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MEDIUM DUTY VEHICLE EMISSION CONTROL COST EFFECTIVENESS COMPARISONS VOLUME I - EXECUTIVE SUMMARY

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Ann Arbor, Michigan 48105

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MEDIUM DUTY VEHICLE EMISSION CONTROL COST EFFECTIVENESS COMPARISONS

VOLUME I - EXECUTIVE SUMMARY

Prepared by

The Environmental Programs Group

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Contract No. 68-01-0417

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
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FOREWORD

This report, prepared by The Aerospace Corporation for the Environmental Protection Agency, Division of Emission Control Technology, presents the results of a comparative analysis of the cost effectiveness of medium-duty vehicle [6,000 to 14,000-lb gross vehicle weight (GVW)] emission control systems.

The study results are presented in two volumes. Volume I, Executive Summary, presents a concise review of important findings and conclusions in the Highlights and Executive Summary sections. Volume II, Technical Discussion, provides a detailed discussion of each study topic and is of interest primarily to the technical specialist. In Volume II, the light-duty vehicles (LDVs -- under 6,000-lb GVW) and medium-duty vehicles (MDVs) selected to form the basis of cost factor comparisons are characterized and delineated in Section 2. The specific emission control systems used in LDV and MDV cost calculations, the characteristic or baseline emission levels prior to incorporation of emission control systems, and the lifetime costs attributable to emission control for the LDV and MDV cases considered are presented in Section 3. A comparison and discussion of LDV and MDV cost factors (expressed as dollars expended per ton of pollutant removed) as a function of emission control system type and as a function of percent reduction in emission rate are summarized in Section 4. A brief summary is given in Section 5 of the heavy-duty vehicle (HDV -- over 14,000-lb GVW) cases examined, including baseline emission assumptions and resultant emission control cost factors. A summary overview of emission control cost factors associated with power plants and other stationary sources is presented in Section 6. Section 7 contains a summary presentation and comparison of LDV, MDV, HDV, and stationary source emission control cost factors. A review of numerous transportation planning studies for selected air quality control regions (AQCRs), with emphasis on

vehicle class distribution (LDV, MDV, and HDV) and annual mileage contributions is presented in Section 8. Section 9 includes emission inventories for LDVs, MDVs, and HDVs for the New York City, Los Angeles, and Phoenix/Tucson AQCRs. These inventories reflect the effects of various possible MDV control strategies. Appendix A contains a listing of the companies and agencies contacted in the data acquisition activity. Appendixes B through E contain backup information relative to the study.

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HIGHLIGHTS

An analysis was made that compared the emission control cost factors (expressed as dollars expended per ton of pollutant removed) of medium-duty vehicles[1] with other major mobile sources and with available stationary source cost data. The LDVs and HDVs, utility power plants, and a number of other stationary sources were considered in the cost factor comparisons. The results indicate that, in the mobile source area, exhaust emission control cost factors ($/ton) in general decrease in numerical value as the vehicle weight increases (i.e., MDVs are more cost-effective than LDVs and HDVs are more cost-effective than MDVs). This same size effect was noted in stationary source cost factor comparisons, where the emission control cost factors decreased in numerical value as the system size (or flow rate of the product being controlled) increased. Further, the stationary sources have lower emission control cost factors (for the same pollutant specie) than the smaller mobile sources; therefore, they are the most cost-effective in terms of emission reduction.

The absolute values of the cost factors reported herein for mobile sources are the result of (and proportional to) necessarily assumptive characteristics in three primary areas: (a) the specific emission control systems (ECSs) considered, (b) the baseline vehicle emission levels used, and (c) the method of apportioning costs between pollutant species (HC, CO, and NO_x).

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[1] Three vehicle categories are used in this report: light-duty vehicles (LDVs--under 6000-lb GVW), medium-duty vehicles (MDVs--6,000 to 14,000-lb GVW), and heavy-duty vehicles (HDVs--over 14,000-lb GVW). The distinction between LDVs and light-duty trucks (LDTs) (regulated as per Federal Register, Vol. 38, No. 151, of 7 August 1973, after the decision of the U.S. Court of Appeals) has not been considered in this report. If the general category of MDVs was defined to include LDTs, the relative impact of MDVs on emission inventories would be larger than is indicated in this report.

With regard to the first area, seven different ECSs were considered encompassing the range of potentially available ECSs. They have considerable variance in emission reduction capability (HC, CO, and NO_x) and in overall system costs. As a consequence, they also exhibit widely varying emission control cost factors.

In the second area, the baseline emission levels (i.e., the characteristic emissions of the MDV prior to the incorporation of a given ECS) have a marked effect on the absolute level of cost factor values, since all pollutant reductions are computed as a fixed percentage of the original or baseline emission level for any given ECS. Thus, the higher the baseline emission, the greater the tons of emission reduction and consequently the lower the cost factor ($/ton) for a given ECS with fixed total costs. Two emission baselines were used to encompass the spectrum of reasonably anticipated MDV engine emission characteristics. The first (and higher) emission baseline is based on tests of 1970 to 1973 model year trucks; it is treated herein as an earlier technology baseline inasmuch as MDV engines will be undergoing further modifications to meet the more stringent requirements of the California 1975 HDV emission standards. The second (and lower) MDV emission baseline is based on extrapolations of emission characteristics exhibited by engines used in 1972 model year LDVs.

With regard to the third area, the numerical cost factor value for any given pollutant specie is directly related to the manner of allocating costs to HC, CO, and NO_x. In this study, those component, maintenance, and operating costs traceable to NO_x control were first segregated (principally EGR-related and fuel costs); all other costs were then equally divided[2] between HC and CO. If other apportionment techniques are desired, the individual cost factors developed herein can be easily recalculated. However,

[2]More explicit allocations would require additional analysis and computations. Evaporative costs, for instance, should be allocated exclusively to HC control.

in terms of comparing the mobile sources, this variability in assumptive technique is not very important, since the same assumptions were made for all mobile sources considered (LDVs, MDVs, and HDVs).

To supplement the analysis, vehicle distributions and annual mileage contributions by class (LDV, MDV, and HDV) were determined, and emission inventories were calculated for the New York City, Los Angeles, and Phoenix-Tucson Air Quality Control Regions (AQCRs). These inventories were structured to reflect the effects of various possible MDV control strategies.

The comparative analyses and supplementary examination of vehicle location, use characteristics, and emission inventories in the AQCRs of interest resulted in the following findings.

I. MOBILE SOURCE COMPARISONS

A. Effect of Emission Control System Type and Baseline Emissions

1. The cost factor variability with ECS type is wide; therefore, caution should be observed when comparing on the basis of discrete cost factors. This variability is illustrated in Table 1 for an MDV (at 6000-lb inertia test weight) as equipped with the seven different ECS considered in this study.

2. For a given baseline emission level, these cost factor variations between ECS result from the combined interactions of different emission reduction characteristics, different total system costs, and the method of apportionment of costs between HC, CO, and NO_x.

3. The higher HC and CO cost factors shown for the catalytic converter ECS in Table 1 are principally the result of converter replacements at approximately 25,000-mi intervals. Extending this replacement interval would result in commensurately lower cost factors.

4. The higher NO_x cost factors shown in Table 1 for the reduction catalyst system are due to converter replacements at 25,000-mi intervals; whereas the higher NO_x cost factors for the rich thermal reactor ECS are due to very high fuel economy losses (25 percent).

5. Two emission baselines were used in the study because MDV engines are in a state of transition, undergoing modifications to meet the

Table 1. Cost Factor Variability with Emission Control System Type and Emission Baseline--MDV at 6000-lb Inertia Test Weight

EMISSION CONTROL SYSTEM TYPE[1]	COST FACTOR, $/ton[2][3]								TOTAL LIFETIME SYSTEM COSTS, $[3][4]
	EARLIER TECHNOLOGY EMISSIONS BASELINE				1972 LDV TECHNOLOGY EMISSIONS BASELINE				
	HC	CO	NO_x	HC + CO + NO_x	HC	CO	NO_x	HC + CO + NO_x	
No. 2 -- IMPROVED CARBURETION	328	23	690	103	978	67	1282	291	415
No 3 -- OXIDATION CATALYST	553	48	690	148	1660	141	1282	342	871
No. 4 -- OXIDATION AND REDUCTION CATALYSTS	553	48	1260	215	1660	141	2340	600	1682
No. 5 -- ELECTRONIC FUEL INJECTION PLUS TRICOMPONENT CATALYST	469	40	364	106	1403	120	675	295	825
No. 6 -- LEAN THERMAL REACTOR	195	13	655	88	585	40	1220	249	518
No. 7 -- RICH THERMAL REACTOR	137	17	1400	199	412	52	2600	555	1267
No. 8 -- ADVANCED LEAN CARBURETION	298	22	288	65	892	67	534	185	414

(1) THE IDENTIFICATION NUMBER CORRESPONDS TO THAT ASSIGNED BY CALSPAN CORPORATION IN REPORT ZP-5223-k-1; THE NAME REFERS TO THE PRINCIPAL OR DIFFERENTIATING FEATURE -- ALL SYSTEMS HAVE EGR

SOME OF THE VALUES PRESENTED IN THIS TABLE ARE BASED ON INCOMPLETE DATA AND SHOULD NOT BE TAKEN AS CONCLUSIVE. DATA FOR SYSTEMS Nos. 2 AND 3 ARE RELATIVELY BETTER DOCUMENTED

THIS TABLE ASSUMES, IN ALL CASES, A DURABILITY FACTOR OF 1

(2) COST FACTOR = DOLLARS EXPENDED PER TON OF POLLUTANT REMOVED OVER VEHICLE LIFETIME

(3) CATALYSTS WERE CHANGED AT 25,000 mi INTERVALS

(4) INITIAL PLUS MAINTENANCE PLUS FUEL COSTS; COSTS ARE ASSUMED TO BE INDEPENDENT OF BASELINE EMISSION LEVEL ASSUMPTIONS

increasingly lower levels of emission standards as prescribed by the federal government and the State of California for engines used in vehicles over 6000-lb GVW. These two baselines were selected to encompass the spectrum of reasonably anticipated MDV engine emission characteristics prior to the addition of the seven specific ECSs evaluated; they are depicted in Figure 1 for HC. The CO and NO_x baselines have different absolute levels, but their slopes are similar to those shown for HC.

6. Cost factors based on the 1972 LDV technology emissions baseline are from two to three times higher than similar cost factors based on the earlier (1970 to 1973 MDVs) technology emissions baseline (Table 1). This reflects the fact that the 1972 LDV technology emissions, prior to adding any of the seven ECS, are two to three times lower than the earlier technology baseline emissions, thus giving lower values for emission reductions over the vehicle lifetime. Since the total system costs are assumed to be independent of the baseline emission levels, the cost factors vary directly and inversely with baseline emission values.

