), changing the target from 0.89 g/BHP-hr to 1.05 g/BHP-hr was associated with a change of R&D cost of approximately $3 per engine. For the 1.32 target level of the 85 percent standard given above, this change will be estimated as increasing to a $5 saving per engine.

A second area where diesel manufacturers would be expected to realize savings from a relaxed standard is in self-audit costs. The target level for the 85 percent standard is such that most engine families expected to be offered in 1984 already meet the standard with substantial margins. Therefore, less self-auditing and less stringent quality control programs would be required. Quality control costs will be estimated as reduced by half, and self-audit rates reduced to 0.2 percent. These changes result in a saving of $11.92 per engine. Total cost saving is then $5 (R&D) + 11.92 (audit plus quality control) = $16.92. Applied to the cost per engine from Chapter V of $195, the 85 percent standard would cost $178.

In the case of the 95 percent standard, as was the case with gasoline-fueled engines, the target levels are sufficiently low as to make the feasibility of attainment uncertain. Therefore, no costs will be estimated.

2. Cost Effectiveness

As is done in Chapter VII, the benefit from implementing any of the alternative standards is found by comparing the emissions of engines built to those standards with the emissions of current engines. Lifetime emissions for current engines are found in Table IV-A. For gasoline-fueled engines they are 1.17 tons HC and 3 tons CO. For diesel engines the current value is 2.18 tons HC. From these starting values, the emission reductions per vehicle from the alternatives are:

Incremental Lifetime Emission Reductions (Tons)

Engine Class and Pollutant	Optional 85% Standard	Statutory 90% Standard	Optional 95% Standard
Gasoline-fueled			
HC	0.93	1.0	1.07
CO	27.8	28.6	29.5
Diesel			
HC	0.11	0.77	1.47

Using the costs estimated above (and allocating gasoline-fueled engine costs equally between HC and CO) the resulting cost effectiveness is:

Cost Effectiveness ($/ton)

Engine Class and Pollutant	Optional 85% Standard	Statutory 90% Standard	Optional 95% Standard
Gasoline-fueled			
HC	240	239	N/A
CO	8	8	N/A
Diesel			
HC	1,618	253	N/A

Since it is not known if the 95 percent standard is feasible at this time, no costs have been estimated and, therefore, cost effectiveness cannot be computed. The 85 percent standard for gasoline-fueled engines is only marginally less cost effective than the 90 percent standard. However, for diesels, the optional standard is shown to be much less cost effective than the statutory standard. This reflects the fact that at the level represented by the 85 percent standard very little emission reductions from current levels would be required, while much of the cost would remain constant (being associated with acquisition of equipment, testing, etc.).

3. Changes in Mobile Source Emissions

Since the feasibility of the 95 percent standard is unknown at present, the impacts of that option will not be evaluated further. The effect of the 85 percent alternative on mobile source emissions would be significant. The following table compares 1999 mobile source emissions for the areas selected in Chapter IV under the base case (no new heavy-duty standard), the 85 percent option and the statutory 90 percent case.

Annual Nonmethane Hydrocarbon and
Carbon Monoxide Emission in 1999 (thousands of tons)

	Base Case	Optional 85% Standard	Statutory 90% Standard
Non-methane hydrocarbons	1155	1058	959
Carbon monoxide	4317	3082	3038

The statutory standard produces a desireable reduction in benefits compared both to the base case and the optional 85 percent standard.

4. Change in Air Qualtity

The optional standard being considered, when incorporated into the overall emission inventory for stationary plus mobile sources, produces some incremental changes. The average air quality improvement for the three cases would be as follows:

Average Percent Reduction
from 1976 Base Year Realized in 1999

	Base Case	Optional 85% Standard	Statutory 90% Standard
Ozone (rollback/EKMA)	52/29	53/30	54/31
Carbon monoxide	67	73	74

This data indicates that an additional one percent air quality improvement for ozone (either rollback or EKMA model) and for CO can be associated with the 90 percent standard over the 85 percent standard. For ozone, this is half of the total improvement.

5. Conclusions

This analysis has concluded that the feasibility of attaining the target emission levels associated with the more stringent 95 percent standard is not known for certain. Therefore, that standard is not a desirable alternative.

The 85 percent standard alternative results in a loss of benefits and some reduction in cost. These changes are in such proportions that the cost effectiveness of the regulations becomes prohibitive for diesel engines. In addition, approximately half of the ozone air quality benefit of the statutory standard would be lost under the 85 percent standard.

The statutory standard represents the best of the three choices at the present time.

CHAPTER VII

COST EFFECTIVENESS

A. Methodology

Cost effectiveness is a measure of what might be termed the economic efficiency of some action directed toward achieving some goal. Expressed as cost per unit of benefit achieved, cost effectiveness can be used to compare various alternative methods of achieving the same goal. In the context of improving air quality, the goal is to reduce emissions of harmful pollutants, and cost effectiveness is expressed in terms of the dollar cost per ton of pollutant controlled.

To evaluate cost effectiveness, two pieces of information on the alternative being evaluated are needed. These are the cost of the alternative and the benefits to be gained. Costs to be used in this chapter will be total identified costs expressed on a per engine basis, including both costs to the manufacturer and costs to the operator (all discounted to January 1 of the model year in which the vehicle is produced). These costs will be allocated equally among the pollutants being controlled. The benefits will be computed as total lifetime emission reductions per vehicle.

In this chapter, the rulemaking provisions will be subjected to two distinct analyses. The first will be an incremental analysis of each of the major components of the package. The second will be an analysis of the package as an integrated strategy. The purpose of these two approaches are different, and the reader is cautioned against misinterpretations of the incremental analysis. In the incremental approach, the effect on costs and benefits of removing individual components will be examined. To varying degrees, both costs and benefits of these components overlap and several components of the package may act together to obtain a given benefit. In such a case, loss of any one part of the package can result in a disproportionate loss of benefits. There are so many overlapping interrelationships that it would be impossible to consider every possible combination of the various components of the package. This analysis will instead look at the single set of options produced by deleting each component one at a time. The total loss of benefits produced by deleting a component will be associated with the cost of that part of the package. Therefore, if one were to simply sum incremental costs or incremental benefits as an attempt at obtaining total costs or benefits, significant amounts of double counting would occur. Such a procedure would be invalid. The integrated cost effectiveness analysis must be used to evaluate overall costs or benefits.

B. Background

In the draft Regulatory Analysis which accompanied the proposed regulations, a cost effectiveness analysis of the proposal was carried out. That analysis considered the overall cost effectiveness of the entire proposal as an integrated compliance strategy. It was indicated in the report that "in a multi-faceted program such as the proposed regulations of this heavy-duty package, it would be desirable to analyze separately the costs and environmental benefits of each aspect of the package. In this way a decision could be made on each element as to its cost effectiveness and whether it should be incorporated into the final regulations." However, data was lacking with which to quantify the benefits associated with individual elements of the proposal. In addition, it was pointed out that the benefits are inter-related and cannot be isolated easily from each other.

During the course of the comment period on the proposed regulations, EPA has endeavored to develop more data, for example on the comparisons between steady state and transient test emissions, and establish methods for estimating changes in emissions which could be associated with changes in the various components of the package. This effort has been sufficiently successful to allow estimated cost effectiveness analysis for the main components of the rulemaking.

It is important to bear in mind that the benefits and costs in this analysis will overlap, and that summing them all would result in double counting. For example, consider the case of extended catalyst lifetimes required under the allowable maintenance provisions and the revised useful life definition. The benefit of increasing catalyst lifetimes is significant. However, if the useful life remained at 50,000 miles, the intent of the allowable maintenance provision for catalyst change intervals would be lost. Therefore, incremental analysis of the allowable maintenance interval and revised useful life will each separately be looking at partly the same benefit in emission reductions.

Allowing the benefits to overlap in this fashion may appear to give too much credit to individual elements of the package. This is not true, since in each case the benefit considered will be the best estimate of what the package would actually gain or lose if that element were retained or removed. The purpose of an incremental analysis is to answer that question for each element. Although it would be desirable, it is not the chief purpose of an incremental analysis to evaluate the benefits of the total package. The benefit attributed to the overall integrated package will be determined separately.

C. Summary

Using all data now available (both that generated by EPA and that submitted to EPA during the public comment period on the proposed regulations), an analysis of the cost effectiveness of each major element of the regulation package and of the overall package as a unit has been done. This analysis developed benefits expressed as tons of pollutant removed (either HC or CO) over the average lifetime of an individual vehicle along with total costs for the same lifetime (discounted to year of sale).

Overall benefits and costs used as a starting reference the existing regulations for 1979 and later model year heavy-duty engines. That is, both overall benefits and overall costs were developed as changes in relation to the case of the existing regulations continuing in effect. Benefits and costs for most of the individual elements of the package (except for the change to the transient test procedure), on the other hand, were evaluated in terms of changes to the final package. The loss in benefits that would occur if each element were removed from the package was evaluated in comparison with the cost reduction that would be produced by that same change. The transient test procedure was evaluated in relationship to the alternative of implementing a standard on the current test procedures corresponding to a 90 percent reduction from the 9-mode gasoline-fueled engine 1969 baseline. Figures VII-1 and VII-2 summarize the benefits developed for gasoline-fueled and diesel engines, respectively. Costs, benefits, and cost effectiveness are tabulated in Tables VII-1 and VII-2. Cost effectiveness figures for other mobile source control strategies are provided in Table VII-3 for comparison purposes.

D. Gasoline-Fueled Engines

1. Transient Test

One of the key facets of the entire regulation package is the proposed transient test procedure. The transient test is being implemented because of the need to make compliance testing for heavy-duty engines a better measure of actual in-use emissions. The CAPE-21 program and resultant transient test procedure were designed to accurately characterize in-use operation and therefore in-use emissions. Throughout this analysis, transient test data will be taken to represent in-use data. The 9-mode steady state procedure fails to accurately measure in-use emission rates for the low emission engines currently being used or for advanced technologies anticipated for future heavy-duty engines. This same failure of the 9-mode test to relate well to in-use emissions has made it difficult to assess the benefit of switching to the transient test. If one does not know the in-use emissions from the current test then the actual benefit of reaching a given level on the transient test cannot be quantified. This was the dilemma facing EPA at the time of the proposal in February 1979. Although there was reason to believe that substantial benefit would accrue as a result of implementing the transient test, there was no way to quantify that benefit.