B. Effect of Vehicle Weight

1. As illustrated in Table 2, both HC and CO cost factors decrease as the vehicle inertia test weight increases. Although Table 2 is based on a single ECS (1975-type passenger car oxidation catalyst system) and the 1972 LDV technology emission baseline, similar trends with vehicle weight occur for all ECS examined, and for both emission baselines examined.

2. This result of decreasing HC and CO cost factor with increasing vehicle weight results from the fact that the baseline emissions increase in level as the vehicle weight increases (shown in Figure 1). Since pollutant reductions for a given ECS were computed as a fixed percentage of the baseline emission level, as the vehicle weight increases the tons of emission reduction increase commensurately, thus giving lower cost factors ($/ton), since the HC and CO related costs were independent of vehicle weight for the cases considered in Table 2.

3. On the other hand, NO_x cost factor variation with vehicle weight is strongly influenced by the baseline emission level selected for comparison. As shown in Table 2, based on the 1972 LDV technology baseline, the NO_x cost factors increase in numerical value as vehicle weight increases until approximately 11,000 lb, where the trend is reversed. This occurs because all fuel economy losses were attributed to NO_x control. The variation of fuel economy with vehicle weight used in the analysis has a continually decreasing rate of loss of fuel economy with increasing weight (e.g., less change in fuel economy

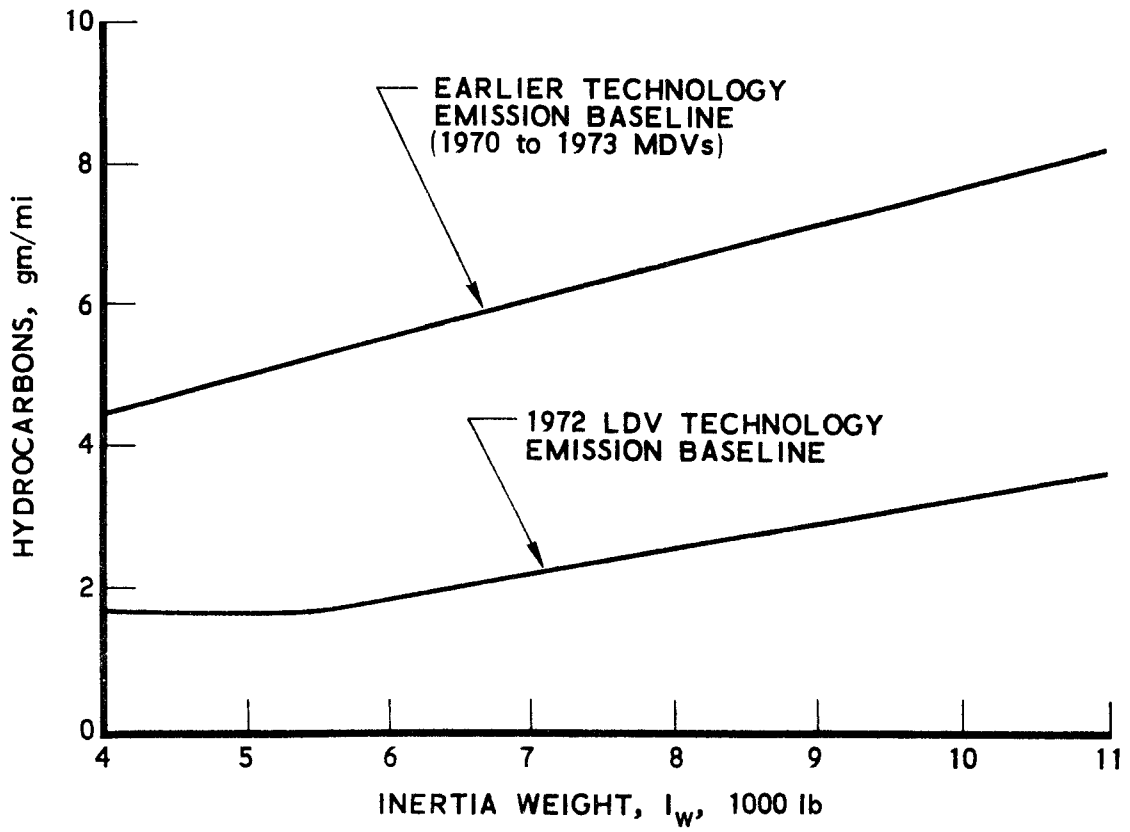

Figure 1. Variation in Baseline Emission Level with Vehicle Test Weight--HC Emissions

from 13,000 to 14,000 lb than from 9,000 to 10,000 lb). The interaction of the fuel economy characteristic line and the NO_x baseline emission level slope thus results in the NO_x cost factor shown in Table 2.

4. However, when comparing with the earlier technology NO_x baseline emission (Table 2), the higher absolute value and steeper slope of the NO_x emission line overrides the fuel economy characteristic noted above and results in NO_x cost factor variations which decrease as vehicle weight increases, as for the case of HC and CO mentioned previously.

C. Gasoline Versus Diesel Powered HDVs

1. Comparison of gasoline- and diesel-powered HDVs on a simple cost factor basis can be misleading because of their inherently different

Table 2. Cost Factor Variability with Vehicle Weight--1972 LDV Technology Emission Baseline (Oxidation Catalyst and EGR Control System)

VEHICLE INERTIA TEST WEIGHT, lb	EMISSION CONTROL COST FACTOR, $/ton		
	HC	CO	NO_x
4,500	1810	180	1215 (1117)
6,000	1660	141	1282 (690)
9,000	1060	60	1350 (643)
11,000	850	43	1360 (617)
14,000	654	30	1300 (560)

VALUES IN PARENTHESES ARE BASED ON EARLIER TECHNOLOGY NO_x EMISSIONS BASELINE

fuel economy characteristics. If the diesel fuel economy advantage is not considered in the cost equation, diesel-powered HDV HC and CO cost factors are in the same general range as those for a gasoline-powered HDV with an oxidation catalyst plus EGR ECS, $243/ton and $20/ton, respectively. If the diesel fuel economy advantage is included, diesel HC and CO cost factors become negative, -$921/ton and -$76/ton, respectively. With EGR, the direct-injection diesel-powered HDV has a NO_x cost factor (approximately $210/ton) in the same general range as gasoline-powered HDV NO_x cost factors.

II. MOBILE AND STATIONARY SOURCE COST FACTOR COMPARISONS

1. Mobile source NO_x control cost factors are appreciably higher than stationary source NO_x cost factors, with typical values of $500 to $1300/ton. Comparable stationary source NO_x cost factors are generally less than $100/ton.

2. Mobile source CO control cost factors, although relatively low in numerical value ($30 to $200/ton), are still considerably higher than the single value of less than $2/ton obtained for the stationary source CO boiler.

3. Mobile source HC control cost factors ($400 to $1800/ton) are much higher than cost factors for stationary source bulk treatment methods for HC control (e.g., storage tanks, bulk loading facilities, and service station holding tank methods with cost factors of $15 to $119/ton). However, service station refueling HC control systems have cost factors in the same general range as mobile source values ($200 to $1400/ton).

4. In all cases permitting comparisons, mobile or stationary source, it is observed that emission control cost factors ($/ton) decrease in value as the system or vehicle size and/or throughput (flow rate of product being controlled) increases. Size effects alone indicate that, in general, stationary source emission control is more cost-effective than mobile source emission control.

III. VEHICLE LOCATION CHARACTERISTICS

1. Recent vehicle location surveys for three AQCRs (New York City, Los Angeles, Phoenix-Tucson) depict the characteristic that trucks decrease as a percentage of total vehicles as the area involved increases in population density (Table 3). This trend is reversed in very small, highly populated, traffic-congested areas such as Manhattan, New York. Here, the percent of trucks increases, apparently because of the need to provide goods and services for the many people in the area and the concurrent difficulty of owning, storing, and/or operating passenger cars in such areas.

Table 3. Vehicle Registration Breakdown by Location--1 July 1972

Based on 1 July 1972 cars in operation and trucks in operation surveys by R. L. Polk Company.

PARAMETER	LOCATIONS					
	NATION	NEW YORK CITY AREAS			SOUTH COAST AIR BASIN AQCR (Los Angeles)	PHOENIX-TUCSON AQCR
		NEW YORK CITY AQCR	NEW YORK CITY (Five Boroughs)	MANHATTAN (New York County)		
TOTAL NUMBER OF VEHICLES	106,211,895	6,637,845	1,772,355	220,614	5,802,658	941,697
PERCENT AUTOMOBILES	81.38	92.1	93.47	86.09	83.75	75.91
PERCENT TRUCKS	18.62	7 91	6 53	13.91	16.25	24.09
PERCENT OF TOTAL TRUCKS BY WEIGHT CLASS						
0 TO 6,000-lb GVW	64.79	51 20	40.22	32.74	59.55	73.40
6,000 TO 14,000-lb GVW	19.09	18 89	19 91	18.86	29.70	18.50
OVER 14,000-lb GVW	16.12	29.91	39.87	48.40	10.75	8.10

2. The distribution of LDTs appears to vary uniformly and inversely with population density.

3. Except for the Los Angeles AQCR, the MDV distribution as percent of total trucks appears not to be strongly affected by population density, but rather to remain near the national average of approximately 19 percent. In the Los Angeles case, where the MDV percentage of total trucks is approximately 30 percent, this anomaly may be the result of the widespread use of heavier campers and motor homes for recreational purposes.

4. The HDVs increase in distribution as percent of total trucks in accordance with increasing population density. This may be the logical result of the need for heavy trucks to move goods into the densely populated areas in accordance with the number of inhabitants involved.

IV. EMISSION INVENTORY EFFECTS

1. Four cases or possible strategies for MDV and HDV emission control were examined to calculate emission inventories from 1970 to 1990 for the three AQCRs considered. The principal features of these emission control strategies and their corresponding LDV, MDV, and HDV emission levels are summarized in Table 4.

2. With no further emission control beyond the presently established LDV regulations (including the 1976 LDV regulations) and the 1974 Federal HDV standards (for all vehicles over 6000-lb GVW), emissions in the 1985 to 1990 period are reduced to approximately 25 to 30 percent of 1970 levels. This is illustrated for the HC inventory in the New York City AQCR as Strategy No. 1 in Figure 2. Similar trends occur for CO and NO_x, and for the Los Angeles and Phoenix-Tucson AQCRs.

3. Implementation of MDV and HDV emission standards equivalent to the California 1975 HDV standards in the 1975 to 1977 period (Strategy No. 2) results in a further sizeable reduction for all three pollutants. This is illustrated in Figure 2 where the 1990 HC inventory is approximately 15 percent of the 1970 value. This assumes, although it may well not be the case, that emission reductions for the current nine mode HDV engine dynomometer procedure are representative of actual vehicle emission reductions.

4. The addition of oxidation catalysts (in 1977 to 1979) and reduction catalysts (in 1980 to 1982) to MDVs has relatively little effect on total emissions by 1990; this is illustrated as Strategies No. 3 and 4, respectively, in Figure 2 for HC. This minimal effect occurs because only MDVs (and not HDVs) are equipped with the catalysts,

Table 4. Control Strategy Emission Levels

STRATEGY NUMBER	EMISSION LEVEL ASSUMPTION								
	LDVs	MDVs				HDVs			
		BASIC FEATURE	EMISSION LEVEL,[1] gm/mi			BASIC FEATURE	EMISSION LEVEL,[1] gm/mi		
			HC	CO	NO_x		HC	CO	NO_x
1	CURRENT FEDERAL LDV REGULATIONS (including the 1976 LDV regulation), ALL FOUR STRATEGIES	1974 FEDERAL HDV STANDARDS	4.25	62.08	6.57	1974 FEDERAL HDV STANDARDS	17.9	179	12.6
2[2]		1975 CALIFORNIA HDV STANDARDS	1.33	38.08	2.06	1975 CALIFORNIA HDV STANDARDS	5.6	112	3.94
3[3][4]		OXIDATION CATALYST ADDED	0.40	4.20	2.06	1975 CALIFORNIA HDV STANDARDS	5.6	112	3.94
4[4][5]		REDUCTION CATALYST ADDED	0.40	4.20	0.45	1975 CALIFORNIA HDV STANDARDS	5.6	112	3.94

(1) VALUES IN gm/mi EITHER BASED ON TEST RESULTS, ON CONVERSION FROM gm/bhp-hr STANDARDS, OR ON ESTIMATES OF CATALYTIC CONVERTER EFFICIENCY

(2) IMPLEMENTED IN CALIFORNIA IN 1975; REST OF UNITED STATES IN 1977

(3) IMPLEMENTED IN CALIFORNIA IN 1977; REST OF UNITED STATES IN 1979

(4) ONLY MDVs ARE REGULATED TO LOWER LEVELS IN STRATEGIES 3 AND 4, i.e. HDVs REMAIN AT 1975 CALIFORNIA HDV STANDARD LEVELS

(5) IMPLEMENTED IN CALIFORNIA IN 1980; REST OF UNITED STATES IN 1982

and they represent a relatively small percent of the total number of vehicles in an AQCR (e.g., MDVs are only 1.5 percent of total vehicles in New York City AQCR), and contribute only a small amount of the total VMT (e.g., MDVs contribute 3.15 percent of the total daily VMT in the New York City AQCR).

5. The various control strategies examined do have a marked effect on the relative percentage contributions of the LDV, MDV, and HDV vehicle classes (shown in Figure 3 and Table 5 for HC in the New York City AQCR). Under Strategy No. 1, HDVs would be contributing as much emissions as LDVs by 1985. Strategy No. 2 would appreciably reduce the HDV contribution, but it would still be approximately three times higher in 1990 than in 1970. Strategies No. 3 and 4 do not further reduce HDV emission levels (apply only to MDV

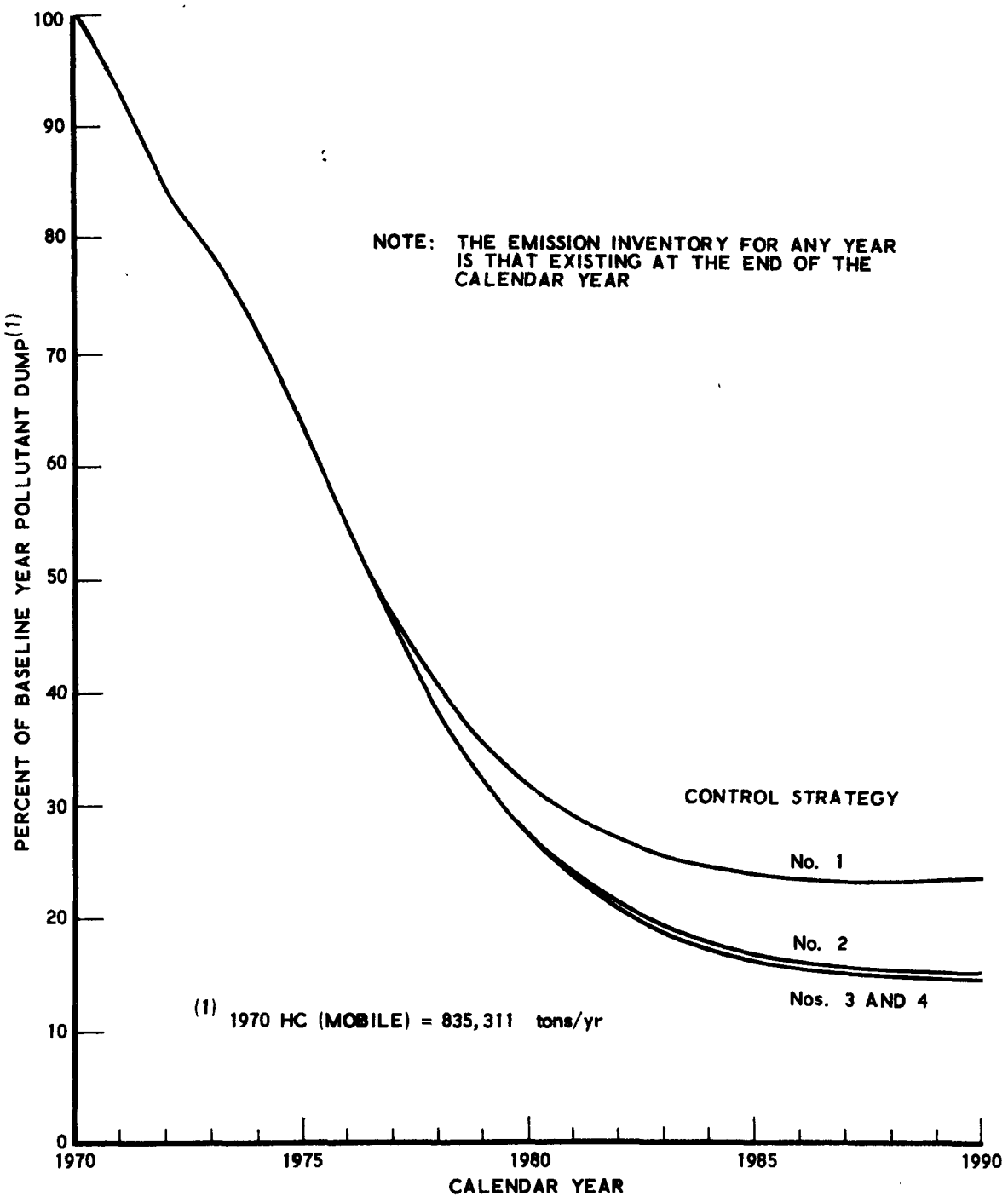

Figure 2. New York City AQCR Mobile Source HC Inventory (Determined Using Anticipated Normal Growth Rates)

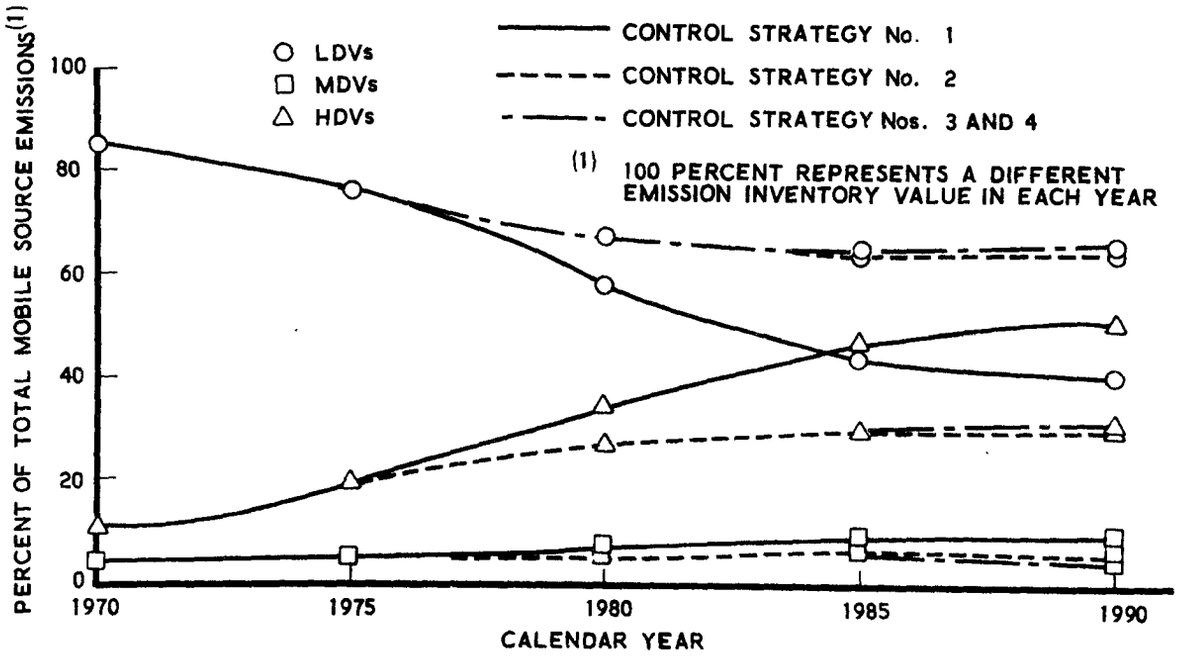

Figure 3. New York AQCR--HC Percentage Contribution of Vehicle Classes (Normal Growth Rates)

emission levels); they would have to be expanded to include HDVs to significantly alter the HDV percentage contribution.

6. In the case of MDVs, their percentage contribution rises steadily from 1970 to 1990 under Strategy No. 1, increasing from 4 to 9 percent as shown in Table 5. This is about 23 percent of the LDV emissions in 1990. Strategy No. 2 reduces 1990 MDV contributions to approximately 6 percent, while Strategies No. 3 and 4 (oxidizing and reducing catalyst in MDVs only) reduce 1990 MDV values to slightly below (approximately 3 percent) 1970 percentage levels.

7. Combined MDV and HDV emissions (vehicles over 6000-lb GVW) exceed LDV HC emissions by approximately 50 percent in 1990 under Strategy No. 1 (Table 5). Under all other strategies examined, the combined percentage of MDV and HDV emissions in 1990 are approximately two times their 1970 percentage levels.