Figure VII-1A

Incremental Lifetime Hydrocarbon Benefits
Gasoline Fueled Engines

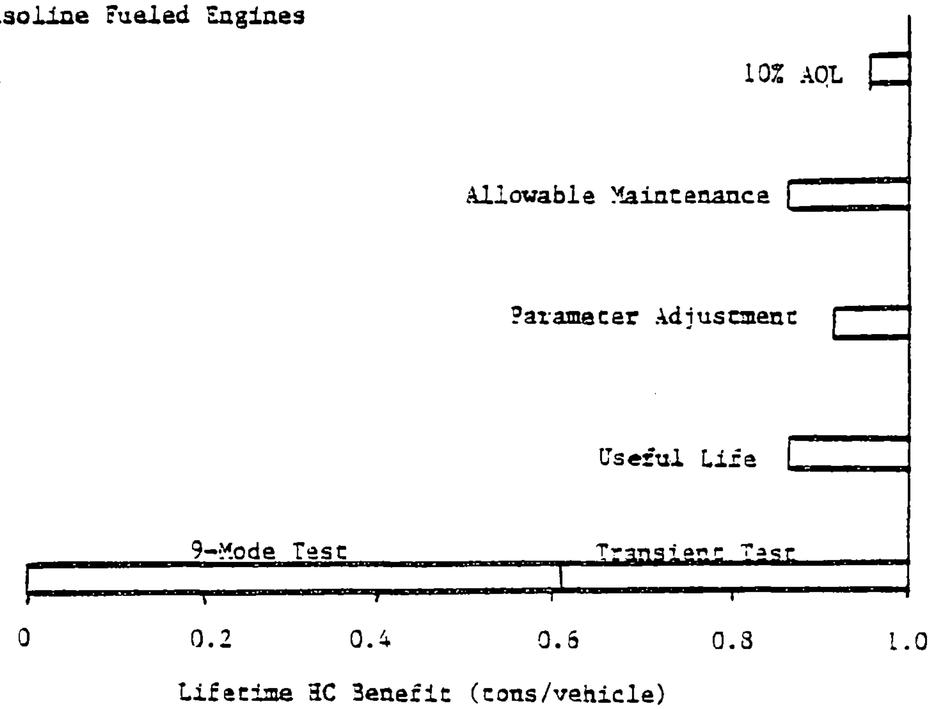


Figure VII-1B

Incremental Lifetime Carbon Monoxide
Benefits - Gasoline Fueled Engines

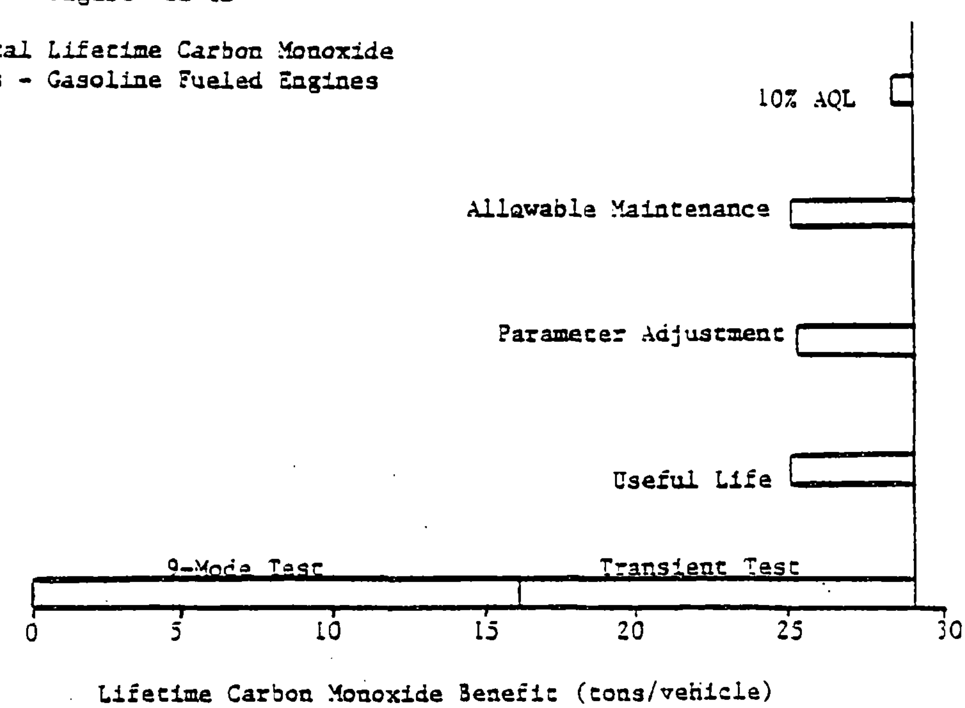


Figure VII-2

Incremental Lifetime Emission
Benefits Diesel Engines

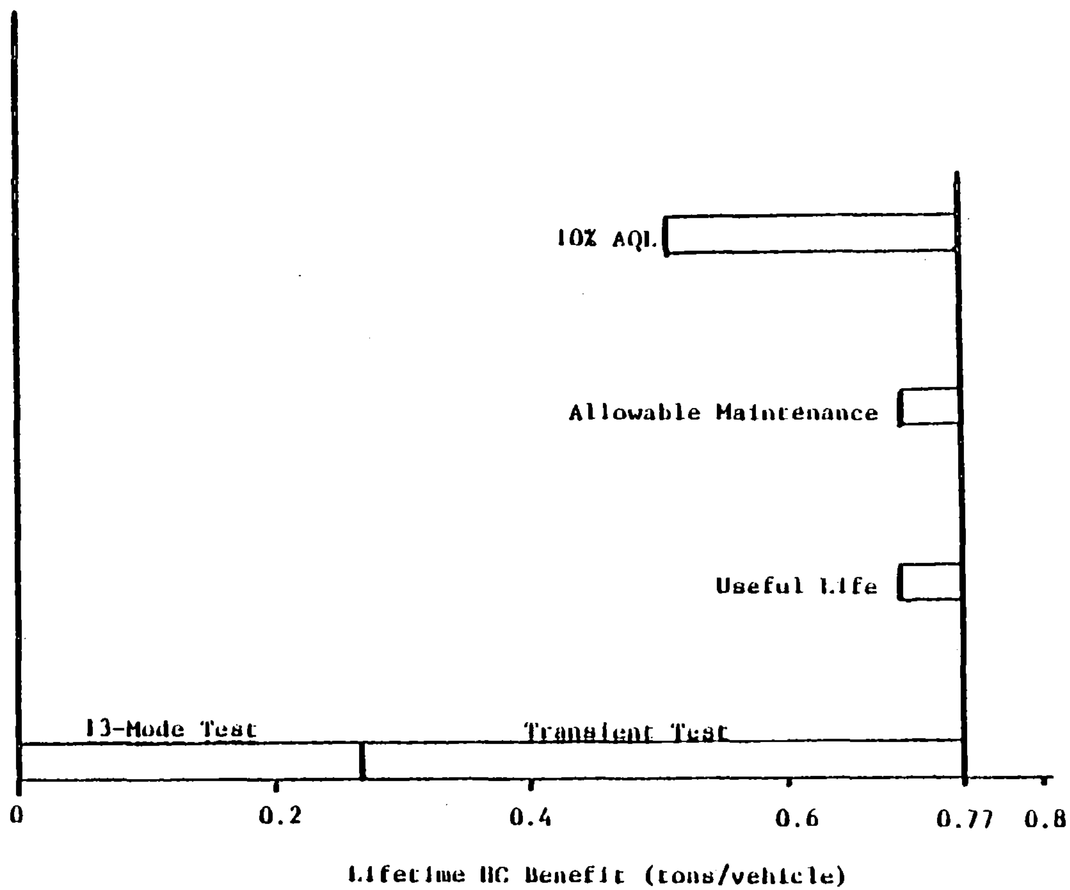


Table VII-1

Incremental Lifetime Cost Effectiveness
Gasoline-Fueled Engines

Option	Cost (Dollars)	Benefit (Tons) HC	Benefit (Tons) CO	Cost Effectiveness ($/Ton) HC	Cost Effectiveness ($/Ton) CO
90 Percent on 9-Mode	426	0.61	16	349	13
Transient Test	51	0.39	12.6	65	2
Useful Life	58	0.13	3.8	223	3
Parameter Adjustment	5	0.08	3.6	31	1
Allowable Maintenance	58	0.13	3.8	223	8
10 Percent AQL	17	0.04	0.5	213	17
Overall Package: a. Transient Test b. Useful Life c. Parameter Adjustment d. Allowable Maintenance e. 10% AQL	477	1.0	28.6	238	8
I/M	29	0.07	2.3	207	6

* Note: Includes all other aspects of the rulemaking except the transient test.

Table VII-2

Incremental Lifetime Cost Effectiveness
Diesel Engines

Option	Cost (Dollars)	Benefit (Tons HC)	Cost Effectiveness ($/Ton)
Steady-State Test	85	0.28	304
Transient Test	110	0.49	224
Useful Life	2	0.05	40
Allowable Maintenance	5	0.05	100
10 Percent AQL	7	0.24	29
Crankcase Control*	10	19.5 lbs.	342
Overall Package a. Transient Test b. Useful Life c. 10% AQL d. Crankcase Control	195	0.77	253

* Naturally-aspirated engines only. Cost allocated over 3 pollutants. See Diesel Crankcase Emission Control, Summary and Analysis of Comments.

Table VII-3

Cost Effectiveness ($/Ton) Comparison
With Other Emission Control Strategies

Control Program	Baseline Emission a/	Emissions After Control Program Initiated a/	Cost Effectiveness ($/Ton) HC	CO	NOx
LDV Statutory Standards b/	HC = 1.5 CO = 15 NOx = 3.1	HC = 0.41 CO = 3.4 NOx = 0.4	470	41	2300
LDT Interim Standards c/	1) HC = 2.0 CO = 20 NOx = 3.1 d/ 2) HC = 4.3 CO = 44 NOx = 5.2 e/	HC = 1.7 CO = 18 NOx = 2.3	200	21	73
I/M for Existing LDVs f/	—	—	78	7.7	2763
Motorcycle Standards 1978/1979 g/	HC = 9 CO = 34.67	HC = 8-22.5 h/ CO = 27.4	364	Neg.	—
1980 +	HC = 8-22.5 CO = 27.4	HC = 8 CO = 19.3	365	Neg.	—
Proposed LDT Action i/	HC = 1.7 CO = 18 NOx = 2.3	HC = 0.8 CO = 10 NOx = 2.3	139-201	10-12	

a/ Emission Levels in grams/mile, except for HD which are g/BHP-hr.
b/ Report: Interagency Task Force on Motor Vehicle Goals Beyond 1980, March 1976.
c/ "Environmental Impact Statement - Emission Standards for Light-Duty Trucks," November 29, 1976.
d/ Trucks 0 - 6,000 lbs. GVWR.
e/ Trucks 6,001 - 8,500 lbs. GVWR.
f/ "Cost Effectiveness Estimated for Mobile Source Emission Control," Vector Research, Inc. for EPA, January 1978.
g/ "Environmental and Economic Impact Statement - Exhaust and Crankcase Regulations for the 1978 and Later Model Year Motorcycles."
h/ Sliding Scale Based on Engine Displacement (cubic centimeters).
i/ "Draft Regulatory Analysis of Proposed Emission Regulations for 1983 and Later Model Year Light-Duty Trucks", EPA Office of Mobile Source Air Pollution Control, June 28, 1979.

In order to quantify the benefit of the transient test, EPA began testing engines on the transient test which represents current technology and future expected technology. This testing program measured emissions on both the transient test and the 9-mode test in order to assess the in-use levels represented by emissions on the 9-mode test. In addition, in preparation for development of a 1985 NOx standard, a 1972-1973 baseline engine testing program is underway. Altogether, at the time of this analysis, there is data on five current technology and prototype technology engines, twelve 1979 engines (representing 86% of projected 1979 sales), seven 1972-1973 engines (representing 46% of 1973 sales), and 15 of the 1969 baseline engines. Not all 1969 baseline engines can be included because 9-mode emission testing was not carried out on all engines. Emission levels from these engines cover a broad range from pre-controlled levels down to the range approaching the new standards. Scatter diagrams of transient emissions versus 9-mode emissions are given in figures VII-3 and VII-4.

Three principal conclusions can be drawn from a review of this data. First, there is a high degree of scatter in the relationship between the two test procedures. For example, at a 9-mode CO level of approximately 15 g/BHP-HR (the range of the new CO standard), transient emissions vary from near 30 to about 120 g/BHP-hr. Second, in spite of this scatter there is a rough relationship between transient and 9-mode emission results. Linear regression lines of transient emissions versus 9-mode emissions are shown in the figures. Two lines are shown in each figure. The first is an estimate using only the pre-control 1969 and 1972/73 baseline results. The second uses 1979 and advanced technology engine data as well. The relatively small change in the regression line resulting from the addition of the latter data set indicates some stability in the relationship. The regression lines based upon all the available data will be used in the remainder of this analysis to relate given 9-mode emission levels to equivalent transient levels. Finally, Figures VII-3 and VII-4 show that there is a limiting range of transient emissions below which the 9-mode procedure is not capable of reliably measuring, and that this level is well above the new transient emission standards for both HC and CO (1.3 g/BHP-hr HC and 15.5 g/BHP-hr CO). 9-mode emissions can be seen to be approaching zero, while transient emissions remain at or above the standards. This can be clearly seen from the intercepts of the regression equations of 2.1 for HC and 62 for CO. The impact of this fact is that there is a limit to the amount of actual benefit which could be expected to result from a 9-mode standard even if set at an extremely low level. It is also an expected result, since the 9-mode test measures no transient components of the overall emissions. This effect should not be interpreted to mean that heavy-duty engines will not be able to reach low transient emission levels, but only that 9-mode testing is incapable of identifying those which can versus those which can

Figure VII-3

Transient vs 9-Mode Emissions for Hydrocarbons

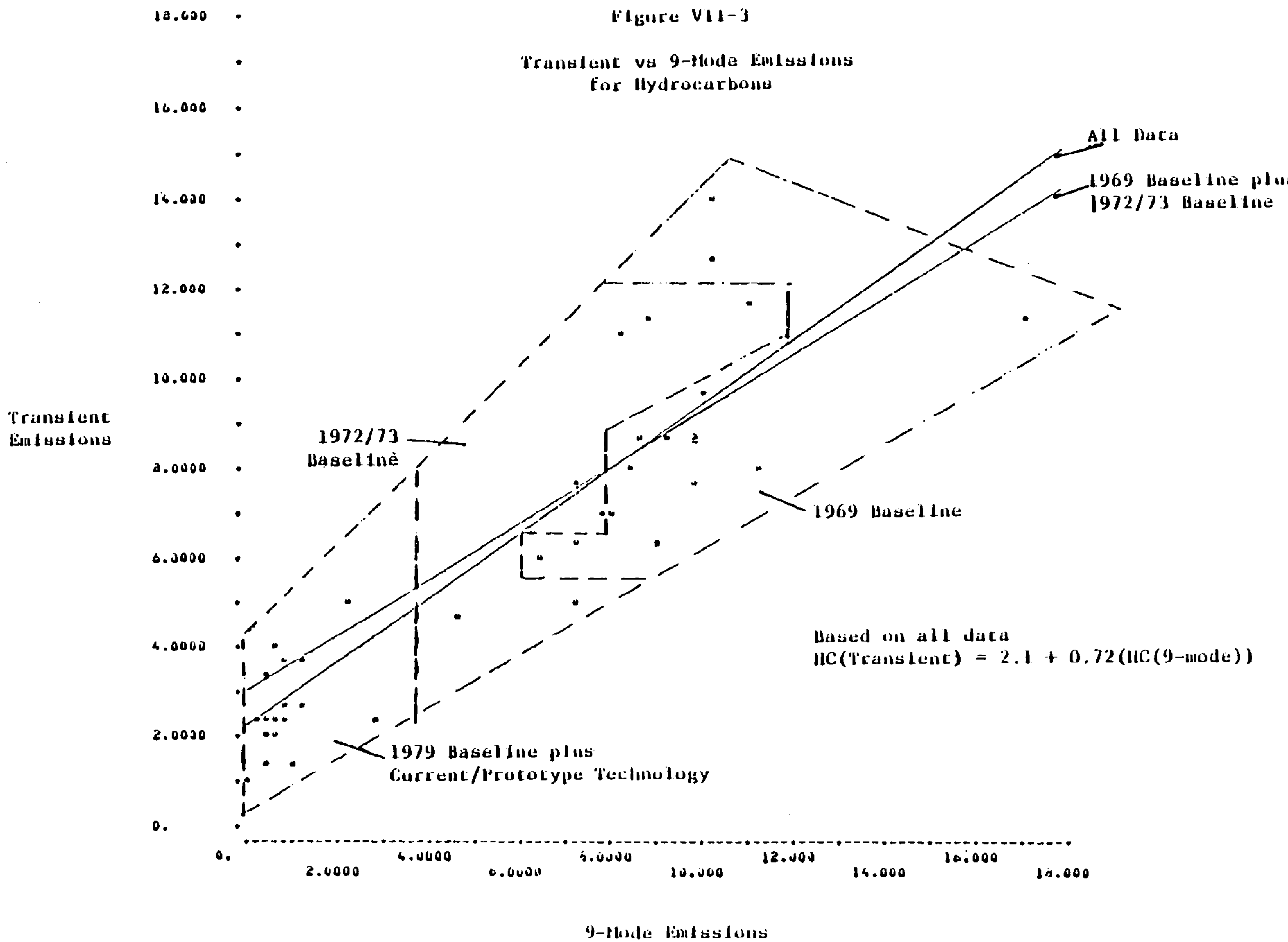
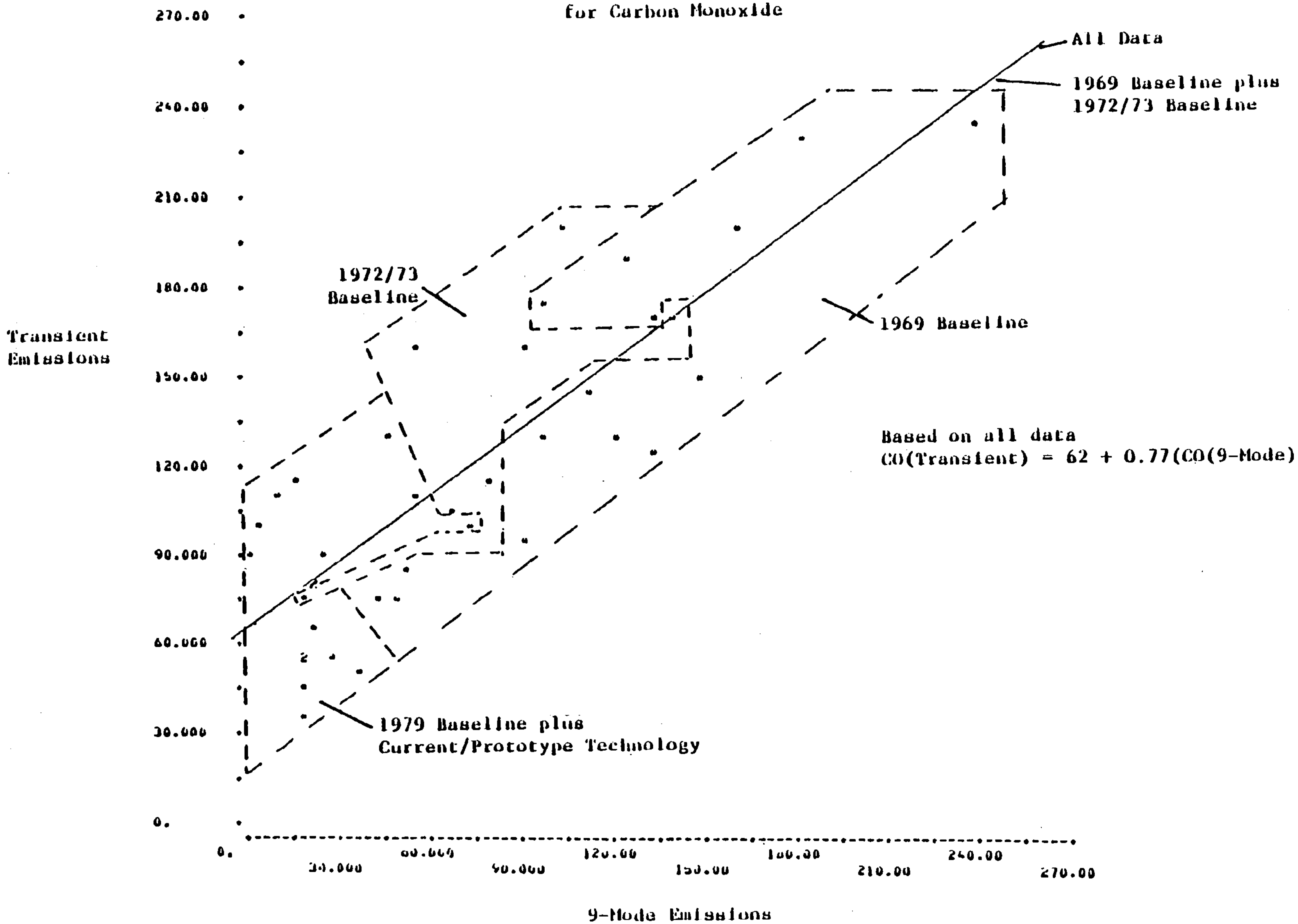


Figure VII-4

Transient vs 9-Mode Emissions
for Carbon Monoxide



not. Based upon both the scatter of the data and the regression lines, there is no 9-mode standard which could reliably attain the desired 90 percent reduction in actual emissions.