With regard to mobile source emission control, the emission control cost factors clearly illustrate that MDV emission control is cost-effective when compared with LDVs equipped with similar control systems.

Table 5. New York City AQCR Mobile Source HC Distribution by Vehicle Class--1970 and 1990

CONTROL STRATEGY NUMBER	PERCENT OF TOTAL MOBILE SOURCE HC INVENTORY							
	1970				1990			
	LDV	MDV	HDV	MDV AND HDV	LDV	MDV	HDV	MDV AND HDV
1	85	4	11	15	40	9	51	60
2(1)	ALL FOUR STRATEGIES HAVE SAME 1970 BASELINE VALUES			15	64	6	30	36
3(2)				15	66	3	31	34
4(3)				15	66	3	31	34

(1) IMPLEMENTED IN 1977 IN NEW YORK CITY AQCR

(2) IMPLEMENTED IN 1979 IN NEW YORK CITY AQCR

(3) IMPLEMENTED IN 1982 IN NEW YORK CITY AQCR

Further, it is also clear that HDV emission control is even more cost-effective, on a dollars per ton of pollutant removed basis.

Currently, the MDV category is a relatively small contributor of emissions. However, if no additional control beyond that regulated for 1974 is added to MDVs, these vehicles would be large emission contributors. For instance, in the New York City AQCR, MDVs in 1970 emitted an amount of HC which was about 5 percent of the amount emitted by LDVs; however, in 1990 the percentage would grow to about 23 percent of the amount emitted by LDVs.

The HDV emissions are a significant portion of the total emission inventory (e.g., approximately 36 percent of HC inventory in New York

City AQCR in 1990) if emission standards no more severe than the 1975 California HDV standards are implemented. If current Federal 1974 HDV standards persist to 1990, the HDV HC percentage contribution in the New York City AQCR would be approximately 60 percent. Therefore, it would appear that advanced HDV emission control strategies would be also most fruitful to pursue, both on the basis of cost effectiveness and emission inventory reduction potential.

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EXECUTIVE SUMMARY

1. INTRODUCTION

This report presents the results of a cost-effectiveness comparative analysis of medium-duty vehicle [MDV -- 6,000 to 14,000-lb gross vehicle weight (GVW)] emission control systems (ECSs).

The MDVs are currently regulated as heavy-duty vehicles (HDVs -- over 6000-lb GVW) with regard to exhaust emission control (i.e., engine-only dynamometer test procedures). However, they have characteristics that appear to permit certification testing of the complete vehicle over the same driving cycle and using the same emission mass measurement techniques used for LDV (less than 6000-lb GVW) certification testing.

The main topic discussed is the development of emission control cost factors for MDVs [expressed as dollars expended per ton of pollutant removed ($/ton)] and the comparison of these with similarly-developed cost factors for light-duty vehicles (LDVs), HDVs, and various stationary sources. Also included is a review of transportation planning information for the New York City, Los Angeles, and Phoenix-Tucson Air Quality Control Regions (AQCRs), with emphasis on vehicle miles traveled (VMT) distribution by vehicle class (LDV, MDV, and HDV). The effects of various MDV control strategies are illustrated with emission inventories for LDVs, MDVs[1], and HDVs for these three AQCRs.

This volume summarizes the more pertinent information from these analyses; Volume II provides further details about the comparative analysis.

[1]The distinction between LDVs and light-duty trucks (LDTs)(regulated as per Federal Register, Vol. 38, No. 151, of 7 August 1973, after the decision of the U. S. Court of Appeals) has not been considered in this report. If the general category of MDVs was defined to include LDTs, the relative impact of MDVs on emission inventories would be larger than is indicated in this report.

2. SELECTION OF MEDIUM-DUTY VEHICLES AND LIGHT-DUTY VEHICLES FOR COST FACTOR COMPARISONS

The individual cases or characteristic vehicles selected for examination of MDV and LDV emission control cost factors are shown in Table 1. A single vehicle, weighing 4500 lb loaded [inertia test weight (I_w)], was selected to represent the LDV class. Four MDV class vehicles were selected:

a. Truck A -- representing the average GVW (8000 lb) of the 6, 000 to 10, 000-lb GVW class

Table 1. Cases for Cost Factor Comparisons

CHARACTERISTICS	VEHICLES				
	LDV	MDV			
		TRUCK 'A'	TRUCK 'B'	MOTOR HOME	TRUCK 'C'
GROSS VEHICLE WEIGHT, lb	<6000	8000 (ave.) of 6-10,000)	12,000 (ave. of 10-14,000)	13,000	14,000
GCW + f(GVW-GCW), lb	4500	6200	8700	11,050	14,000 (fully loaded)
I_w, lb	4500[1]	6000	9000	11,000	14,000[2]
ENGINE, CID	350[1]	350	350	350	350
FUEL ECONOMY, mpg (over Federal Driving Cycle)	12.0	10.0	7.25	6.2	5.4

[1] SALES-WEIGHTED VALUES FOR 1972 STANDARD SIZE CAR ARE: I_w = 4800 lb; CID = 371.4 cu in.

[2] REPRESENTS A FULLY-LOADED MDV OR A PARTIALLY-LOADED HDV

b. Truck B -- representing the average GVW (12, 000 lb) of the 10, 000 to 14, 000-lb GVW class

c. Motor Home -- at 13, 000-lb GVW representing the class of larger motor homes becoming increasingly popular in recent years

d. Truck C -- at 14, 000-lb I_W representing a fully loaded upper GVW weight class MDV; at this I_W value it also represents partially-loaded lower GVW range HDVs (e. g., 16, 000 to 19, 500-lb GVW HDV class)

The inertia test weight of trucks A and B and the motor home were determined from a correlation of GVW as a function of I_W relationships of vehicles tested in the MDV baseline emission characterization program recently conducted by EPA.

A single engine size [350-cu in. displacement (CID)] was selected for all five vehicles to remove instances of engine-size-related variability in the cost factor calculations. This engine size is frequently used in both the MDV and LDV classes.

The fuel economy characteristics (mpg) for the five vehicles in Table 1 are based on a consistently varying fuel economy versus I_W characteristic for a 350-CID engine.

In summary, the cases selected (Table 1) represent "reasonable" vehicles for the LDV class and the MDV GVW spectrum (6, 000 to 14, 000 lb). In addition, the motor home at I_W = 11, 000 lb and truck C at I_W = 14, 000 lb may also characterize a portion of the HDV class (GVW over 14, 000 lb) at small or intermediate payload weights.

3. CANDIDATE EMISSION CONTROL SYSTEMS AND BASELINE EMISSION LEVELS

The determination of cost factors resulting from the incorporation of emission control systems (ECS) to reduce exhaust emissions requires the examination of several important variables. These cost factors, expressed as dollars expended per ton of pollutant removed ($/ton), depend not only on

the particular ECS employed, but also on the "baseline" vehicle emission level (i. e., the characteristic emissions of the vehicle prior to the incorporation of a given ECS).

3. 1 CANDIDATE EMISSION CONTROL SYSTEMS

A technical evaluation of various emission control approaches for MDVs was recently completed for EPA by the Calspan Corporation. The Calspan report describes in detail the characteristics of eight ECSs for possible application to MDVs. Seven of these ECS were selected for cost factor comparisons in the present study (ECS No. 2 through No. 8); the components involved and the principal or differentiating feature of each are described in Table 2. The characteristics of these ECSs in terms of resultant exhaust emissions and postulated attendant fuel economy reductions are also shown in the table. Some of the values presented in this table are based on incomplete data and should not be regarded as conclusive. Data for systems Nos. 2 and 3 are relatively better documented.

3. 2 BASELINE EMISSION LEVELS

The selection of a meaningful baseline emission level (or levels) is of extreme importance. Pollutant reductions attributed to a given ECS are measured directly from baseline values; therefore, resulting cost factors ($/ton pollutant removed) are directly proportional to the baseline emission level. Because of this relationship, the widest possible data base was examined and analyzed prior to selecting baseline emission levels. Several discrete data sources were available, as discussed below.

3. 2. 1 Calspan MDV Correlations

Calspan performed correlation analyses of the emission data generated in the recently conducted EPA MDV emission characterization program. Regression analyses of 76 1970 to 1973 model year truck emission data samples resulted in the truck HC correlation line shown in Figure 1. The CO and NO_x correlations exhibited slope characteristics similar to those shown for HC, but with different absolute levels (omitted

Table 2. Candidate Emission Control Systems

No.	DESCRIPTION	EMISSION FACTOR[1] "R"			FUEL REDUCTION ECONOMY, PERCENT	PRINCIPAL FEATURE[2]
		HC	CO	NO_x		
2	EI + IC + QHI + AI + EGR	0.65	0.55	0.60	5	IMPROVED CARBURETION
3	EI + IC + QHI + EGR + AI + OC	0.18	0.15	0.60	5[3]	OXIDATION CATALYST
4	EI + IC + QHI + EGR + RC + AI/CAI + OC	0.18	0.15	0.10	12	OXIDATION AND REDUCTION CATALYSTS
5	EI + EFIC + EGR + RC/OC	0.18	0.15	0.10	3	ELECTRONIC FUEL INJECTION WITH TRICOMPONENT CATALYST
6	EI + IC + QHI + EGR + LTR	0.50	0.35	0.375	8	LEAN THERMAL REACTOR
7	EI + FC + EGR + AI + RTR	0.08	0.35	0.17	25	RICH THERMAL REACTOR
8	EI + FIC + IQHI + AI + EGR	0.40	0.30	0 35	3	ADVANCED LEAN CARBURETION

(1) $$\text{"R"} = \frac{\text{EMISSIONS AFTER CONTROL SYSTEM ADDED}}{\text{BASELINE EMISSIONS BEFORE CONTROL SYSTEM ADDED}}$$

SOME VALUES PRESENTED IN THIS TABLE ARE BASED ON INCOMPLETE DATA AND SHOULD NOT BE REGARDED AS CONCLUSIVE. DATA FOR SYSTEMS NOS. 2 AND 3 ARE RELATIVELY BETTER DOCUMENTED

(2) ALL SYSTEMS HAVE EXHAUST GAS RECIRCULATION SYSTEMS

(3) DIFFERS FROM 8 PERCENT USED BY CALSPAN CORPORATION

EI = ELECTRONIC IGNITION
IC = IMPROVED CARBURETION
QHI = FAST WARM-UP INTAKE MANIFOLD
IQHI = ADVANCED INTAKE MANIFOLD
AI = AIR INJECTION
CAI = AIR INJECTION INTO OXIDATION CATALYST
EGR = EXHAUST GAS RECIRCULATION
OC = OXIDATION CATALYST
RC = REDUCTION CATALYST
RC/OC = TRICOMPONENT CATALYST (TRI)
FC = FAST CHOKE
FIC = ADVANCED LEAN CARBURETION
LTR = LEAN THERMAL REACTOR
RTR = RICH THERMAL REACTOR