Using the data of Figures VII-3 and VII-4, the emission benefits of converting to the transient test can be estimated. We will first evaluate the average lifetime emissions of an engine controlled to a 9-mode standard representing 90 percent reduction from the 1969 9-mode baseline levels. Next, average lifetime emissions from an engine controlled to the transient standard will be evaluated. Comparison of the two will indicate the benefit of the transient test. Since the only variable we desire to examine is the change in test procedure, all other aspects of the rule-making will be allowed to remain intact with either test procedure. That is, both the 9-mode and transient standards will be evaluated based upon the inclusion of redefined useful life, parameter adjustment, allowable maintenance and a 10 percent AQL. These have the effect of maintaining in-use emissions at or near levels of certification engines.

a. 90 Percent on the 9-mode

A 90 percent reduction from baseline standard on the 9-mode represents levels of 1.0 g/BHP-hr HC and 12 g/BHP-hr CO. The HC standard is being met by current engines, but the CO is not. In fact, based upon the CO requirement, EPA believes that catalytic converters would be needed to achieve compliance.

Production engine targets (certification levels) for the above standards can be calculated in the same fashion as that developed in Section 5 below. In that section, the production target is estimated as (0.65) x (standard/D.F.) for a 10% AQL. The DF appropriate to heavy-duty catalyst equipped engines is derived in the "allowable maintenance" section of the Analysis of Comments as 1.7/100,000 miles. Therefore, the production target levels would become 0.65 x 1.0/1.7 = 0.38 g/BHP-HR (HC) and 0.65 x 12/1.7 = 4.6 g/BHP-HR (CO) as measured on the 9-mode test.

From this starting point, then, we will let in-use emissions increase at a rate corresponding to a DF of 1.7 - so long as the catalyst system remains operational. Average emissions under that condition can be expressed as:

$$HC = 0.38 + 0.027\,(M/10{,}000) \quad \text{9-mode}$$
$$CO = 4.6 + 0.32\,(M/10{,}000) \quad \text{9-mode}$$

where M = mileage

The relationship between transient and steady state, as given in Figures VII-3 and VII-4, are:

$$HC(\text{Transient}) = 2.1 + 0.72\,[HC(\text{9-mode})] \quad g/BHP\text{-}hr \quad (VII\text{-}1)$$
$$CO(\text{Transient}) = 62 + 0.77\,[CO(\text{9-mode})] \quad g/BHP\text{-}hr \quad (VII\text{-}2)$$

Equations (VII-1) and (VII-2) can be used to estimate transient emissions relative to the 9-mode values just computed. The results are:

$$HC = 2.4 + .02\,(M/10{,}000) \quad g/BHP\text{-}hr \qquad (VII\text{-}3)$$
$$CO = 65 + .25\,(M/10{,}000) \quad g/BHP\text{-}hr \qquad (VII\text{-}4)$$

In using the results of equation (VII-3) and (VII-4), it is specifically assumed that engines designed to the 9-mode standard would produce in-use emissions according to the relationship of equations (VII-1) and (VII-2). What has not been considered is the possibility that new engines may be designed to "beat" the cycle and produce low 9-mode results without a corresponding lowering of transient (in-use) results. This is a real possibility, but cannot be quantified. Insofar as some manufacturers were to choose such a route, the benefits here being attributed to the 9-mode procedure would be lost.

Under the allowable maintenance restrictions of this rulemaking, catalysts are expected to have a minimum change interval of 100,000 miles. However, based upon probability, not all catalysts will have exactly the same lifetime. Nor will all catalysts need to be changed at the same point due to failure. We will treat each catalyst as having a finite lifetime, beyond which emission performance will begin to degrade at a rapid rate. This could result from occasional high-temperature conditions or other operating conditions which will affect system integrity, or randomly occurring factors during catalyst system manufacturer which affect durability of the system as extended mileage accumulates. A distribution generally found appropriate for lifetime phenomena is the Weibull distribution.1/ This distribution has the form:

$$F = 1 - \exp\left[-\left(\frac{M}{\theta}\right)^b\right] \qquad (VII\text{-}5)$$

If a catalyst were to fail on an in-use vehicle with extended mileage, it is quite possible that it would not be replaced. Therefore, average in-use emissions will increase somewhat near the end of the useful life period. It is reasonable to assume that a vehicle with a failed catalyst would emit at levels of 1979 engines. The failed catalyst mode emissions would be:

$$HC = 3.0 \quad +0.02\,(M/10{,}000) \quad g/BHP\text{-}HR \text{ Transient}$$
$$CO = 88 \quad +0.22\,(M/10{,}000) \quad g/BHP\text{-}HR \text{ Transient}$$

The zero mileage levels in the above equations come from EPA's 1979 HD baseline testing program. The mileage factors are based upon a review of the 1979 certification DF's (which for current engines are additive values). All HC DFs but one were zero, and the average CO DF was 1.1. Based upon the belief that in-use DFs for HC would be non-zero, a DF of 0.1 was used for HC in combination with the 1.1 for CO. These are additive values over 50,000 miles.

The in-use fleet average emission rate can be estimated by combining the catalyst and non-catalyst emissions according to the fraction of failed catalysts (F):

$$HC = [2.4 + .02\ (M/10,000)]\ [1-F] + [F]\ [3.0 + 0.02\ (M/10,000)]$$
$$CO = [65 + 0.25\ (M/10,000)]\ [1-F] + [F]\ [88 + 0.22\ (M/10,000)]$$

Combining terms, these can be simplified to the following:

$$HC = 2.4 + .02\ (M/10,000) + 0.6F \quad g/BHP\text{-}HR \text{ Transient (VII-4)}$$
$$CO = 65 + 0.25\ (M/10,000) + F[23 - .03\ (M/10,000)] \quad g/BHP\text{-}HR \text{ Transient (VII-5)}$$

The only remaining task is to specify the fraction of failed catalysts (F) according to the Weibull distribution of equation VII-5. We will consider catalyst system design such that the catalyst change point of 100,000 miles corresponds to a maximum of 10 percent failed catalysts. We will further assume a "Weibull slope" of b=3. Based upon these two factors, the "characteristic value" θ=211,726 miles. A plot of this function is given in Figure VII-5 and illustrations of the effect it has on increasing emission rates at high mileage can be found in Section 2 under the discussion of useful life (Figure VII-6). The equation for F is:

$$F = 1 - \exp\left[-\left(\frac{M}{211,726}\right)^{-3}\right] \qquad \text{(VII-6)}$$

For an average lifetime of 114,000 miles, this equation indicates that about 14 percent of the catalysts would be expected to fail. Equations (VII-4), (VII-5), and (VII-6) can be used to evaluate lifetime emissions. The vehicle lifetime used is 114,000 miles.2/ Over this lifetime, the average emission rate is 2.54 g/BHP-hr (HC) and 67.3 g/BHP-hr (CO). To convert these rates to tons of emissions over the whole vehicle life involves the relationship between fuel consumption per BHP-hr and fuel consumption per mile of truck travel:

$$\frac{g}{BHP\text{-}HR} \times \frac{BHP\text{-}HR}{lb.\ fuel} \times \frac{6.1\ lb.\ fuel}{gallon} \times \frac{gallons}{mile} \times \frac{114,000\ miles}{lifetime} \times \frac{ton}{454 \times 2000\ gm}$$

From the EPA 1979 baseline testing program, the sales weighted fuel consumption per BHP-hr (inverse of the second factor) is 0.7, and the fuel economy is 5 mi/gal. Using these numbers, the conversion factor is:

$$\frac{6.1 \times 114,000}{0.7 \times 5 \times 454 \times 2000} = .22$$

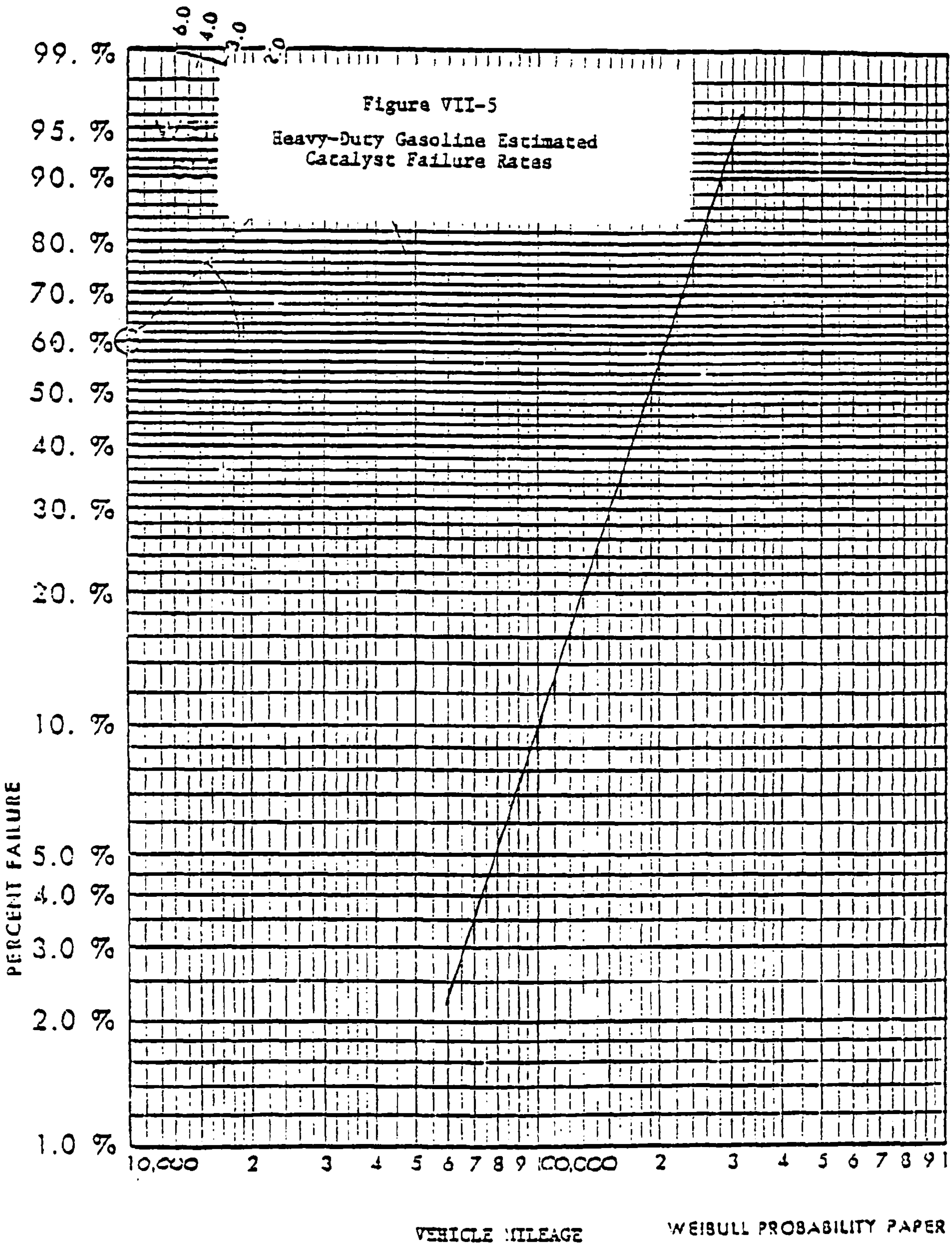


Figure VII-5
Heavy-Duty Gasoline Estimated
Catalyst Failure Rates
6.0
4.0
3.0
2.0
99. %
95. %
90. %
80. %
70. %
60. %
50. %
40. %
30. %
20. %
10. %
5.0 %
4.0 %
3.0 %
2.0 %
1.0 %
PERCENT FAILURE
10,000
2
3
4
5
6
7
8
9
100,000
2
3
4
5
6
7
8
9
1
VEHICLE MILEAGE
WEIBULL PROBABILITY PAPER

The resulting lifetime emissions of a catalyst-equipped gasoline-fueled heavy-duty engine designed to meet a 90 percent reduction standard on the 9-mode test procedure are:

0.22 x 2.54 = .56 tons HC and 0.22 x 67.3 = 15 tons CO

Lifetime emissions of the 1979 in-use fleet which constitutes our baseline reference case have been estimated in chapter IV as 1.17 tons HC and 31 tons CO. The net benefit of the final rule-making, if it were to be based upon a 90 percent reduction on the 9-mode, would be 1.17 - .56 = 0.61 tons HC and 31 - 15 = 16 tons CO.

b. Transient Test Procedure

The impact of converting to the transient test procedure will be lower certification emission levels. As noted for the 9-mode standard, the production target level for a 10 percent AQL has been estimated in Appendix A at (0.65) x (standard/DF). Using the transient standards of 1.3 g/BHP-hr HC and 15.5 g/BHP-hr CO, these target levels are:

0.65 x 1.3/1.7 = 0.50 g/BHP-hr Transient HC
0.65 x 15.5/1.7 = 5.9 g/BHP-hr Transient CO

Based upon the DF of 1.7/100,000 miles, these can be expressed as (so long as catalyst operates):

HC = 0.50 + 0.035 (M/10,000) g/BHP-hr
CO = 5.9 + 0.41 (M/10,000) g/BHP-hr

Adding in failed catalysts we get:

HC = [0.50 + 0.035 (M/10,000)] [1-F] + [F] [3.0 + 0.02 (M/10,000)]
CO = [5.9 + 0.41 (M/10,000) [1-F] + [F] [88 + 0.22 (M/10,000)]

Which simplify to:

HC = 0.50 + 0.035 (M/10,000) + F [2.5 - .015 (M/10,000)] g/BHP-hr (VII-7)
CO = 5.9 + 0.41 (M/10,000) + F [82 - 0.19 (M/10,000)] g/BHP-hr (VII-8)

Equations (VII-7) and (VII-8) yield average lifetime emission rates of .76 g/BHP-hr HC and 11 g/BHP-hr CO. Converting to life-time emissions in tons we get .22 x .76 = .17 tons HC, .22 x 11 = 2.4 tons CO. The net benefit over the 90 percent on the 9-mode standard is .56 - .17 = .39 tons HC and 15 - 2.4 = 12.6 tons CO.