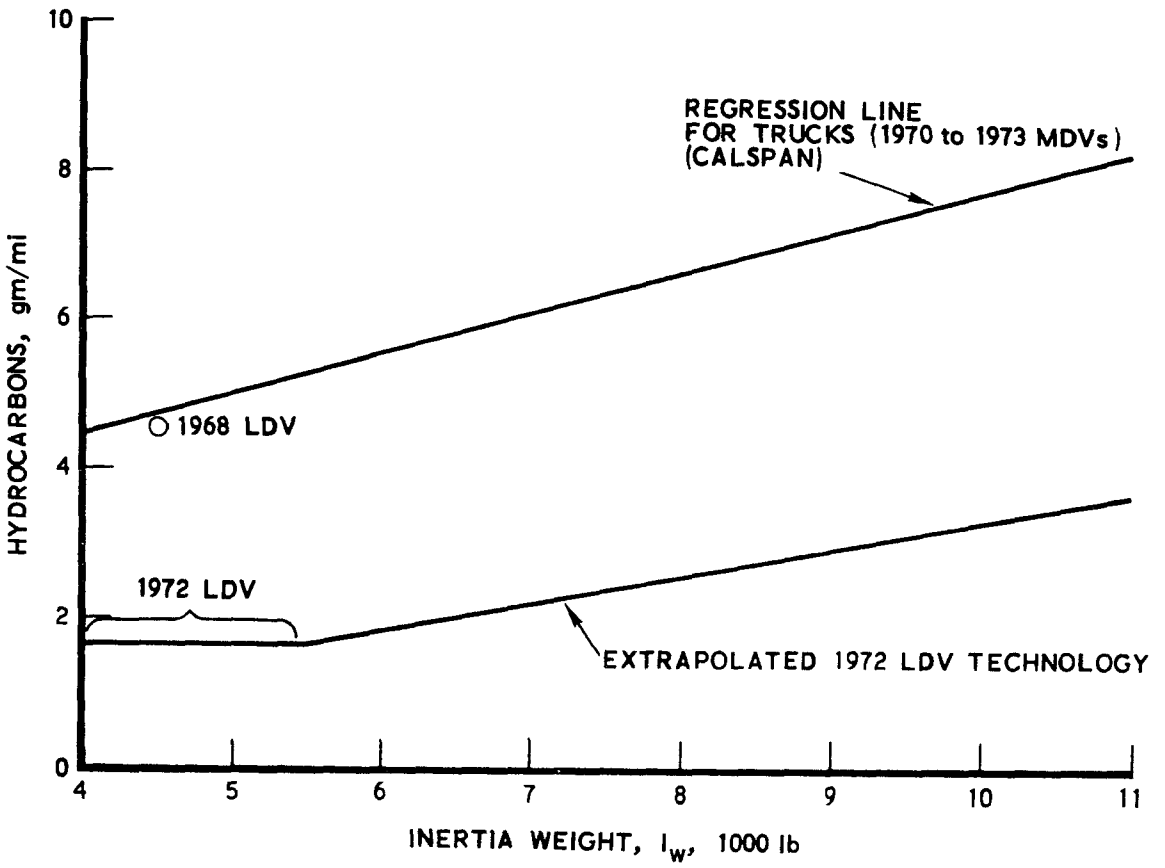

Figure 1. Hydrocarbon Emission Baselines Used for Cost Comparisons

here for brevity). These 76 trucks encompassed the I_W range from 4, 500 lb to 10, 000 lb, with an average I_W of approximately 5, 740 lb. They consisted of a composite of tuned and untuned vehicle tests.

3. 2. 2 The 1972 LDV Technology Trends

Another emissions data base examined is that characteristic of 1972 LDV engines. In this regard, Calspan reported the following values (corrected for the 1975 Federal Test Procedure) for a large sample of LDVs.

$$HC = 1.70 \text{ gm/mi}$$
$$CO = 16.50 \text{ gm/mi}$$
$$NO_x = 4.00 \text{ gm/mi}$$

Of interest was the variation in emission rate that would occur if LDV engines with these emission certification characteristics were used in MDVs, on the basis or assumption that such engines probably represent the best available engine technology prior to the incorporation of specific ECS components as exemplified by ECS No. 2 through No. 8. Data from a ten-truck test program conducted by EPA in June through August 1972 were used to provide this variation of emission rate with I_w characteristic.

Each of the ten trucks was tested at inertia weights corresponding to 0, 25, 50, and 100 percent load. From these data, the average rate of change of emission rate with a change of I_w was determined. A hypothetical "1972 LDV technology baseline" variation of emission rate with I_w was constructed (see Figure 1) which consisted of the 1972 LDV emission certification level up to I_w = 5500 lb plus a variation with I_w above 5500 lb per the delta emission/delta I_w slope factor as determined from the EPA ten-truck test series. It is estimated that this characteristic would represent the lowest obtainable emissions with MDV engines incorporating the types of engine modifications made to date for LDVs (e. g., combustion chamber, ignition timing, and spark retard) and without the incorporation of emission control systems as illustrated in Table 2.

3. 2. 3 Final Emission Baseline Selections

The truck emission correlation developed by Calspan from the EPA MDV emissions characterization program was used to represent the MDV class prior to the addition of specific ECSs. It is treated herein as an "earlier" technology baseline inasmuch as HDV engines will be modified to meet the more stringent requirements of the California 1975 HDV standards. A second emission level baseline was also used -- the extrapolated 1972 LDV technology emission characteristics. It is considered that these two baselines encompass the spectrum of MDV emission characteristics that can be reasonably expected of MDVs that do not have the specific ECSs of Table 2 applied to them. Hence, by computing cost factors based

on these two baselines, the range of reasonably expected cost factors will be obtained.

The two selected emissions baselines are summarized in Figure 1 for HC. Also shown, for comparison purposes, are characteristic 1968 LDV HC emission values, which can be considered representative of "earlier" technology LDVs.

3.3 EMISSION CONTROL SYSTEM COSTS

In developing the ECS costs reported herein, the initial hardware costs and maintenance cost assumptions as reported by Calspan were used. These ECSs and their costs were applied to both the LDV and MDV cases of Table 1.

Since cost factor determination is based on emission reduction, it was necessary to compute both costs and emission reductions over the complete vehicle lifetime to amortize the effects of initial hardware costs. The average lifetime of passenger cars has been previously reported as 8.4 years and 85,000 mi. For the MDV, or truck case, similar data were not available; therefore, an analysis of average truck lifetime values was performed. The average truck lifetime was found to be approximately 12.6 years and the average single-unit truck lifetime mileage was computed to be approximately 110,000 mi.

3.3.1 Cost Summaries

A summary of ECS initial costs is given in Table 3. They apply for both the LDV and MDV cases examined, since all LDVs and MDVs use a 350-CID engine. To determine cost factors ($/ton pollutant removed) for each exhaust species (HC, CO, and NO_x), it was necessary to apportion costs on this basis. The following assumptions were made in this regard.

a. One-third of the costs of electronic ignition, testing or inspection[2] and tricomponent catalysts was allocated to each constituent (HC, CO, and NO_x).

[2]Testing or inspection may or may not be required; if required, costs may be different from those assumed.

Table 3. Emission Control System Initial Cost Summary -- LDV or MDV (350-CID Engine)

COMPONENTS	CALSPAN No.						
	2	3	4	5	6	7	8
ELECTRONIC IGNITION (EI)(1)	20	20	20	20	20	20	20
FAST CHOKE (FC)						5	
QUICK HEAT INTAKE (QHI)	5	5	5		5		5
IMPROVED CARB. (IC)	10	10	10		10		
ADVANCED CARB. (AC)							30
ELECTRONIC FUEL INJ. (EFI)				100			
EXHAUST GAS RECIRC - (EGR)(2)	30	30	30	30	30	30	30
THERMAL REACTOR (LTR/RTR)					59	59	
AIR INJECTION (AI)	38	39	39			38	38
OXIDIZING CATALYST (OC)		69	70				
REDUCING CATALYST (RC)			90(2)				
TRICOMPONENT CATALYST (TRI)				67(1)			
CATALYST BYPASS		10	10	10			
EVAPORATIVE CONTROL SYSTEM (EVAP. CS)	14	14	14	14	14	14	14
TESTING OR INSPECTION(1)(3)	7	7	7	7	7	7	7
TOTAL	124	204	295	248	145	173	144
HC/CO RELATED	85	165	166	187	106	134	105
NO_x RELATED	39	39	129	61	39	39	39

(1) 1/3 COST ALLOCATED TO EACH CONSTITUENT (HC, CO, NO_x)

(2) COST ALLOCATED TO NO_x CONTROL ONLY

(3) MAY OR MAY NOT BE REQUIRED; COSTS MAY BE DIFFERENT THAN THOSE ASSUMED

b. Exhaust gas recirculation system and reducing catalyst costs were allocated to NO_x control only.

c. All other costs were allocated to HC/CO control and were divided equally between HC and CO.

Maintenance costs are summarized in Table 4 for the LDV and in Table 5 for the MDV. The maintenance assumptions are the same for both cases and are based on the Calspan report. The resulting LDV and MDV cost differences are related to the different average lifetime values, as shown. The assumptions made in apportioning maintenance costs to HC, CO, and

Table 4. Maintenance Costs for ECS -- LDV with 350-CID Engine (8.4 years and 85,000 mi)

MAINTENANCE ASSUMPTIONS, $/mi	COMPONENT	CALSPAN No. 2	3	4	5	6	7	8
-60/50,000 (1)	EI	-102	-102	-102	-102	-102	-102	-102
NONE REQUIRED	FC							
NONE REQUIRED	QHI							
15/50,000	IC	26	26	26		26		
45/50,000	AC							77
28/50,000	EFI				48			
4/10,000 (2)	EGR	34	34	34	34	34	34	34
NONE REQUIRED	LTR/RTR							
10/25,000	AI	34	34	34			34	34
107/25,000 (3)	OC		214	214				
143/25,000 (3)	RC			286 (2)				
110/25,000 (3)	TRI				220 (1)			
5/10,000	BYPASS		42	42	42			
12.50/25,000 (1)	EVAP. CS	42	42	42	42	42	42	42
3/YEAR	INSPECTION	25	25	25	25	25	25	25
TOTAL		59	315	601	309	25	33	110
HC/CO RELATED		51	307	307	228	17	25	102
NO_x RELATED		8	8	294	81	8	8	8

(1) 1/3 OF COST OR SAVINGS ALLOCATED TO EACH CONSTITUENT (HC, CO, NO_x)
(2) COST ALLOCATED TO NO_x CONTROL ONLY
(3) CONVERTERS CHANGED AT 25,000 AND 50,000 mi ONLY

NO_x were similar to the initial cost allocations. The maintenance costs for catalytic converter replacements were based on the replacement intervals stated in the tables.