The emissions calculated for the transient test case are the emissions for the entire rulemaking package. Therefore, the benefit of the entire package can be obtained by comparing these levels to those previously calculated for the 1979 in-use fleet

(1.17 tons HC and 31 tons CO). The emission benefit over the baseline levels is then 1.17 - .17 = 1.0 tons HC and 31 - 2.4 = 28.6 tons CO.

c. Costs

The cost analysis of Chapter V determined costs attributable to various aspects of the regulation package. Discounted costs per engine are given in Table V-LL. Applying the profit and overhead factor of 1.29 developed in Section B-1 of Chapter V, these values become:

Item	Discounted Cost per Engine
R + D	19.58
Certification Testing	3.16
Certification Facilities	10.40
SEA Facilities	14.16
SEA Testing	1.04
Self Auditing	19.43
Hardware	326.37
Unleaded Fuel	258.72
Muffler and Spark Plug Saving	-176.13
Total Cost Per Engine	476.74

This total cost corresponds to the transient test benefits derived earlier and can be used to compute the cost effectiveness of the overall package as given in Table VII-1.

Cost per engine for the case of a 90 percent standard on the 9-mode test can be derived by the following changes. Certification facility costs are eliminated. The SEA facility cost becomes $11.73 due to a savings of $300,000 per SEA test site by deleting the need for CVS systems (equipment plus facility). The catalyst required to meet the 9-mode standard will also be less expensive. EPA estimates a reduction in catalyst loading from 45 gm/ft^3 to 38 gm/ft^3 nd reducing the catalyst volume to engine CID ratio from 1.0 to 0.9. These changes reflect the less stringent standard, but the continued requirement to perform over the full useful life. These changes reduce catalyst cost by $32.25. An additional $6 would be saved because of air pump modifications required for the full package but not for the 90 percent on the 9-mode case. Total cost reduction is then $10.40 (cert facilities) + $2.43 (SEA facilities) + $38.25 (hardware) = $51.08. Cost for the 9-mode case is thus $476.74 - 51.08 = $425.66, and the cost attributable to the transient test is $51.08. Resulting cost effectiveness is shown in Table VII-1.

2. Redefinition of Useful Life

In section 1b above, the lifetime emissions per vehicle using the transient test procedure were calculated to be 0.17 tons of HC and 2.4 tons of CO. These numbers, as has been noted, presumed that all other aspects of the rulemaking were intact. The basic assumption made in that regard was that the combined package would result in in-use emissions which closely match the performance of certification vehicles. The only exception was due to the failure of a small percentage (14 percent of total) of catalysts on a random basis near the end of the vehicle useful life.

The evaluation of the new useful life definition will proceed by estimating the loss of benefits and reduction in costs that would occur if this element were removed from the package while all other elements remained intact. This method will make it possible to evaluate the impact of not implementing useful life on the overall package while at the same time estimating the cost effectiveness of this element.

a. <u>Benefits</u>

The extension of the useful life definition to the average full lifetime rather than something approximating half of the full life as is done in current practice has the effect of requiring that vehicles will be able to meet emission standards throughout their average life. This will require new vehicle emission rates to be lower so as to not exceed the standards after accounting for emissions deterioration over approximately twice the mileage interval of current practice. Full life useful-life will also require the use of control systems which are sufficiently durable to last the vehicle's lifetime. This makes the useful life change a key to the effectiveness of the allowable maintenance provisions.

These two aspects of full life useful-life - lower initial emission rates and more durable components - provide the basis for estimating the benefits of this element of the rulemaking. If full life useful life were dropped in favor of the current 50,000-mile useful life then both of these areas would suffer. Emission target levels would increase and system durability would not have to be proven beyond 50,000 miles. The latter fact would have its major emission impact in relation to catalysts. If catalyst durability need only be proven to 50,000 miles then a "50,000 mile catalyst" will be used instead of a "100,000 miles catalyst".

Following the procedure used in section 1b, these changes can be quantified. We will use a catalyst system DF of 1.3 over 50,000 miles to get production target levels, which have been noted as (0.65) x (standard/DF) for 10 percent AQL. These are 0.65 x 1.3/1.3 = 0.65 g/BHP-hr HC and 0.65 x 15.5/1.3 = 7.7 g/BHP-hr CO. These levels form the starting point for vehicles whose catalysts remain intact. For those catalysts that fail the emissions will be as used in section 1b. The resulting emission rates for a 50,000 miles useful life are:

$$HC = 0.65 + 0.039(M/10,000) + F[2.3 - 0.019(M/10,000)] \text{ g/BHP-hr} \quad \text{(VII-9)}$$

$$CO = 7.7 + 0.46(M/10,000) + F[80 - 0.245(M/10,000)] \text{ g/BHP-hr} \quad \text{(VII-10)}$$

Equation (VII-6) for F, when modified for a 50,000 mile useful life, becomes:

$$F = 1 - \exp\left[-\left(\frac{M}{105,863}\right)^{-3}\right]$$

In this case, catalyst failures will be much greater, with up to 70 percent having gone beyond their lifetime by the end of a 114,000 mile useful life. To illustrate this, Figure VII-6 presents the average HC emission rate as a function of vehicle mileage for the 50,000 mile useful life case and the complete rulemaking. The average HC emission rate rises from 0.76 g/BHP-hr for the complete rulemaking to 1.36 g/BHP-hr with a 50,000 mile useful life. Over its full life, a vehicle in the latter category would emit 0.22 x 1.36 = 0.30 tons HC and 0.22 x 28 = 6.2 tons CO. The net loss in benefits from eliminating the useful life changes is then 0.30 - 0.17 = 0.13 tons HC and 6.2 - 2.4 = 3.8 tons CO.

b. Costs

Costs attributed to changing useful life from 50,000 miles to 100,000 miles are basically the costs of building more durable catalyst systems and meeting a lower emission target. For a 50,000 mile useful life, catalyst loading is reduced to 30 g/ft3 and catalyst volume to engine CID ratio is reduced to 0.9. Cost reduction is $58.05 per engine. Cost effectiveness appears in Table VII-1.

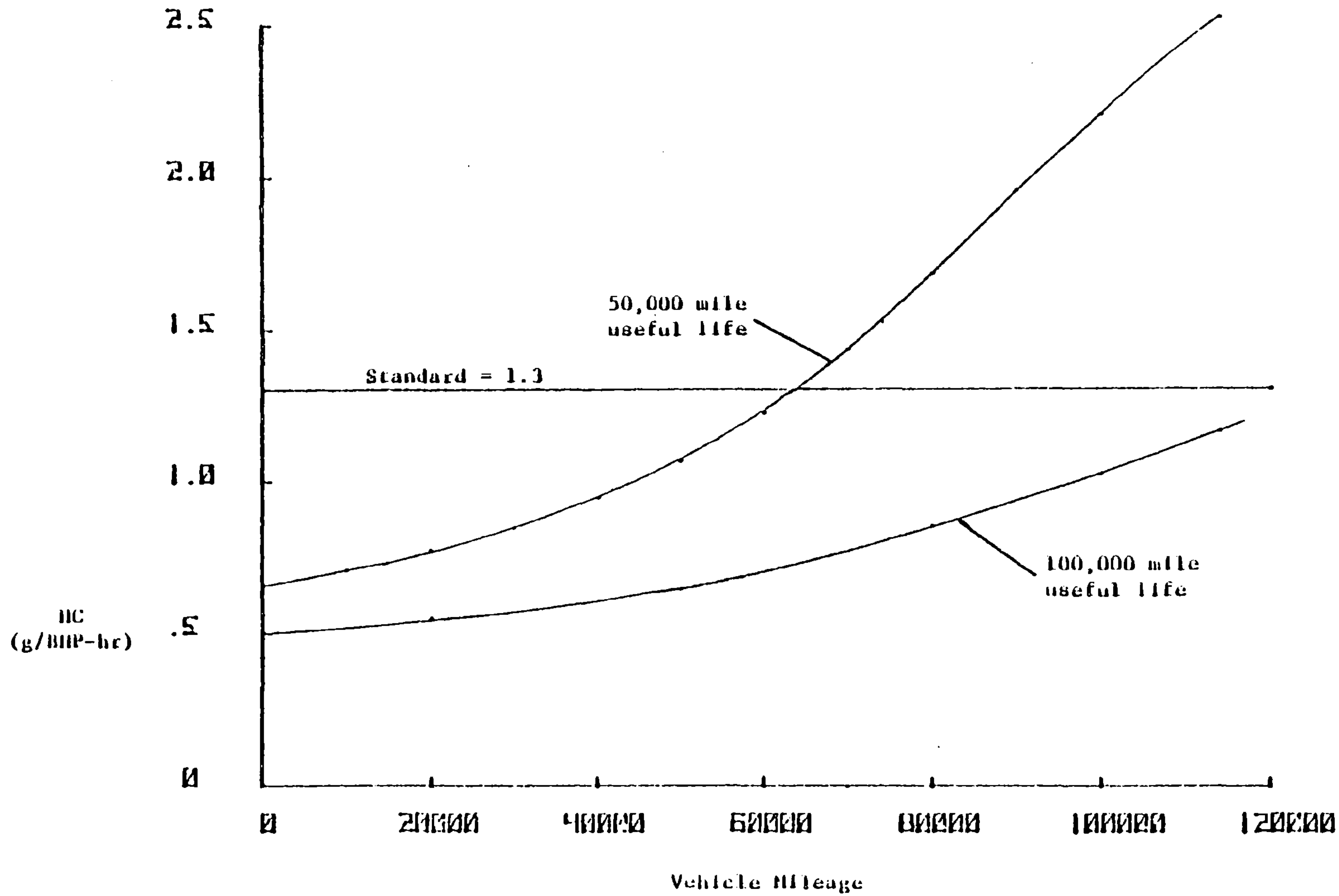
3. Parameter Adjustment

The parameter adjustment provisions of this rulemaking are designed to correct one of the largest causes of excess emissions. EPA's restorative maintenance study3/ examined the incidence of maladjusted parameters in 300 light-duty vehicles in 3 different cities. For these vehicles, which were less than one year old and had less than 15,000 miles accumulated, it was determined that over 72 percent were maladjusted on at least one specification for timing, idle CO, idle RPM.4/ As discussed in the parameter adjustment portion of the Summary and Analysis of Comments, similar rates are expected for heavy-duty gasoline-fueled engines.

The benefits to be derived from parameter adjustment are likely to be the same for heavy-duty as those identified for light-duty in the restorative maintenance study. The study indicated an average reduction in HC of 32 percent and CO of 60 percent, for the 300 vehicle fleet.5/ Individual vehicles experiencing maladjustment showed significantly greater reductions than the

Figure VII-6

Fleet-Weighted Average
HC Emission Rate vs Mileage



average. The average reductions, it should also be noted, were for low-mileage vehicles which had been screened to eliminate vehicles which had been abused or extensively modified. Therefore, whole life impact of parameter adjustment will probably be greater than the benefits being estimated here.

The loss of benefits that would be experienced by elimination of parameter adjustments is calculated as follows:

Lifetime emissions with parameter adustments = 0.17 tons HC
2.4 tons CO

Lifetime emissions without parameter adjustment =
0.17/(1-0.32) = 0.25 tons HC
2.4/(1-0.60) = 6.0 tons CO

Lifetime benefit of parameter adjustment =
0.25 - 0.17 = 0.08 tons HC
6.0 - 2.4 = 3.6 tons CO

The costs of implementing parameter adjustment have been addressed in the Economic Impact section of the Summary and Analysis of Comments. Parameter adjustment is expected to cost approximately $5 per engine. Cost effectiveness based upon this amount is given in Table VII-1.

4. Allowable Maintenance Restrictions

These regulations will affect a wide variety of emission related components. The overall impact will include decreasing the amount of emission maintenance required to maintain proper vehicle emission rates. This will reduce the likelihood of excess in-use emissions due to mal-maintenance.

Benefits attributable to many of the maintenance items are difficult to quantify. However, one of these, the catayst change interval, exerts what is perhaps the major emissions influence and can be estimated. The allowable maintenance regulations will result in a minimum catalyst change interval of 100,000 miles. Depending upon the actual useful life to which various manufacturers will certify, catalyst lifetimes longer than 100,000 miles may be used in some cases. However, we will use 100,000 miles for the analysis. Without the allowable maintenance restrictions, catalyst change intervals corresponding to current vehicle useful lives (50,000 miles) are expected. Based upon the position that catalysts on in-use vehicles are not likely to be changed, even though catalyst changeover would be specified in the maintenance instruction, then the in-use fleet woud not perform as expected. Emissions would increase after the 50,000 mile point and with a shorter lifetime higher rates of catalyst failure would occur.

Emission rates for this situation would be essentially the same as those developed for a 50,000 mile useful life in Section 2a above. Lifetime loss of benefits from dropping the allowable maintenance regulations would thus be the same as those developed for useful life:

0.13 tons HC and 3.8 tons CO.

Costs would be the same as those estimated for useful life also. Results are in Table VII-1.

5. Selective Enforcement Auditing (SEA)

The question to be evaluated with regard to SEA concerns the acceptable quality level (AQL) to be used in that program. This level identifies the maximum failure rate that can occur in audits of production engines before there is a significant probability of a suspension or revocation of certification. The heavy-duty SEA programs will use a 10 percent AQL, meaning that 90 percent of production engines must comply with emission standards.

a. Benefits

The benefits will be estimated by evaluating the change in emissions which would result if the AQL were relaxed from 10 percent to 40 percent. In general, changing the AQL results in a change in the mean production level target the manufacturer will aim for. The degree of change can be calculated from statistical considerations. There are various ways that these calculations can be approached, all of which give similar results. Here we will follow, with some modifications, the method used by Ford Motors in their comments on the NPRM.

The question can be expressed in general terms as that of determining an interval about the mean of a limited sample of engines which will, with a desired confidence level, contain the desired percentage of the population:

$$x \pm K s \qquad \text{(VII-12)}$$

Where x is the sample mean (production target level).
" s is the sample standard deviation.
" K is a tabulated statistical factor depending on sample size, the desired percentage of the population (AQL), and the desired confidence level.

Here, x must be set so that the upper level of the interval $x \pm Ks$ falls at the level of the standard divided by the DF.

Values of K can be found in statistical text books, for example, Table 3.2 of "Statistical Design and Analysis of Engineering Experiments" by Lipson & Sheth.

In our case x represents the target production mean and s the production variability. The desired confidence level will be that presented by Ford: 80 percent. The desired percentage of the population (the pass rate) was determined by Ford as follows.

Using the "power curves" for the SEA sampling plans, Ford determined the pass rate associated with the desired probability of failing the SEA (manufacturer's risk). These "power curves" are presented in Section V, Figure 4 of the Ford comments of 06/29/79 and display probability of failing the audit versus actual proportion of engines not in compliance. Ford used a 0 percent manufacturers risk to derive a desired pass rate of 65 percent for a 40 percent AQL and 95 percent for a 10 percent AQL. The use of a 0 percent manufacturers risk is considered overly conservative, and the EPA calculations will be based upon a 10 percent manufacturers risk. That is, the final result will be such that there will be an 80 percent confidence that the manufacturer's risk will be no greater than 10 percent. Independent calculations of production target levels by the use of the standard "t" statistic yield the same results when an overall confidence level of 90 percent is used (e.g. 90 percent confidence that 90 percent of the population will be below the target level in the case of 10 percent AQL). The desired pass rates for a 10 percent manufacturers risk are 57 percent for a 40 percent AQL and 88 percent for a 10 percent AQL.

Ford used a sample size of 3 pre-production engines to evaluate emission levels. Sample size of 3-5 engines seem to be typical of most manufacturers and 3 will be used for these calculations. If a manufacturer wished to be able to raise his target level without increasing his risk of failure, a larger sample of engines could be tested.