The lifetime fuel costs for the LDV and MDV cases are summarized in Table 6. The fuel economy values shown conform to Table 1 and the fuel economy penalties attributed to emission control are based on Table 2. The basic fuel cost used, 38¢/gallon, is considered a nominal value. In all cases, all fuel cost penalties were allocated to NO_x control.

Table 5. Maintenance Costs for ECS -- MDV with 350-CID Engine (12.6 years and 110,000 mi)

MAINTENANCE ASSUMPTIONS, $/mi	COMPONENT	CALSPAN No.						
		2	3	4	5	6	7	8
-60/50,000 (1)	EI	-132	-132	-132	-132	-132	-132	-132
NONE REQUIRED	FC							
NONE REQUIRED	QHI							
15/50,000	IC	33	33	33		33		
45/50,000	AC							99
28/50,000	EFI				62			
4/10,000 (2)	EGR	44	44	44	44	44	44	44
NONE REQUIRED	LTR/RTR							
10/25,000	AI	44	44	44			44	44
107/25,000 (3)	OC		321	321				
143/25,000 (3)	RC			429(2)				
110/25,000 (3)	TRI				330(1)			
5/10,000	BY,PASS		55	55	55			
12.50/25,000 (1)	EVAP. CS	55	55	55	55	55	55	55
3/YEAR	INSPECTION	38	38	38	38	38	38	38
TOTAL		82	458	887	452	38	49	148
HC/CO RELATED		69	445	445	329	25	36	135
NO_x RELATED		13	13	442	123	13	13	13

(1) 1/3 COST OR SAVINGS ALLOCATED TO EACH CONSTITUENT (HC, CO, NO_x)
(2) COST ALLOCATED TO NO_x CONTROL ONLY
(3) CONVERTERS CHANGED AT 25,000; 50,000; AND 75,000 mi ONLY

In summary, the MDV costs are the same as the LDV costs, except for maintenance and fuel cost differentials occasioned by the differences in: average lifetimes, average lifetime mileages, and fuel economy.

4. MEDIUM-DUTY VEHICLE AND LIGHT-DUTY VEHICLE COST FACTOR COMPARISONS

The comparison parameter selected to determine the relative cost effectiveness between emission controls for LDVs, MDVs, HDVs, and

Table 6. Fuel Cost Summary for Vehicle Lifetime (85, 000 mi for LDV and 110, 000 mi for MDV)

PARAMETER	LDV	MDV			
		NO. 1 TRUCK "A" (I_w=6,000)	NO. 2 TRUCK "B" (I_w=9,000)	NO. 3 MOTOR HOME (I_w=11,000)	NO. 4 TRUCK "C" (I_w=14,000)
FUEL ECONOMY, mpg	12.0	10.0	7.25	6.20	5.40
GALLONS USED	7090	11,000	15,170	17,720	20,350
FUEL COST @38¢/gal	$2700	$4185	$5760	$6740	$7740
FUEL PENALTY COST, $					
ECS NO. 2 (5%)	135	209	288	337	387
ECS NO. 3 (5%)	135	209	288	337	387
ECS NO. 4 (12%)	324	500	690	810	929
ECS NO. 5 (3%)	81	125	173	202	232
ECS NO. 6 (8%)	216	335	461	540	619
ECS NO. 7 (25%)	675	1045	1440	1685	1935
ECS NO. 8 (3%)	81	125	173	202	232

stationary sources is the $/ton of pollutant removed over the vehicle and/or control system lifetime. In the case of mobile sources, cost factors were determined for the following pollutants and combinations: HC, CO, NO_x, and HC + CO + NO_x.

4.1 COMPARISONS BY EMISSION CONTROL SYSTEM TYPE

Figures 2 and 3 illustrate the variance of emission control cost factor with MDV I_w for ECS No. 2 and No. 3[3] when applied to engines

[3]Similar data for ECS No. 4 through No. 8 are not displayed here for purposes of brevity; their trend results are generally similar to Figures 2 and 3.

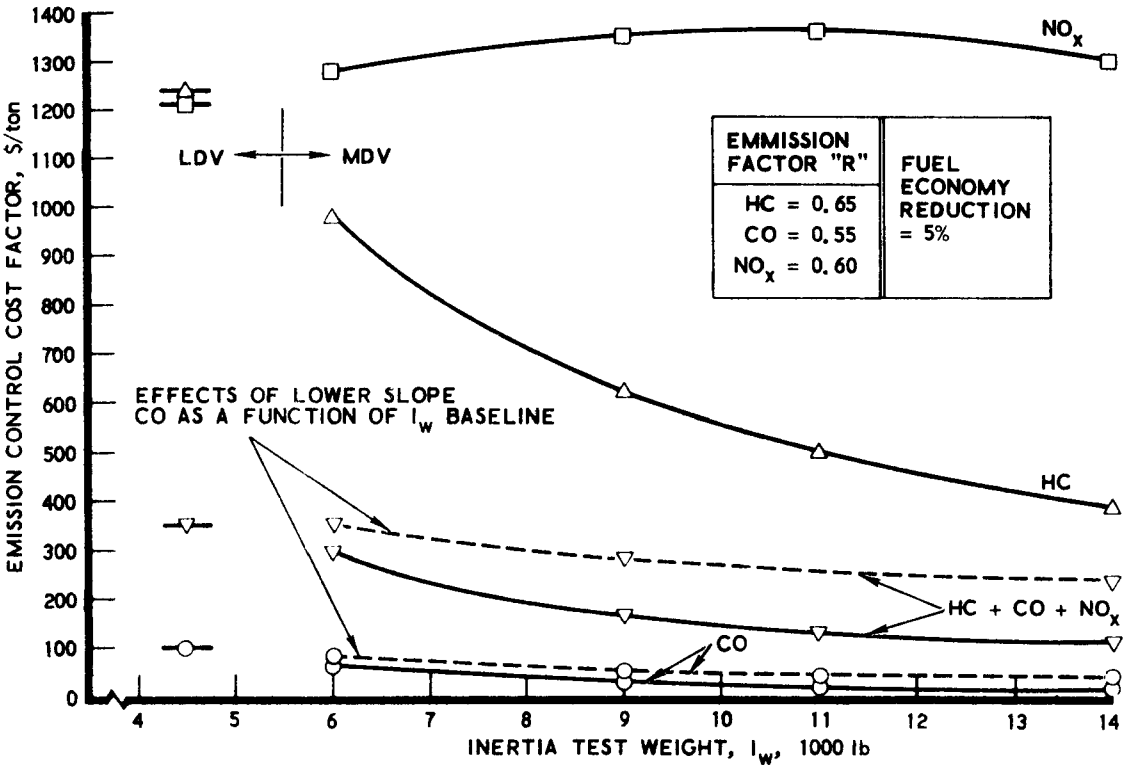

Figure 2. Cost Factors for ECS No. 2 -- 1972 LDV Technology Baseline (EI + IC + QHI + AI + EGR)

conforming to 1972 LDV technology baseline characteristics. The symboled points represent the MDV cases of Table 1; the comparison LDV case at I_w = 4500 lb. is also shown. The HC, CO, and HC + CO + NO_x cost factors decrease with increasing I_w and are less than the LDV cost factors of the same type. These cost factors would be expected to decrease as I_w increases, since the costs involved are nearly independent of I_w and the emission reductions increase in numerical value as I_w increases. This is because of the positive slope (relative to I_w) of the baseline emissions assumptions (Figure 1). The effects of an "alternate" 1972 LDV technology

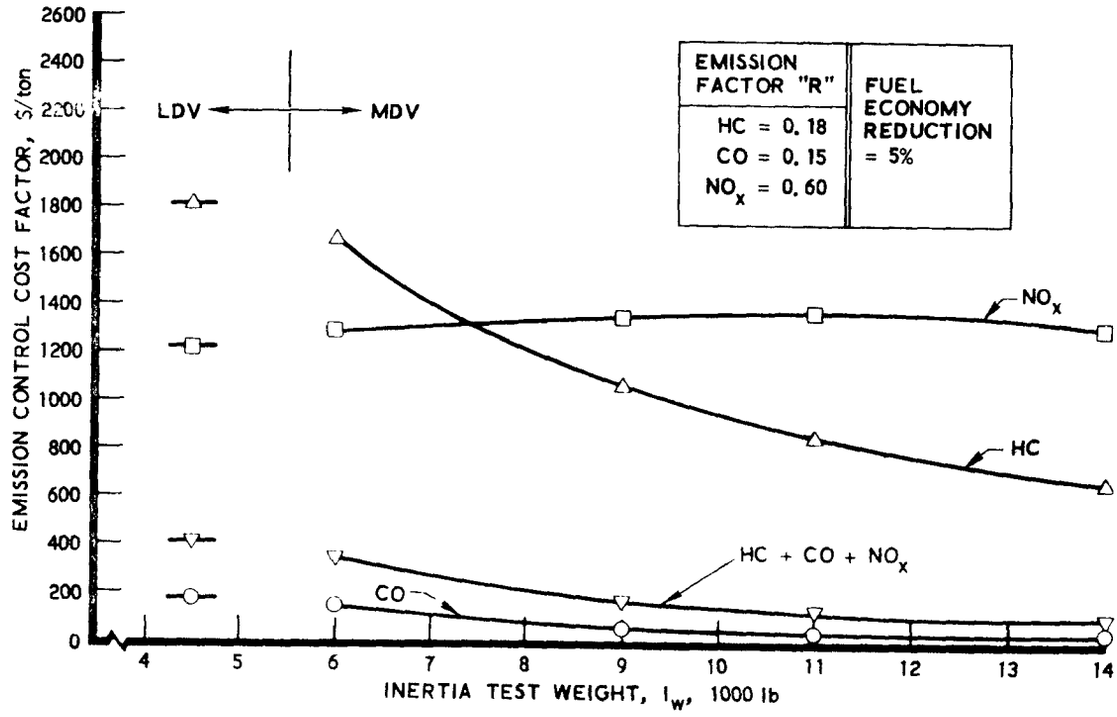

Figure 3. Cost Factors for ECS No. 3 -- 1972 LDV Technology Baseline (EI + IC + QHI + EGR + AI + OC)

CO baseline slope are also depicted in Figure 2. The absolute value of the cost factor (CO, HC + CO + NO_x) is higher (due to the lower slope of the alternate CO baseline); however, the MDV cost factors are still lower than for the LDV case.