Based upon these factors (80% confidence level, pass rates of 57 percent (40 percent AQL) and 88 percent (10 percent AQL), sample size of 3) a value of K can be determined from statistical tables. The result is K = 1.1 for a 40 percent AQL and K = 2.7 for a 10 percent AQL.

Emission variability was presented by Ford as being a function of the low-mileage target (LMT = standard/deterioration factor). That is, a lower target will be associated with a lower variablity such that the ratio is constant. EPA believes that it would be more correct to use the ratio of variability to actual production level (s/x rather than s/LMT) as a constant. This approach was that generally used by other manufacturers. This change is the second modification to the Ford approach made by EPA (the first being to change the "manufacturers risk" from 0 percent to 10 percent).

The relationship between the production target level x as a function of the variability (s/x) can now be developed for either a

40 percent AQL or 10 percent AQL. Equation (VII-12) can be expressed as:

$$x + K s = LMT$$

Dividing through by x,

$$1 + K (s/x) = LMT/x$$

or

$$x/LMT = 1/[1 + K(s/x)]$$

K having been determined for each AQL, this becomes:

$$x/LMT = 1/[1 + 1.1(s/x)] \qquad 40\ \%\ AQL$$

$$x/LMT = 1/[1 + 2.7(s/x)] \qquad 10\%\ AQL$$

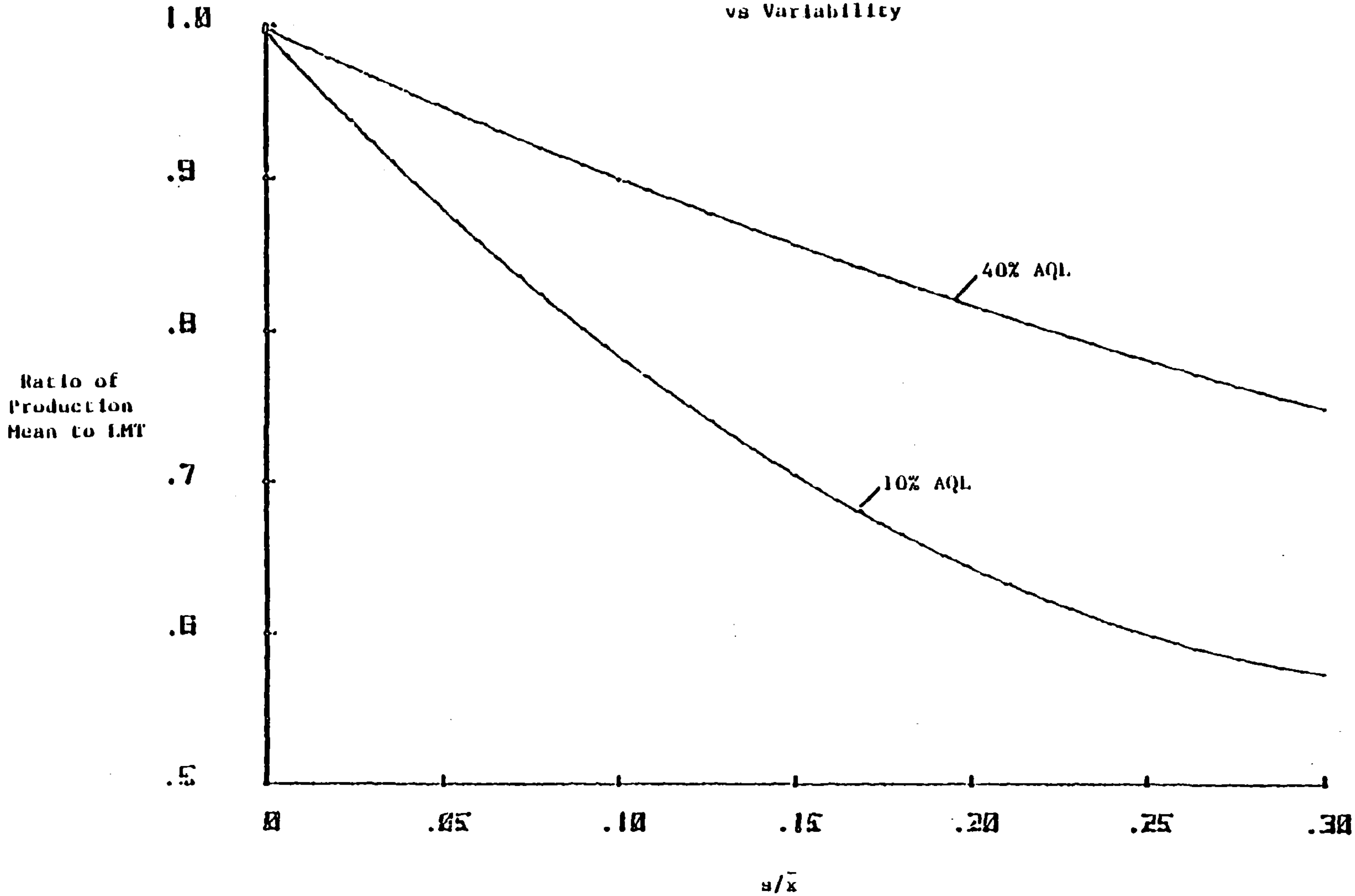
Figure VII-7 is a graphical presentation of these two equations. From that figure, once the s/x ration is known, the target level as a fraction of the LMT can be found for either AQL.

The only piece of data now needed to estimate target ratio for the two AQLs is the appropriate s/x ratio. Ford was the only commenter to submit significant data on variability for gasoline-fueled engines. In its testimony at the May 14-15, 1979 hearings, Ford stated that its median value of s/LMT was approximately 0.24.6/ At the hearing, Ford was questioned on the basis for that estimate and was asked to submit substantiating data. Ford indicated that this value was based upon "recent California audit data of medium heavy-duty trucks."6/ Ford's written comments of 06/29/79 contained a table of s/LMT data (Section V, Table I, pg. 9). The highest reported median value was 0.20 for California audits of passenger cars. The medium-duty truck data cited at the hearings by Ford turned out to be 0.08 for HC and 0.12 for CO. No mention was made in the submission of the rather large drop in s/LMT values. That the change was intended is verified by the fact that the markings of various s/LMT ratios in Ford's graphical presentation from the hearing were whited out on the 06/29/79 submission. Furthermore, Ford continues to use the 0.24 value in its illustrations of the effects of the 10 percent AQL, but has dropped any reference to its representing their median value. Reducing variability from Ford's original 0.24 value to the 0.08-0.12 range would radically change the target values which Ford would project by its own methodology. Using their un-modified presentation, such a change would move the target level for a 10 percent AQL to approximately the level originally derived by Ford for the 40 percent AQL. Thus, Ford would now have to acknowledge the feasibility of the 10 percent AQL.

There is some possiblity that as the level of emission de-

Figure VII-7

Production Target Levels
vs Variability



clines, the s/x ratio may increase somewhat. Therefore, this analysis will use the Ford California passenger car data (for vehicles certified to 0.41/9/1.5 g/mile) to estimate future heavy-duty variablity. The Ford data is presented as s/LMT ratios rather than s/x ratios as desired. However, Ford indicated in its 06/29/79 submission, at pg. 6, that current vehicles are such that x is approximately equal to or slightly les than LMT. Therefore, current s/LMT data will be used to estimate the current s/x value as well.

From Figure VII-4, with s/x = 0.2, the value of x/LMT is given as 0.82 for a 40 percent AQL and 0.65 for a 10 percent AQL.

Emission rates for the two AQLs can now be calculated. The 10 percent AQL case has already been done in section 1b for the transient test procedures. Lifetime emissions were calculated to be 0.17 tons HC and 2.4 tons CO. For the 40 percent AQL case, using the same methodology as section 1b, emissions can be expressed as:

$$HC = 0.63 + 0.04(M/10,000) + F[2.4 - 0.024(M/10,000)] \quad (VII-13)$$

$$CO = 7.5 + 0.52(M/10,0000 + F[81 - 0.30(M/10,000)] \quad (VII-14)$$

Lifetime emissions calculated from equations (VII-13) and (VII-14) are 0.21 tons HC and 2.9 tons CO. The net loss of benefits for a 40 percent AQL versus a 10 percent AQL is then 0.17 - 0.21 = 0.04 tons HC and 2.4 - 2.9 = 0.5 tons CO.

b. <u>Costs</u>

EPA believes that a 10 percent AQL versus a 40 percent AQL would mean some increase cost for hardware to meet lower engine target levels plus an increase in self audit and quality control program costs. EPA believes that engine target levels are sufficiently close together that the same catalyst system would be used for either. However, the 40 percent AQL could allow a reduction in the size of the air pump required. Chapter V has estimated the cost of increased air pump capacity as $26 (before profit and overhead markup) for the 10% AQL case. For the 40% AQL case, a savings of $10 will be used ($12.90 with markup) for the air pump. Manufacturers designing to the 40 percent AQL case would probably also have somewhat more freedom in choosing how far away from the engine to place the catalyst, but this would not have a substantial cost impact.

In addition to the $12.90 for hardware, the costs for the 10 percent AQL case include expenses for internal quality control programs and self audits. Quality control program costs will be the same for either AQL. However, at a 10% AQL, manufacturers are expected to increase self audit rates to more accurately determine the 90 percent compliance level of their production engines. The 40% AQL case will use a self audit rate of 0.2 percent, which is typical of light-duty vehicles now operating with a 40% AQL. For a 10% AQL, this will be increased to 0.6 percent the first year, 0.5 percent the second year, and 0.4 percent for the third and subsequent years. The change in cost associated with these self-audit rates is $3.77. Total differential cost for the two cases is then $12.90 (hardware) + 3.77 (audit rates) = $16.67. This figure is used in Table VII-1 to compute cost effectiveness.

6. Inspection and Maintenance (I/M)

The analysis which has been done so far has contained no specific reliance on I/M programs. In the overall rulemaking neither specific benefits nor costs for I/M programs have been included. However, there are ways in which I/M would enhance the effectiveness of the rulemaking and help insure full realization of possible benefits. Therefore, some discussion of I/M in relation to this rulemaking is appropriate even though it is not required by the regulations being promulgated.

In the context of this rulemaking package, I/M can be viewed as an "insurance policy" for many of the benefits. The presence of an I/M program, which EPA expects would be implemented in those areas requiring maximum benefits, will insure against neglect or abuse of emission related systems by the vehicle owner. The two principal areas when this might occur are misfueling with leaded fuel or tampering with emission related hardware.

EPA has estimated that misfueling in light-duty vehicles occurs in up to 8 percent of the vehicles, with perhaps 6 percent of these being persistent misfuelers (leading to catalyst poisoning).7/ There are no corresponding estimates for heavy-duty vehicles since catalysts have yet to be used. However, something similar seems possible. The incentive for misfueling is largely an economic one, due to the lower cost of leaded fuel compared to unleaded fuel. In an area having an I/M program, the vehicle owner would be faced with a much more powerful economic incentive against misfueling. This incentive would be the cost of replacing the vehicle catalyst, which would be nearly $500, should he fail the I/M test. Rather than incur this expense, EPA believes the owner would avoid misfueling his vehicle. Thus, I/M insures against the loss of benefits which might result from misfueling without actually generating the costs associated with catalyst replacement.

A similar situaion would occur in relation to tampering. Current engine systems are easy to adjust, and could be adjusted differently for an I/M test than they are for normal operation. For future engines this will not be the case. Engines complying with the parameter adjustment regulations will be difficult to adjust in such a way as to adversly affect emissions. The potential for costly repairs from failure of an I/M test (such as replacing a damaged carburetor) would make the occurrence of such maladjustment unlikely. Other forms of tampering, such as removal of the catalyst or other components, would also be difficult enough to be deterred by the need to pass an annual I/M inspection.

The above scenario allows a rough estimate to be made of the benefits an I/M program might realize. Assumptions are as follows: 6 percent of the vehicles would be misfueled initially, without I/M. Their catalysts would fail to the 1979 engine level used earlier for failed catalyst emission rates. An additional 4 percent of the catalysts will be estimated to have failed by the end of the average useful life period due to occasional misfueling. This is equivalent to 2 percent failed over the whole life in terms of emissions. Tampering will be accounted for by including an additional 5 percent. Catalyst failures would then total to 6 percent + 2 percent + 5 percent = 13 percent. After the fashion of the calculations done in section 1b above, there will be a 13 percent shift in emissions from rates for operating catalysts to rates for failed catalysts. Referring to the equations immediately preceeding equation (VII-7), the change in emission can be expressed as:

$$\text{HC increase} = 0.13[(3 + 0.02(M/10{,}000)) - (0.5 + 0.035(M/10{,}000))]$$

$$\text{CO increase} = 0.13[(88 + 0.22(M/10{,}000)) - (5.9 + 0.41(10{,}000))]$$

Lifetime emission benefit of the I/M program using these relations is 0.07 tons HC and 2.3 tons CO.

Cost for the I/M program consists of a $5 annual inspection fee. On the belief that I/M will deter the problems of misfueling and tampering, no other new costs will be incurred. The fee costs over the vehicle life (8 years), discounted to year of sale, are $29.34. This is used to compute the cost effectiveness found in Table VII-1.

It could be argued that once an I/M program is put in place to deter tampering and misfueling, that some of the benefits derived from other components of the overall regulation (parameter adjustment, useful life, allowable maintenance) could be secured by I/M. However, it is the intent of the regulatory strategy to force the design of durable emission control systems that are not highly susceptible to mal-maintenance. It is less costly for the consumer to pay for these features as part of the new vehicle engine design than to have to secure maintenance or replace parts later on. If the parameter adjustment, full useful life and allowable maintenance provisions of the regulations were dropped in favor of reliance of an I/M program to obtain the related benefits, the cost of field maintenance and replacement catalysts would then have to be charged to the I/M program. Considering the catalyst situation alone makes this approach much less efficient than the approach of retaining all parts of the regulation package and backing it up with I/M. We have previously estimated the incremental cost of a full life versus a half life catalyst to be $58. The cost of a replacement catalyst considering after-market parts markup is about $481.

7. Idle Test

The idle standard applies to CO emissions from gasoline fueled engines. Based upon the idle emission data now available to EPA, any emission reduction brought about by the need to certify to an idle standard would be minimal. However, the need to maintain low idle emissions in connection with implementation of Section 207(b) of the 1977 Clean Air Act Amendments, and I/M programs, would produce an emission reduction for in-use vehicles. This is further discussed in the Idle Test portion of the Summary and Analysis of Comments.

Costs associated with implementation of the idle test are only the actual cost of running the additional certification test. No new test equipment is required. There is also no impact on other costs (e.g. control hardware). Expressed as a cost per engine, the costs are negligible. Because this is so, a cost effectiveness computation would not be meaningful and will not be attempted.

E. Diesel Engines

1. Overall Rulemaking

To estimate the benefit of the overall rulemaking for diesel engines, we will first calculate emission rates attributable to the new standard, and then compare these to the 1979 in-use fleet emissions. The analysis for diesel engines will focus only on HC, because CO emissions from diesels are sufficiently low as to be unaffected by the new standards.

In section 7 below, it is estimated that for a 10% AQL, the production target level emission rate would be (0.72) x (standard - DF). The 0.72 factor accounts for the necessary margins to have a 90 percent statistical confidence of passing an assembly line audit. The DF in this case is an additive deterioration factor over the useful life to which an engine is certified. An additive DF is used because historical data is available in this form. While the full life for diesel engines is approximately 475,000 miles, that lifetime includes one or more engine rebuilds.8/ The benefits and costs to be estimated for this rulemaking will be for the entire 475,000-mile life. Engine rebuilding is done for performance reasons only and is not required or substantially affected by these regulations. Compliance with this rulemaking is not expected to affect diesel engine operating costs, maintenance costs, or rebuild costs. As an engine approaches the rebuild point, its emissions will tend to increase somewhat. After rebuild, the emission rates are expected to be returned to a level at or slightly below that expected from extrapolation of the linear DF. The net emission impact of the rebuild operation will therefore tend to cancel the excess emissions which occurred prior to the rebuild. For this analysis then, no special steps are taken to include rebuild emissions and a single DF will be assumed adequate on average. The useful life for certification purposes will be the estimated mileage to engine rebuild which is approximately 250,000 miles. From 1979 certification data, the sales weighted DF for HC is 0.023 g/BHP-hr for 100,000 miles. Lacking a better estimate, the transient DF rate will be considered to be the same as the 13-mode rate. For 250,000 miles this values becomes approximately .06 g/BHP-hr.

The production target emission level is thus 0.72 x (1.3 - .06) = 0.89 g/BHP-hr. Combined with the above DF, the average lifetime emission rate can be calculated by evaluating the value at half of the full life, or 237,500 miles. This corresponds to .89 + .055 = .945 g/BHP-hr. Conversion of this average rate to tons over the vehicle lifetime can be done after the manner developed in section D 1 (a) above for gasoline-fueled engines.

$$\frac{\text{Total}}{\text{Tons}} = \frac{\text{g}}{\text{BHP-hr}} \times \frac{\text{brake specific}}{\text{fuel consumption}} \times \frac{\text{density}}{\text{of fuel}} \times \frac{\text{average}}{\text{m.p.g.}} \times \frac{\text{useful}}{\text{life}} \times \frac{\text{gm to ton}}{\text{conversion}}$$

$$\frac{\text{Total}}{\text{Tons}} = \frac{\text{g}}{\text{BHP-hr}} \times \frac{\text{BHP-hr}}{\text{.43 lb. fuel}} \times \frac{\text{7.1 lb. fuel}}{\text{gal. fuel}} \times \frac{\text{gallons}}{\text{5.8 miles}} \times$$

$$\frac{\text{475,000 miles}}{\text{lifetime}} \times \frac{\text{tons}}{\text{454 x 2,000 gm}}$$

which becomes

g/BHP-hr x 1.49 = Lifetime Tons.

Using the conversion factor, the lifetime emission for a diesel vehicle becomes 0.945 x 1.49 = 1.41 tons HC.

Lifetime HC emissions for the 1979 in-use fleet which make-up the base case for overall benefits have been calculated in Chapter IV as 2.18 tons. The net benefit of the complete rulemaking for diesel engines is then 2.18 - 1.41 = 0.77 tons HC.

The cost of the overall rulemaking for diesels has been developed in Chapter V. Discounted costs per engine are broken down in Table V-LL. Applying the profit and overhead factor of 1.29 developed in Section B-1 of Chapter V, these costs become:

Item	Cost Per Engine (discounted)
R & D	42.74
Certification Testing	7.99
Certification Facilities	49.57
SEA Facilities	29.27
SEA Testing	1.87
Self-Auditing	20.51
Hardware	43.06
Total	195.01

Cost effectiveness results are given in Table VII-2.

2. Transient Test

The implementation of the transient test procedure is a key element of the program for diesel engines. The need for the purchase of new electric dynamometers to replace existing eddy-current dynamometer results in considerable cost for diesel engine manufacturers. A large number of comments were received during the comment period questioning the real need for the transient test procedure for diesel engines. The "test procedure" issue of the Summary and Analysis of Comments treats all these comments at length. In that issue, the benefits of converting to the transient test are also calculated. Those results will be used here.

Briefly summarized, diesel engine families were examined on a family by family basis. For each family, the additional reduction in emissions obtained by implementing the transient test was calculated in comparison to implementing a 13-mode standard derived from a 90 percent reduction from the 9-mode gasoline-fueled engine baseline. These results were then sales weighted for the overall fleet. In order to make comparison between 13-mode and transient emission reductions, some means of estimating the transient emission rate associated with a given 13-mode emission rate was needed. This was done by using the limited transient test data on diesel engines to estimate a transient to 13-mode ratio. Based upon 10 available pairs of test data, this ratio is 2.40. The sales weighted average reduction per engine is 0.49 tons HC.

The emission benefit that could be expected from implementing the 90 percent reduction on the steady-state (90 percent from the 9-mode gasoline baseline) can be derived from the difference between the overall rulemaking and the benefits just estimated for the transient test. This value is 0.77 - .49 = 0.28 tons.

Changes in costs related to choice of test procedure include development costs, hardware costs, and test facility costs (certification and SEA). All of these would decline if the 13-mode standard were adopted instead of the transient standard. Cost items given in section 1 that would change, are given below:

Item	Cost with Transient Test	Cost with 13-mode
R & D	42.74	11.65
Cert. Facilities	49.57	.00
SEA Facilities	29.27	16.72
Hardware	43.06	26.07

Net change in cost = $110.20.

The net change in cost is the cost associated with implementing the transient test procedure and its related standards. Total cost for the 13-mode test can be computed from the above as $195.01 - $110.20 = $84.81.

The decrease in R & D and Hardware costs are associated with the fact that the 13-mode standard would be easier for diesel engines to meet. The revised values were determined in the same fashion as the original cost in Chapter V. 1979 certification data was reviewed, and using an HC target level of 0.7 (10% AQL and a standard of 1.0), engine family specific estimates of R & D and hardware costs were made.

Facility costs declined because with the 13-mode test manufacturers will not need to purchase new dynamometers or CVS sampling systems.

3. Redefinition of Useful Life

Considering the current durability procedure as corresponding to a 100,000-mile useful life, the difference in emissions between that and a 250,000-mile useful life is related to the shift of production target levels due to the shorter lifetime. Based upon the DF used earlier, the shift in production target level would be 0.0345 g/BHP-hr giving .05 tons net change in emissions over the total engine life. This change in target emission levels is small enough as to preclude the identification of specific associated cost changes. It is only possible to say that a small change in stringency would be expected to produce some small change in costs. Based upon engineering judgement, this cost will be estimated as $2 per engine.

4. Parameter Adjustment

Since at this time no parameters have been identified to be adjusted under these regulations for diesel engines, there will be no emission benefit for diesels. Likewise, there will be no cost.

5. Allowable Maintenance Restrictions

These regulations principally affect turbocharger and fuel injector service intervals. All but one of the major manufacturers already specify turbocharger intervals consistent with the regulations. The one exception, Mack, does not seem to have any unique situation making the shorter interval necessary. Rather, it seems to reflect a more conservative approach to specifying maintenance. EPA does not believe Mack would have any difficulty meeting the required intervals, nor would it incur any significant cost. Injector changes to meet the regulations, if any, would be incorporated into the much more significant changes in injectors necessitated by the emission standards themselves. Those changes have been estimated in Chapter V as $20 per engine. The impact of the allowable maintenance regulations will therefore be estimated at 0-$5 per engine. By reducing somewhat the need for maintenance on diesel engines, some reduction of in-use emissions might be expected. Assuming a benefit similar to the useful life provisions, a value of 0.05 tons will be used.

6. Selective Enforcement Auditing (SEA)

The question at issue with regard to SEA is the choice of AQL to be implemented. Evaluation of the 10% AQL will be made in relation to a 40% AQL. The impact of the AQL on emissions is to allow a higher production engine target level in order to pass an SEA audit with a 40% AQL instead of a 10% AQL, all other things being the same. The amount of change can be calculated by standard statistical techniques. The method used here is based upon the standard "t" statistic and is similar to that used by Caterpillar to estimate target levels in its comments on the rulemaking. Needed are the desired confidence of passing an audit and production variability (coefficient of variation). A confidence level of 90 percent corresponds to that generally used by manufacturers. Concerning the coefficient of variation, the only data submitted was by Caterpillar, and that data indicated that a value of 0.16 was representative.9/ This value has been used in these calculations. Later data submitted after a request to Mack indicated that for 1979 engines the coefficient of variation was in the range of .08 to .14.10/ Earlier Mack data had supported the 0.16 value.11/

The formulas and typical calculations for estimating production target levels can be found in section E of Appendix A. Results depend upon both the coefficient of variation and the number of preproduction engines evaluated. For a range of these values, the ratio of production target level (x) to the standard minus the DF (LMT) would be as follows:

	10% AQL		40% AQL	
No. of engines	X/LMT (cov=0.16)	X/LMT (cov=0.20)	X/LMT (cov=0.16)	X/LMT (cov=0.20)
3	0.72	0.68	.85	.82
5	0.76	0.72	.90	.88
7	0.77	0.73	.92	.90

These results indicate the flexibility in target levels. A higher coefficient of variation could lead to a lower target level, or a manufacturer could test more engines and retain the same target level.

Based upon a coefficient of variation of 0.16 and a sample size of 3 engines (which seems most characteristic of current practice), target value ratios of 0.72 (10% AQL) and 0.85 (40% AQL) will be used. Production target levels are found by subtracting the appropriate DF from the standard and then applying the AQL factor:

10% AQL
$$0.72\,(1.3 - 0.06) = 0.89 \text{ g/BHP-hr}$$

40% AQL
$$0.85\,(1.3 - 0.06) = 1.05 \text{ g/BHP-hr}$$

As shown in section 1, the average lifetime emission rate must be increased a small amount (0.055 g/BHP-hr) to account for deterioration. When this is done, lifetime emission rates for two AQL's can be calculated to be:

$$(0.89 + 0.055)\ 1.49 = 1.41 \text{ tons HC} \quad 10\% \text{ AQL}$$

$$(1.05 + .055)\ 1.49 = 1.65 \text{ tons HC} \quad 40\% \text{ AQL}$$

The net benefit of the 10% AQL versus the 40% AQL is then 1.65 - 1.41 = 0.24 tons.

Cost differences associated with the two AQL values include development costs, SEA testing costs and self auditing cost.

Item	Cost at 10% AQL	Cost at 40% AQL
R + D	42.74	39.78
SEA Testing	1.87	2.33
Self Auditing	20.51	16.19

Net change in cost = 6.82

The net change in cost is the cost associated with implementing the 10% rather than the 40% AQL and is used to estimate cost effectiveness in Table VII-2. The changes in R & D costs were estimated on an engine family by engine family basis, as above for the cost of the transient test procedure. Change in production target levels were not great enough to affect hardware costs. SEA testing costs increase slightly for the 40 percent AQL, reflecting the increased average number of engines expected to be tested to arrive at a pass/fail decision for a 40 percent AQL versus a 10 percent AQL (15 engines versus 12 engines). Self auditing costs reflect a change in self audit rates. Self audit costs are based upon an audit rate of 0.2 percent for a 40 percent AQL. For a 10 percent AQL, self audit rates are assumed to be 0.6 percent the first year, 0.5 percent the second year, and 0.4 percent thereafter. Quality control program costs ($12.90) remain unchanged.

References

1/ Discussed in many statistical texts. See, for example, "Statistical Design and Analysis of Engineering Experiments," Lipson & Sheth, p. 36.

2/ "Average Lifetime Periods for Light-Duty Trucks and Heavy-Duty Vehicles," EPA Report SDSB 79-24, G. Passavant, November 1979.

3/ An evaluation of Restorative Maintenance on Exhaust Emissions of 1975-1976 Model Year In-Use Automobiles, EPA-460/3-77-021, December 1977.

4/ Ibid., Table IV-2.

5/ Ibid., Table B-18.

6/ Page 346 of Hearing Transcript and Page 1 of Ford "Supplemental Statement on Heavy-Duty Engine Selective Enforcement Auditing", May 14, 1979.

7/ Memorandum, "Fuel Switching," Benjamin Jackson, EPA Office of Enforcement, August 2, 1979.

8/ Average Lifetime Periods for Light-Duty Trucks and Heavy-Duty Vehicles, EPA Report SDSB 79-20, G. Passavant, November 1979.

9/ See pages 10-13 of the Caterpillar submission of August 15, 1979.

10/ Letter, R.E. Kendall, Mack Trucks, Inc., to Mr. John Anderson, October 26, 1979.

11/ Letter, R. E. Kendall, to Steven Turchen, November 17, 1977 and follow-on submission to Benjamin Jackson, February 14, 1978 and April 18, 1978.

Appendix A

REVISED EMISSION FACTORS FOR HEAVY-DUTY GASEOUS REGULATORY ANALYSIS

A number of changes to the MOBILE-1 factors and the air quality model inputs are needed for the final analysis of the heavy-duty package. Transient data on old and new heavy-duty engines can be used to update emission factor estimates. For future standards, emission target levels for manufacturing production have been identified, and projected in-use deterioration rates established for the components of the final package. Growth rates for regional heavy-duty gasoline (HDG) and heavy-duty diesel (HDD) vehicle miles traveled (VMT) need to be adjusted consistent with projected increased dieselization rates. Light-duty truck emission factors appropriate to the proposed LDT package are also needed, and dieselization of LDTs needs evaluation.

A. Incorporate HD Transient Data Into Emission Factor Equations

Heavy-Duty Gasoline

The DF's are based upon light-duty experience with various emission control systems. The EPA transient testing program for HD engines has not provided data at this time to revise the DF's, so they will remain as is.

The 1969 baseline engines were overhauled prior to testing and will be assumed to be at their new vehicle emission rates. While this is not strictly true, residual deterioration associated with basic engine wear should be quite small (witness the near-zero DFs from certification durability engines). The "pre-1970" HDG new vehicle emission rate will therefore be revised to equal the sales weighted 1969 baseline values. The 1969 baseline data represents 81.5 percent of 1969 sales of HDG engines.

1972-1973 baseline data is available at this time for seven engines representing 46.4% of 1973 sales. This data will be used to update the 1970-78 factors. There is insufficient data to distinguish 1970-1973 from 1974-1978 and a single factor will be used for both. The 1974 HD standards were not of such stringency as to produce any significant change in HC or CO emission control hardware. During the period of interest for our air quality analysis (late 1980's and beyond), vehicles of that vintage will have only a minor impact on overall HD emissions.

1979 baseline data is available at this time on 12 engines representing 86% of 1979 sales projection. This data will be used to update the 1979-1983 emission factors. Note that the analysis will use 1984 as the first year of implementation for the new standards and transient test procedure.

Since the 1979 baseline data is from certification engines, some allowance needs to be made for the difference between those engines and production line engines (since there was no SEA program) This will be done by estimating the historic ratio of certification levels to new engine emission rates.

In Figure 4 of the "Summary and Analysis of Comments to the NPRM: Revised Heavy Duty Engine Regulations for 1979 and Later Model Years", the sales weighted certification levels for 1974 heavy-duty engines are given as 4.8 (HC)/24 (CO) g/BHP-hr on the 9-mode test. The revised transient emission factor for that year derived from the 1972/1973 baseline program (Table 1A) is 12.7/211 g/mile new vehicle emission rate. To compare these two rates it is necessary to estimate the transient emission levels associated with the 1974 9-mode certification levels. These are estimated at 9.6/145 g/mile. (The methodology for these estimates can be found in Chapter VII. It involves estimating an approximate transient g/BHP-hr level corresponding to the 9-mode steady-state level, and converting that level to g/mile.)