The NO_x cost factors, however, vary with MDV I_w discretely with ECS type and vary in absolute value from slightly below LDV values to slightly above LDV values. The shape of the NO_x cost factor curves is a result of the combined interactions of NO_x baseline emission level slope, variations in NO_x emission factor "R," and the shape of the fuel economy

as a function of I_w characteristic (decreasing rate of change of fuel economy as I_w increases).

Similar cost factor results are shown in Figures 4 and 5 for ECS No. 2 and No. 3 when applied to engines conforming to the earlier technology emissions baseline. On this basis of comparison, even the NO_x cost factor for MDVs is below the LDV value. This is because the MDV NO_x baseline emissions are considerably higher than the LDV NO_x emission rate selected as comparable in terms of technology level, thus giving greater NO_x reductions (for the same ECS type and NO_x "R" factor) and concomitant lower NO_x cost factors.

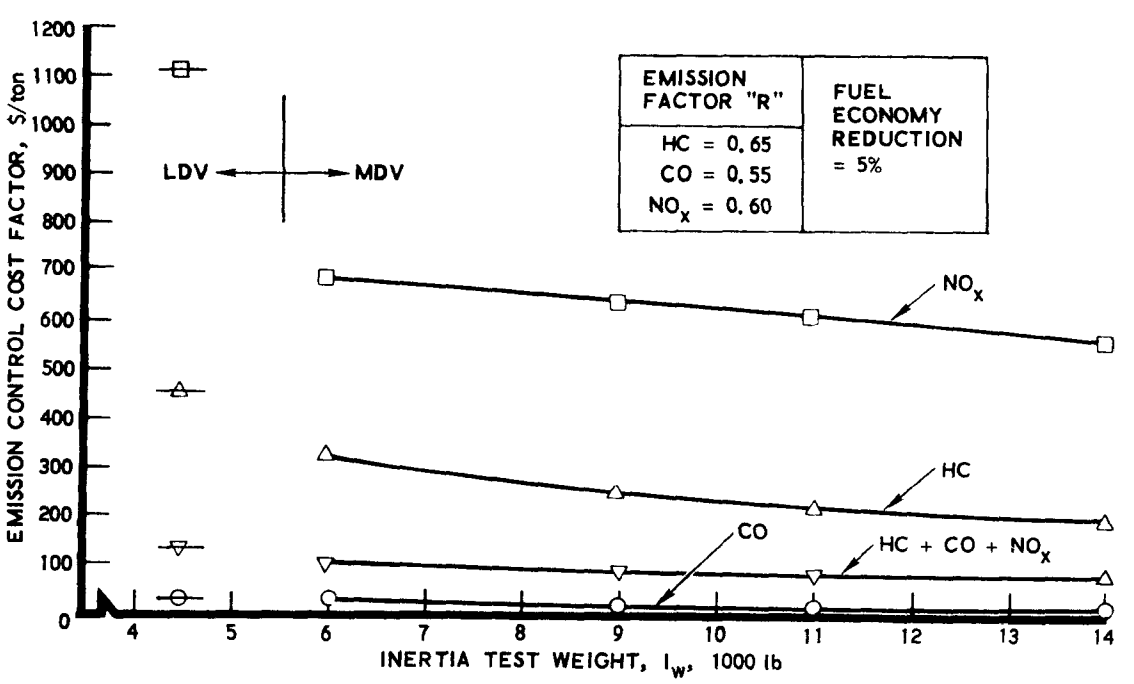

Figure 4. Cost Factors for ECS No. 2 -- Earlier Technology Baseline (EI + IC + QHI + AI + EGR)

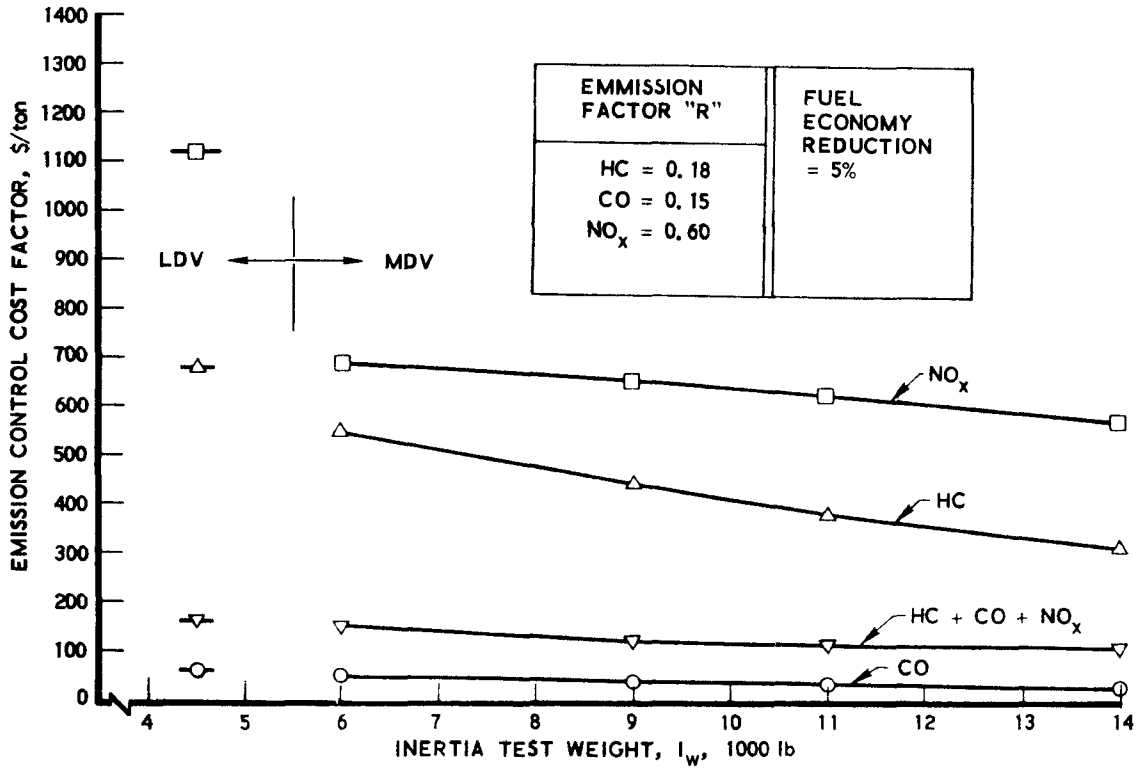

Figure 5. Cost Factors for ECS No. 3 -- Earlier Technology Baseline (EI + IC + QHI + EGR + AI + OC)

4.2 MEDIUM-DUTY VEHICLE AND LIGHT-DUTY VEHICLE COST FACTOR COMPARISONS

As illustrated in the previous four figures, for the same ECS, MDVs have HC, CO, and HC + CO + NO_x cost factors that can range from approximately equal to LDV cost factors at the I_w = 6000 lb level to considerably less than LDV values at the I_w = 14,000 lb level. The MDVs have NO_x cost factors that can be somewhat above LDV NO_x cost factors when comparing on the 1972 LDV technology baseline, but that are substantially below LDV values when compared on the earlier technology baseline.

Cost factor numerical values vary considerably with ECS type; therefore, caution should be observed when attempting to compare ECS on the basis of discrete cost factor characteristics (HC, CO, or NO_x).

It should be recognized that the numerical level of any cost factor is a simple reflection of the values selected initially for baseline emissions and ECS cost characteristics. As discussed previously, two emission level baselines were used in the present analysis to bound the problem. Cost factors based on the earlier technology baseline may be reasonably characteristic of applying ECS to the MDVs with HDV engines as modified to meet the first level of emission control (1969 to 1974 heavy-duty engine requirements). Cost factors based on the 1972 LDV extrapolated technology baseline may be reasonably characteristic of applying ECS to MDVs incorporating engines as modified to meet 1972 LDV certification levels (assuming emission variations due to differences in drive train, aerodynamic drag, etc., are relatively small). Assuming that control system costs are the same for both emission baselines may be an oversimplification. The exact cost factor for a given MDV engine combination would depend on the specific engine involved and the modifications made to it (e. g., combustion chamber, ignition timing, and spark retard) prior to the addition of specific ECSs of the types examined herein (ECS No. 2 through No. 8).

Regardless of the basis of emission baseline comparison, it is clear that emission control of MDVs in terms of HC, CO, and HC + CO + NO_x cost factors is more cost effective than when applying similar controls to LDVs. This result occurs principally because of the higher MDV emission levels prior to adding a given ECS, and also results in the lower cost factors as I_w (or MDV GVW size) increases because the baseline emissions are greater with increasing I_w.

5. HEAVY-DUTY VEHICLE COST COMPARISONS

A brief analysis of HDV emission control cost factors was made to compare cost factors for all of the principal sources in the mobile source spectrum (LDVs, MDVs, and HDVs). A single HDV size (22,600-lb GVW) was selected for analysis.

A gasoline engine and direct-injection and prechamber diesel engines were considered as power plants for the HDV case. The ECS Nos. 2, 3, 6, and 8 (as described in Table 2) were selected for addition to the gasoline engine. The only ECS considered for the diesel engine was EGR; the diesel engine itself has low HC and CO emission rates, when compared with an uncontrolled gasoline engine.

Gasoline engine lifetime values of 12.6 years and 130,000 mi were used for cost amortization purposes. For the diesel, an engine lifetime of 12.6 years and 475,000 mi was selected.

Cost factor analysis indicated that comparison of gasoline- and diesel-powered HDVs on a simple cost factor basis can be misleading because of their inherently different fuel economy characteristics; the diesel fuel economy (mpg) is approximately 1.5 times the gasoline engine mpg value. If the diesel fuel economy advantage is not considered in the cost equation, the diesel-powered HDV HC and CO cost factors are in the same general range as those for a gasoline-powered HDV with an oxidation catalyst plus EGR ECS ($243/ton and $20/ton, respectively). If the diesel fuel economy advantage is included, diesel HC and CO cost factors become negative (-$921/ton and -$76/ton, respectively).

With EGR, the direct-injection diesel has an NO_x cost factor (approximately $210/ton) in the same general range as gasoline-powered HDV NO_x cost factors. However, the prechamber diesel can have NO_x cost factors as high as $540/ton because of lower uncontrolled NO_x emission rates.