From the above two data sets the ratio of new vehicle emission rate (g/mile) to certification level (g/mile) can be estimated at 12.7/9.6=1.3 for HC and 211/145=1.45 for CO. These ratios were applied to the 1979 baseline to derive the new vehicle emission rates for 1979-1983 in Table 1A.

Heavy-Duty Diesel

At this time, transient test data on diesel engines is extremely limited. This data will be used in two different manners to estimate HDD emission factors. The first, which is probably somewhat more accurate, but is also considerably more complicated, will be used to estimate HC rates. The second will be used for CO.

For HC emission rates, the method is based upon that approach developed to evaluate the cost effectiveness of the transient test procedure for HC control. Since CO from HDD will not be affected by the new procedure, CO was not evaluated. Details of the calculations are found in the "Test Procedure" section of the Summary and Analysis of Comments. Available test data on diesel engines from SwRI and Cummins was used to estimate an approximate ratio of transient HC emissions to 13-mode HC emissions. This ratio is estimated at 2.40. Since there were relatively few engines tested (10 used for this ratio), rather than use the transient HC emissions directly, the ratio was applied to 1979 certification data to estimate a sales weighted 1979 transient emission result. The certification data can be found in Table 6 of the "Test Pro-

Table 1-A

Revised Exhaust Emission Rates
Heavy-Duty Gas Vehicles
For All Areas Except California and High Altitude

Pollutant	Model Year	A (g/mile) New Vehicle Emission Rate	B (g/mile) Deterioration Rate (Per 10,000 Miles)
HC	Pre-1970	18.3	0.58
HC	1970-1978	12.7	0.53
HC	1979-1983	6.3	0.53
CO	Pre-1970	228	3.06
CO	1970-1978	211	6.15
CO	1979-1983	210	6.15

Table 1-B

Revised Exhaust Emission Rates
Heavy-Duty Diesel Vehicles
For All Areas Except California and High Altitude

Pollutant	Model Year	A (g/mile) New Vehicle Emission Rate	B (g/mile) Deterioration Rate (Per 10,000 Miles)
HC	Pre-1984	4.0	0.007
CO	Pre-1984	8.7	0.11

cedure" write-up. The sales-weighted 13-mode certification result from that table is 0.594 g/BHP-hr on the 13-mode test. This converts to .594 x 2.4 = 1.42 g/BHP-hr estimated 1979 transient emission level. To convert to g/mile involves the relation between fuel consumption per BHP-hr and fuel consumption per mile of truck travel:

$$\frac{g}{\text{BHP-hr}} \times \frac{\text{BHP-hr}}{\text{lb fuel}} \times \frac{\text{lb fuel}}{\text{per gallon}} \times \frac{\text{gallons}}{\text{mile}} = \text{g/mile}$$

From the SwRI test data, fuel/BHP-hr is estimated at 0.43 lb/ BHP-hr.

The density of diesel fuel is 7.1 lb/gallon. Fuel economy was derived from fuel economy data for various HDD vehicle classes combined with projected sales splits to give an overall sales-weighted fuel economy for current diesel engine of 5.8 mpg.

Using these numbers, the conversion factor is:

$$\frac{7.1}{0.43 \times 5.8} = 2.85$$

The resulting estimated diesel HC emission rate is 1.42 x 2.85 = 4.047 g/mile. This number is based upon 1979 certification data, which includes deterioration factors, if any. The sales-weighted 1979 certification DFs are 0.023 for HC and 0.38 for CO. These are additive values over a durability test approximately equal to 100,000 miles. The zero mileage emission rates for diesels are found by removing the DF. In g/mile, these DFs are .066/100,000 mi HC, 1.08/100,000 mi CO. The resulting HC emission rate is 3.98 g/mile. Considering the accuracy of the various inputs to this calculation, the result will be rounded to 4.0 g/mi. Existing emission factors suggest that there is little or no year-to-year variation in HDD emission factors, therefore, a single factor will be estimated for all pre-1984 HDD engine.

For CO emissions, the available CO data was used directly. Individual engine results are tabulated below:

HDD Transient Test Data (g/mile)

Engine	CO
1978 Caterpillar 3208	7.14
1976 Cummins NTC-350	16.64
1978 Detroit Diesel 6V-92T	8.66
1979 Cummins NTCC-350	8.53
1978 Detroit Diesel 8V-71N	
#1 fuel	9.43
#2 fuel	10.91
1979 Detroit Diesel 6V-92TA	
"1 fuel	3.57
#2 fuel	4.40
Average:	8.66

Since these results are for new or nearly new engines, no zero mileage DF adjustment is necessary. HC and CO emission factors are included in Table 1-B.

B. Modify Baseline Emission Inventory

Since the 1976 baseline emission inventory for both HDG and HDD has been computed based upon the existing emission factors, these values should be adjusted to account for the change to new factors. This should be done for each area analyzed by applying a correction ratio. The correction ratio would be determined by computing 1976 composite emission factors using the old and then the new emission factor equations. The ratio of the new composite factors to the old ones would be used to correct the baseline emission inventory.

C. Develop Estimates of Future HD Emission Factors

Heavy-Duty Gasoline

Given the existence of an SEA program, statistical relationships can be established between the standards and the design values of emissions. Determining factors are the low mileage target (which is equal to the standard divided by the deterioration factor), the emission variability, the number of preproduction engines available for testing (typically 3), and the desired level of confidence that production engines would be able to pass an SEA. The details of the necessary calculations will be found in Chapter VII. For HDG, they are based upon a modification of the approach used by Ford and allow for an 80% confidence that the "manufacturer's risk" during an SEA would be no more than 10%.

In addition to new vehicle emission rates, estimates of deterioration rates are also needed. Expected deterioration rates for the catalyst systems to be used on HDG engines have been analyzed in the Analysis of Comments for the rulemaking (see the "allowable maintenance" issue). That analysis indicates that a catalyst DF of 1.7 over 100,000 miles should be reasonable.

The resulting emission rates are calculated in Chapter VII, Section D1b to be:

HC = 0.50 + 0.035 (M/10,000) g/BHP-hr
CO = 5.9 + 0.41 (M/10,000) g/BHP-hr

These can be converted to grams per mile, again based upon information in Chapter VII, Section D1a. The conversion factor is 1.74, and yields the following results:

HC = 0.87 + 0.06 (M/10,000) g/mi
CO = 10.3 + 0.72 (M/10,000) g/mi

Because of such aspects of the final rulemaking as the transient test, parameter adjustment, full life useful life, allowable maintenance and SEA, in-use deterioration rates are expected to correspond closely to certification levels. However, as catalysts approach the end of their useful ife, a small number of them can be expected to fail. Therefore, average HDG emission rates will increase somewhat near the end of the useful life. Projections of catalyst failures made in the regulatory analysis indicate that approximately 15% of the catalysts would fail. These are distributed according to a Weibull distribution, and are assumed to fail to the level of a well maintained 1979 engine.

Vehicles with failed catalysts will be assumed to emit at levels corresponding to well-maintained 1979 engines. The zero-mileage emission rates will be taken from the EPA 1979 HDG baseline data. The DFs will be those derived in Chapter VII, Section D1a, converted to g/mile:

HC (failed catalyst) = 4.9 + 0.035 (M/10,000) g/mi
CO (failed catalyst) = 145 + 0.38 (M/10,000) g/mi

If F is the fraction which has failed, then the average emission rate can be developed as follows:

HC (average) = [0.87 + 0.06 (M/10,000)][1-F] + [4.9 + 0.035 (M/10,000)][F]

HC (average) = 0.87 + 0.06 (M/10,000) + F [4.0 - 0.025 (M/10,000)]

CO (average) = [10.3 + 0.72 (M/10,000)][1-F] + [145 + 0.38 (M/10,000)][F]

CO (average) = 10.3 + 0.72 (M/10,000) + F [135-0.34 (M/10,000)]

These final results are given in Table 2.

Heavy-Duty Diesel

New vehicle hydrocarbon emission rates for diesels were estimated following the procedure used by Caterpillar. This method estimates the maximum desired production mean level based upon the AQL and variability and then establishes a target level to assure attainment of the desired production level based upon a small sample of pre-production engines (e.g. 3). The calculations are given in Chapter VII of the Regulatory Analysis. Expressed in g/mile, the zero mileage emission rate is 2.5 g/mi.

HDD carbon monoxide emission rates fall below the final standards and therefore continue at the level of existing engines.

Table 2

Projected Exhaust Emission Rates
For All Areas Except California and High Altitude

Applicable to 1984 and Later Years

Heavy-Duty Gasoline

$HC = 0.87 + 0.06\ (M/10{,}000) + F_H[4.0-0.025\ (M/10{,}000)]$

$CO = 10.3 + 0.72\ (M/10{,}000 + F_H[135-0.34\ (M/10{,}000)]$

Where,

M = Mileage.

F_H = Fraction of failed catalysts = $1-\exp[-\left(\frac{M}{211{,}726}\right)^3]$

Heavy-Duty Diesel

$HC = 2.5 + 0.007\ (M/10{,}000)$

$CO = 8.7 + 0.11\ (M/10{,}000)$

Light-Duty Trucks

$HC = 0.39 + 0.016\ (M/10{,}000) + F_L[1.5 + 0.022\ (M/10{,}000)]$

$CO = 4.8 + 0.17\ (M/10{,}000) + F_L[18.6 + 0.30\ (M/10{,}000)]$

Where,

$F_L = 1-\exp[-\left(\frac{M}{269{,}141}\right)^3]$

The resulting equations are found in Table 2.

D. <u>Growth Rates for VMTs</u>

The rollback model usually assumes a common growth rate for HDG and HDD, which has been based to some extent upon the pollutant in question and the ambient problem associated with that pollutant. That is, CO, which is seen as an urban core area "hot spot" problem, is limited to low growth on the assumption that urban core VMTs are near saturation levels. HC, on the other hand, can increase at a greater rate because of the broader regional impact of HC emissions. One and two percent growth rates, respectively, have been used for these pollutants.

The analysis for the Final HD Regulations indicates a significant shift in diesel utilization rates. For major urban areas, negative growth in the HDG fleet is expected, while the diesel fleet will increase substantially. The analysis indicates that the usual MOBILE-1 growth rates need to be adjusted to account for this change. The results developed below result in growth of HDG plus HDD VMTs at about 2% per year, but apportion that growth unevenly between the two classes.

Future fleet projections used are those of the Interagency Study1/ for the 1980-1990 time period. The totals for HDG and HDD are summarized below:

Projected HD Fleet Population 2/
Vehicle Class 3/

HDG	III-V	VI	VII	VIII	Total
1973	1,595,000	2,442,000	335,000	437,000	4,809,000
1980	1,778,000	2,474,500	299,000	298,000	4,849,500
1985	2,036,000	2,123,000	217,000	184,000	4,560,000
1990	2,237,000	1,682,000	115,000	65,000	4,099,000
HDD					
1973	-	75,000	161,000	718,000	954,000
1980	-	332,500	224,000	1,067,000	1,623,500
1985	-	947,000	314,000	1,243,000	2,504,000
1990	-	1,682,000	425,000	1,247,000	3,354,000

1/ "Interagency Study of Post-1980 Goals for Commercial Motor Vehicles," June, 1976.
2/ Interagency Study, Fig. I-5, I-6.
3/ Class III-V = 10,000-19,500 lb. GVW, Class VI = 19,500-26,000 lb. GVW, Class VII = 26,000-33,000 GVW, Class VIII = above 33,000 lb. GVW.

Over the 1973-1990 period, the total HDG fleet is projected to decline at an average rate of -0.9% per year, while the HDD fleet will increase by +7.7% per year an average. The overall fleet is projected to grow at an average rate of +1.5% per year.

Of more direct interest are those portions of the fleet contributing most to urban VMTs (as distinguished from interstate travel, for example). This generally can be done by looking at the lighter weight classes. Classes III-V and VI accumulate most of their VMTs on local or short hauls. For these classes, the following average growth rates between 1973 and 1990 are projected (% per year):

	III-V	VI	III-VI
HDG	+2.0	-2.2	-0.2
HDD	-	+20	+20
Total	+2.0	+ 1.7	+ 1.8

The growth in the size of the fleet will not correspond exactly to changes in VMTs. The Interagency Report also projected VMTs for 1973 and 1990 for local trips, short haul trips, and long haul trips.

Annual HD VMT's 4/
(Billions of Miles Per Year)

			1 9 7 3		
	Local	Short	Long	Local & Short	Total
HDG	35.8	10.7	3.3	46.5	49.8
HDD	10.4	18.3	30.6	28.7	59.3
Total	46.2	29.0	33.9	75.2	109.1

			1 9 9 0		
	Local	Short	Long	Local & Short	Total
HDG	22.8	5.6	2.0	28.4	30.4
HDD	42.3	38.8	54.3	81.1	135.4
Total	65.1	44.4	56.3	109.5	165.8

The average annual growth rates represented by these figures are as follows:

	Local	Short	Long	Local & Short	Total
HDG	-2.6	-3.7	-2.9	-2.9	-2.9
HDD	+8.6	+4.5	+3.4	+6.3	+5.0
Total	+2.0	+2.5	+3.0	+2.2	+2.5

4/ Interagency Report, Fig. I-7.

Comparing fleet growth rates with VMT growth rates reveals significant differences. They reflect a decline in sales of larger (and higher annual mileage) gasoline trucks and increasing sales of lighter (and lower annual mileage) diesel trucks. The VMT projections are the most appropriate to use since the rollback and EKMA models work on VMT growth rates. On the assumption that the shrinkage in HDG VMTs may be somewhat overstated, we will use the following growth projections:

Growth Rate of Annual VMTs to Use for Air Quality Projections

HDG = -2.0% per year
HDD = +5.0% per year

E. LDT Estimated 1984 Emission Factors

The LDT emission factors for future vehicles require estimates of "full life" deterioration rates and new vehicle production targets.

LDT's are expected to continue using oxidation catalysts similar to current systems. Therefore, similar DFs to current vehicles are expected. To determine a "full life" DF, we assume catalysts will be sufficiently durable to last the entire useful life and to maintain deterioration characteristics similar to those observed on current 50,000 mile systems. The full life DF can then be determined by linear extrapolation of the 50,000 mile DF. 1979 certification data yields the following LDV and LDT average DFs:

LDV	DF(HC) = 1.20	DF(CO) = 1.18	(197 vehicles)
LDT	DF(HC) = 1.18	DF(CO) = 1.11	(60 vehicles)

In the interest of simplicity, a rounded off DF of 1.2/50,000 miles will be used for both HC and CO. Assuming manufacturers might certify for useful lives of about 100,000 miles this becomes 1.4/100,000 miles.

Manufacturers base their estimates of production line mean values upon limited testing of pre-production vehicles (typically 3). In order to ensure that an SEA audit will be passed with some desired confidence factor (we will use 90%), their target emission levels will, of necessity, be some point below the required level (because of production variability and the small sample size). This point can be estimated by standard statistical techniques, using the "t" statistic. The following relationships will be used:

LMT = low mileage target = standard/DF

m = maximum desired production mean = LMT -1.28s

x = target new vehicle emission rate = $m - s\,(t/\sqrt{n})$

Where,

s = standard deviation of emission levels

t = "t" statistic for 90% confidence level and n-1 degrees of freedom

n = sample size

To perform the calculations, an estimate of emission variability is needed. Data on variability expressed in the form of s/LMT was submitted by Ford in their comments on the LDT NPRM. That data indicated a value of s/LMT of 0.20 for LDVs certified to the 0.41/9/1.5 California standards. This value was higher than that found by Ford on vehicles certified to higher standards, and Ford felt that it would be even higher at lower standards.

For our analysis, we will assume that variability expressed as s/x is essentially constant. A value of s/x can be estimated from the Ford s/LMT data. Ford indicated in the submission of its data that current engines are such that $\bar{X}$ is approximately equal to or somewhat less than LMT. Therfore, current s/LMT dta can be used as an estimate of the current s/x ratio. For engines built to meet a 10% AQL, we will assume that s/x remains constant (rather than s/LMT) as x goes down. To examine the effect of s/x increasing, we will calculate results using both 0.20 and 0.24.

We have:

$x = m - s\,(t/\sqrt{n})$

$m = LMT - 1.28s$

$s/x = 0.20$ or 0.24

Combining these we get, depending on the s/x ratio used:

$x = LMT - .20x(1.28 + t/\sqrt{n})$ or $x = LMT - .24x(1.28 + t/\sqrt{n})$

$x(1.256 + .20t/\sqrt{n}) = LMT$ or $x(1.307 + .24t/\sqrt{n}) = LMT$

$x/LMT = 1/(1.256 + .20t/\sqrt{n})$ or $x/LMT = 1/(1.307 + .24t/\sqrt{n})$

For sample size n = 3,5,7, the results are as follows:

n	t	x/LMT (s/x = 0.20)	x/LMT (s/x = 0.24)
3	1.886	0.68	0.64
5	1.533	0.72	0.68
7	1.440	0.73	0.70

Based upon what seems to be the most common sample size (3) and the s/x = 0.20 ratio, we will use an x/LMT ratio of 0.68. The above tabulations indicate that manufacturers could raise production target levels by increasing sample size or reducing variability. For example, if s/x were .24 instead of .20, increasing the sample size from 3 to 5 would allow maintenance of the same target value.

New vehicle emission rates for these ratios are:

0.68 (0.8/1.4) = 0.39 HC   0,68 (10/1.4) = 4.8 CO

A DF of 1.4/100,000 miles will yield the following:

HC = 0.39 + 0.016 (M/10,000)
CO = 4.8 + 0.19 (M/10,000).

These rates would apply to LDTs until such time as a catalyst failure occurred. As catalysts approach the end of their useful life, random failures will begin to occur. These failures would be expected to follow a Weibull distribution of the form:

$$F = 1 - \exp\left[-\left(\frac{M}{\theta}\right)^{b}\right]$$

One of the principle uses of the Weibull distribution is in characterizing lifetime phenomena,5/ so that it is well suited to our purposes. To specify the distribution, we will assume the catalyst change point of 100,000 miles corresponds to a 5% failure rate (giving the manufacturers 95% confidence of catalyst survival). We will further assume a "Weibull slope" of b = 3. Based upon these parameters, θ = 269,141 miles. A plot of this function is given in Figure 1.

For those catalysts that fail, emission rates characteristic of well maintained, pre-catalyst engines are desired. Based upon review of emission factors for LDT's,6/ new vehicle emission rates of 1.9 HC, 23.4 CO will be used and combined with a DF of 1.1.

Then:

HC (failed catalyst) = 1.9 + 0.038 (M/10,000)

CO (failed catalyst) = 23.4 + 0.47 (M/10,000)

5/ Discussed in many statistical tests. See, for example, "Statistical Design and Analysis of Engineering Experiments," Lipson and Sheth, p. 36.

6/ "Mobile Source Emission Factors - Final Document," EPA-400/9-78-005, March, 1978, Table II-1.

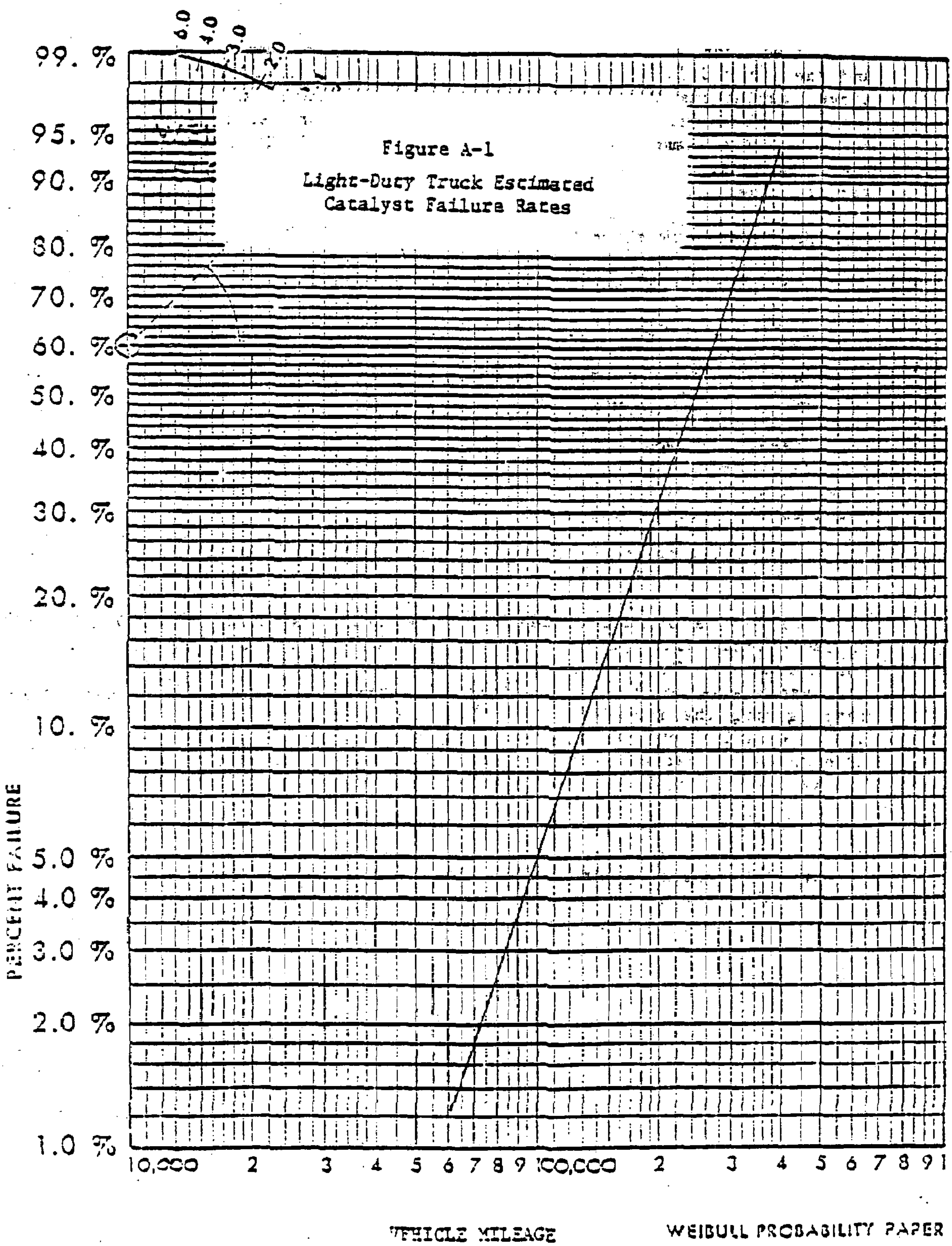


Figure A-1
Light-Duty Truck Estimated
Catalyst Failure Rates
6.0
4.0
3.0
2.0
99. %
95. %
90. %
80. %
70. %
60. %
50. %
40. %
30. %
20. %
10. %
5.0 %
4.0 %
3.0 %
2.0 %
1.0 %
PERCENT FAILURE
10,000
2
3
4
5
6
7
8
9
100,000
2
3
4
5
6
7
8
9
1
VEHICLE MILEAGE
WEIBULL PROBABILITY PAPER

Combining the OK catalyst and failed catalyst emission rate according to the fraction (F) of failed catalysts, we get:

$$HC = [0.39 + 0.016 (M/10,000)][1-F] + [1.9 + 0.038 (M/10,000)][F]$$
$$HC = 0.39 + 0.0116 (M/10,000) + F [1.51 + 0.022 (M/10,000)]$$

$$CO = [4.8 + 0.17 (M/10,000][1-F] + [23.4 + 0.47 (M/10,000)][F]$$
$$CO = 4.8 + 0.17 (M/10,000) + F [18.6 + 0.30 (M/10,000]$$

These results are included in Table 2.

The above factors are for gasoline fueled LDTs. In future years, some dieselization of LDTs is expected. Reproduced in Table 3 is data from the Summary and Analysis of Comments for the Light Duty Diesel Particulates package. This table gives diesel fractions for future LDV sales. These same projections will be used to estimate the fraction of LDT diesels.

For 23 certified LDV and LDT diesels in 1979 the average emissions are 0.60 (HC)/1.75 (CO). The two LDT diesels in this set span the average values. The following values will be used to estimate diesel LDT emission:

LDT Diesel Emission Rates

HC = 0.60 g/mile
CO = 2.0 g/mile

These levels are sufficiently low to be independent of AQL or emission standard. The average DF for 11 durability vehicles was low enough to neglect.

F. Develop Future HD Emission Standards for Optional Cases

In the course of evaluating the Clean Air Act mandated 90 percent reduction standard, optional reductions of 85 percent and 95 percent will be examined also. The standards corresponding to these levels would be 1.9/23.3 g/BHP-hr HC/CO for 85 percent and 0.64/7.7 g/BHP-hr HC/CO for 95 percent. Corresponding emission factors are derived below:

Heavy-Duty Gasoline

Following the methodology developed earlier, zero mileage emission rates for HDG would be:

85 Percent Standard

HC = 0.65 (1.9/1.7) = 0.73 g/BHP-hr
CO = 0.65 (23.3/1.7) = 8.9 g/BHP-hr

Table 3

Year-by-Year Projections of the Diesel Fraction of Light-Duty Vehicle Sales 7/

Model Year	Diesel Fraction (%)
1981	4.7%
1982	7.5%
1983	8.9%
1984	9.5%
1985	11.4%
1986	13.8%
1987	16.5%
1988	17.6%
1989	18.7%
1990	19.7%
1991	20%
1992	20%
1993	20%
1994	20%
1995	20%

7/ Source: Summary and Analysis of Comments, EPA Light-Duty Diesel Particulate Final Rulemaking, Table I-5.

95 Percent Standard

$$HC = 0.65\ (.64/1.7) = 0.24\ g/BHP\text{-}hr$$
$$CO = 0.65\ (7.7/1.7) = 2.9\ g/BHP\text{-}hr$$

Converting these to grams per mile and adding in deterioration rates corresponding to a 1.7 DF these become:

85 Percent Standard

$$HC\ (OK\ Catalyst) = 1.3 + 0.09\ (M/10{,}000)\ g/mile$$
$$CO\ (OK\ Catalyst) = 15.5 + 1.08\ (M/10{,}000)\ g/mile$$

95 Percent Standard

$$HC\ (OK\ Catalyst) = 0.42 + 0.03\ (M/10{,}000)\ g/mile$$
$$CO\ (OK\ Catalyst) = 5.0 + 0.35\ (M/10{,}000)\ g/mile$$

Failed catalyst emission rates will be the same as those previously used for HDG in Section C. The average emission rates are then:

85 Percent Standard

$$HC\ (average) = 1.3 + 0.09\ (M/10{,}000) + F\ [3.6-0.05\ (M/10{,}000)]$$
$$CO\ (average) = 15.5 + 1.1\ (M/10{,}000) + F\ [129-0.72\ (M/10{,}000)]$$

95 Percent Standard

$$HC\ (average) = 0.42 + 0.03\ (M/10{,}000) + F\ [4.5-0.01\ (M/10{,}000)]$$
$$CO\ (average) = 5.0 + 0.35\ (M/10{,}000) + F\ [140-0.03\ (M/10{,}000)]$$

These results are included in Table 4.

Heavy-Duty Diesel

The zero mileage emission rates can be estimated as was done in Chapter VII of the Regulatory Analysis, Section E. As before, only HC is affected since diesel CO emission naturally fall below even the 95 percent reduction standard.

In g/BHP-hr, the zero mileage emission rates are:

85 Percent Standard

$$0.72\ (1.9-0.06) = 1.32\ g/BHP\text{-}hr$$

95 Percent Standard

$$0.72\ (0.64-0.06) = 0.42\ g/BHP\text{-}hr$$

Converting to grams per mile and including the DF, the final results are:

<u>85 Percent Standard</u>

$$HC = 3.8 + .007\ (M/10{,}000)\ \text{g/mile}$$

<u>95 Percent Standard</u>

$$HC = 1.2 + .007\ (M/10{,}000)\ \text{g/mile}$$

These equations are included in Table 4.

Table 4

Optional Projected Exhaust Emission Rates For All Areas Except California and High-Altitude

Applicable to 1984 and Later Years

A. 85 Percent Reduction Standard (1.9/23.3 g/BHP-hr HC/CO) 1/

Heavy-Duty Gasoline

$HC = 1.3 + 0.09 (M/10,000) + F_H [3.6-0.05 (M/10,000)]$

$CO = 15.5 + 1.1 (M/10,000) + F_H (129+0.72 8M/10,000)]$

Heavy-Duty Diesel

$HC = 3.8 + 0.007 (M/10,000)$

$CO = 8.7 + 0.11 (M/10,000)$

B. 95 Percent Reduction Standard (0.64/7.7 g/BHP-hr HC/CO) 1/

Heavy-Duty Gasoline

$HC = 0.42 + 0.03 8M/10,000) + F_H [4.5-0.01 (M/10,000)]$

$CO = 5.0 + 0.35 (M/10,000) + F_H [140 + 0.03 (M/10,000)]$

Heavy-Duty Diesel

$HC = 1.2 + 0.007 (M/10,000)$

$CO = 8.7 + 0.11 (M/10,000)$

Note: M and F_H are as defined in Table 2.

1/ Percent reductions given indicate standards which are equal to the stated percent reduction from a 1969 gasoline-fueled baseline.

Table 4

Optional Projected Exhaust Emission Rates For All Areas Except California and High-Altitude

Applicable to 1984 and Later Years

A. 85 Percent Reduction Standard (1.9/23.3 g/BHP-hr HC/CO) 1/

Heavy-Duty Gasoline

$HC = 1.3 + 0.09\ (M/10{,}000) + F_H\ [3.6-0.05\ (M/10{,}000)]$

$CO = 15.5 + 1.1\ (M/10{,}000) + F_H\ (129+0.72\ 8M/10{,}000)]$

Heavy-Duty Diesel

$HC = 3.8 + 0.007\ (M/10{,}000)$

$CO = 8.7 + 0.11\ (M/10{,}000)$

B. 95 Percent Reduction Standard (0.64/7.7 g/BHP-hr HC/CO) 1/

Heavy-Duty Gasoline

$HC = 0.42 + 0.03\ 8M/10{,}000) + F_H\ [4.5-0.01\ (M/10{,}000)]$

$CO = 5.0 + 0.35\ (M/10{,}000) + F_H\ [140 + 0.03\ (M/10{,}000)]$

Heavy-Duty Diesel

$HC = 1.2 + 0.007\ (M/10{,}000)$

$CO = 8.7 + 0.11\ (M/10{,}000)$

Note: M and F_H are as defined in Table 2.

1/ Percent reductions given indicate standards which are equal to the stated percent reduction from a 1969 gasoline-fueled baseline.