6. STATIONARY SOURCE EMISSION CONTROL COSTS

This section summarizes emission control cost factors ($/ton pollutant reduced) for several categories of stationary sources. Several combustion modification approaches to NO_x reduction in utility steam boilers were considered since this is an important source of the pollutant. In addition, cost factors were determined for the following sources: (a) nitric acid plant (NO_x), (b) refinery cracking unit (CO), (c) bulk gasoline loading (HC), (d) service station tank filling (HC), (e) automobile refueling (HC), and (f) petroleum storage tanks (HC).

6.1 CONTROL COSTS FOR NO_x

The NO_x control cost factors for a utility power plant boiler of a 250-MW size vary from -$29/ton to $43/ton, depending upon the specific emission control technique and the fuel type used. Low excess air firing alone generally results in cost savings (due to fuel savings) and permits NO_x reductions of 25 to 30 percent. Low excess air firing plus either two-stage combustion or flue gas recirculation can provide a 50 to 60 percent reduction in NO_x at costs in the $3 to $43/ton range.

Available data indicate that the NO_x cost factors of utility boilers rise sharply as the size of the boiler decreases (e.g., values of $150 to $180/ton for gas-fired units and $50 to $90/ton for oil-fired units at a 115-MW rating, compared to the -$29/ton to $43/ton range for the 250-MW size).

A comparable value for a nitric acid plant with catalyst reduction for NO_x control is $69/ton.

6.2 CONTROL COST FOR CO FROM REFINERY CRACKING UNITS

The single stationary source CO cost factor determined was less than $2/ton for a CO boiler in a refinery cracking unit. Since CO is

usually controlled to low levels in stationary sources by good design and operating practices, there are very few examples of specific CO control systems.

6.3 CONTROL COSTS FOR HC

Stationary source HC control cost factors vary widely; however, they are characterized by increasing cost factor values as the size, quantity, or flow rate of the controlled product decreases. For example, petroleum storage tanks with floating roofs for HC control have a cost factor of $15/ton, vapor recovery units in gasoline bulk loading installations have a cost factor of $33/ton, and vapor recovery units in service station holding tank filling operations have a cost factor of $119/ton.

Vapor recovery systems for use in service stations to control automobile refueling losses are reported by various sources to be between $200 and $1400/ton, depending upon the system complexity. Based on actual service station tests, analyses conducted by the San Diego County Air Pollution Control District estimate these cost factors between $200 and $480/ton.

7. MOBILE AND STATIONARY SOURCE COST FACTOR SUMMARY

Representative emission control cost factors developed for LDVs and MDVs (Section 4.1), HDVs (Section 5), and various stationary sources (Section 6) are all summarized in this section to permit an overview comparison.

Mobile and stationary source emission control cost factors are listed in Table 7, by emission constituent, to facilitate the comparison. The cost factors for LDVs and MDVs are those derived from 1972 LDV technology emission baseline assumptions. The ranges of mobile source cost factor values (Table 7) include ECS No. 2 through No. 8 for LDVs and MDVs;

Table 7. Summary of Emission Control Cost Factors

EMISSION SOURCE		COST FACTORS, $/ton REMOVED[1]		
		HC	CO	NO_x
MOBILE SOURCES	LIGHT DUTY VEHICLES (4500 lb inertia test weight)	550 to 1800[2] (1800)[3]	60 to 180[2] (180)[3]	500 to 2300[2] (1200)[3]
	MEDIUM DUTY VEHICLES 6000 lb INERTIA TEST WEIGHT	400 to 1650[2] (1650)[3]	40 to 140[2] (140)[3]	500 to 2600[2] (1280)[3]
	9000 lb INERTIA TEST WEIGHT	280 to 850[2] (850)[3]	18 to 60[2] (60)[3]	500 to 2800[2] (1350)[3]
	HEAVY DUTY VEHICLES (15,000 lb test weight) GASOLINE-POWERED	100 to 350[2] (350)[3]	6 to 27[2] (27)[3]	200 to 550[2] (550)[3]
	DIESEL-POWERED	240 to 360[4] -921 to -1375[5]	20 to 21[4] -76 to -80[5]	200 to 850
STATIONARY SOURCES	UTILITY BOILERS (250 MW) LEA	--	--	0 to -29[6]
	LEA + TWO STAGE	--	--	3 to 43[6]
	LEA + FGR	--	--	6 to 35[6]
	NITRIC ACID PLANT (catalyst reduction)	--	--	69
	REFINERY CRACKING UNIT (CO boiler)	--	1.67	--
	PETROLEUM STORAGE TANKS (floating roof)	15	--	--
	GASOLINE BULK LOADING (vapor recovery)	33	--	--
	SERVICE STATION--TANK FILLING (vapor recovery)	119	--	--
	SERVICE STATION--AUTO FILLING (vapor recovery)	200 to 1400	--	--

(1) THE VALUES SHOWN IN THIS TABLE ARE BASED ON A NUMBER OF ASSUMPTIONS AND LIMITATIONS AS INDICATED IN THE TEXT OF THE REPORT

(2) FUNCTION OF SPECIFIC EMISSION CONTROL SYSTEM EMPLOYED

(3) VALUES IN PARENTHESES ARE FOR 1975-TYPE CATALYST CONTROL SYSTEM

(4) FUEL ECONOMY IMPROVEMENT OVER GASOLINE ENGINE NOT INCLUDED

(5) FUEL ECONOMY IMPROVEMENT OVER GASOLINE ENGINE ALLOCATED TO HC AND CO CONTROL

(6) VARIES WITH FUEL TYPE (gas, oil, coal)

ECS No. 2, 3, 6, and 8 for gasoline-powered HDVs; and EGR for diesel-powered HDVs. However, for each LDV, MDV, and gasoline-powered HDV case, the cost factor based on ECS No. 3 (1975-type passenger car oxidation catalyst plus EGR) is shown in parentheses for a common baseline of comparison.

Two types of cost factors are shown in the table for diesel-powered HDV HC and CO control. The positive-valued cost factors are computed without regard to the fuel economy advantage of the diesel, as discussed in Section 5. The negative-valued cost factors (relative to gasoline engine baseline emission levels) are the result of including diesel fuel cost advantages in the cost factor equation.

8. VEHICLE LOCATION AND TRAVEL CHARACTERISTICS

Numerous transportation planning studies were reviewed, and both passenger car and truck registration surveys were used to develop the characteristics of vehicle distribution by type and size (GVW), and the vehicle miles travelled (VMT) by each vehicle class in the New York City, Los Angeles, and Phoenix-Tucson AQCRs.

Table 8 lists the results of this examination. It summarizes the human and vehicle populations, including percent breakdown values for autos and trucks in the above AQCRs and selected metropolitan subdivisions of the New York City AQCR, and, in the case of trucks, gives the percent breakdown by GVW.

Based on this registration-by-county-derived data base, the characteristic of decreasing percent of trucks as the area increases in population density is clearly shown by the Phoenix-Tucson, Los Angeles, and New York City AQCRs. The anomaly of Manhattan logically infers that in such smaller, highly populated, traffic-congested areas, the percent of

Table 8. Vehicle Miles Traveled Data Summary -- Circa 1970

PARAMETER	AREA							
				NEW YORK CITY AREAS				
	NATION	PHOENIX-TUCSON AQCR	SOUTH COAST AIR BASIN AQCR (Los Angeles)	TRI-STATE (New York City AQCR)	NINE COUNTIES	NEW YORK CITY (Five Boroughs)	MANHATTAN (New York County)	DOWNTOWN MANHATTAN
POPULATION	--	1,429,000	9,700,000	17,402,249	11,560,000	7,890,000	1,590,000	--
TOTAL NUMBER OF VEHICLES(1)	106,211,895	821,000	5,600,000	6,793,490	3,659,000	1,762,000	231,000	--
PERCENT AUTOMOBILES(2)	81 38	75 91	83 75	92 1	92.86	93 47	86.09	--
PERCENT TRUCKS(2)	18 62	24.09	16.25	7.9	7 14	6.53	13.91	--
TRUCK GVW BREAKDOWN(2) (Percent)								
0 TO 6,000 lb (LDT)	64.79	73.4	59.55	51.20	45.59	40 22	32.74	--
6,000 TO 14,000 lb (MDV)	19.09	18 5	29.70	18.89	22.47	19 91	18.86	--
OVER 14,000 lb (HDV)	16 12	8.1	10.75	29.91	31.94	39 87	48.40	--
TOTAL DAILY VMT(1)	--	17,000,000	150,000,000	169,369,470	99,000,000	34,146,000	6,035,000	
PERCENT VMT BY TRUCKS(1)	--	17 3	13.5	16 7	--	10 2	17.3	42 0
TRUCK VMT BREAKDOWN(3) (Percent)								
0 TO 6,000 lb	--	73.4	59 55	51.20	45 59	40 22	32.74	32 74
6,000 TO 14,000 lb	--	18.5	29 70	18.89	22 47	19.91	18.86	18.86
OVER 14,000 lb	--	8.1	10.75	29.91	31.94	39.87	49.40	49.40
VMT/VEHICLE(1)	--	20 7	26.8	25 0	27.3	19 3	26 1	--
VMT/TRUCK(1)	--	14.87	22.25	32.7	--	30 27	32 49	--
PERCENT VMT								
LDV (Automobiles + LDT)	--	95 4	94.54	91 85	--	93.9	88.19	71.4
MDV	--	3 2	4 0	3.15	--	2 03	3 26	7 9
HDV	--	1 4	1.46	5.0	--	4 07	8.55	20 7

(1) FROM VARIOUS TRANSPORTATION PLANNING STUDIES
(2) BASED ON 1 JULY 1972 REGISTRATION DATA FOR BOTH PASSENGER CARS AND TRUCKS PROVIDED BY R L. POLK COMPANY
(3) ASSUMED TO BE THE SAME AS GVW BREAKDOWN

trucks increases because of: (a) the continued need to provide goods and services for the people in the area, and (b) the concurrent difficulty of owning, storing, and/or operating passenger cars in such areas.

The distribution of LDTs (under 6000-lb GVW) appears (Table 8) to uniformly vary inversely with population density, decreasing in percentage of total trucks as the population density increases. Except for Los Angeles, the MDV distribution appears not to be affected by population density, but

rather to remain near the national average. In Los Angeles this anomaly may be the result of the widespread use of heavier camper bodies and motor homes used for recreational purposes. Thus, the distribution between LDTs and MDVs may be a logical result of region-peculiar use characteristics in Los Angeles.

The HDVs, on the other hand, increase in distribution as the percent of total trucks in accordance with increasing population density. Again, this may be the logical result of the need for heavy trucks to move goods into the heavily populated areas in accordance with the number of inhabitants involved.

The "total daily VMT" and "percent VMT by trucks" values shown are those derived from transportation planning studies for the area in question. The truck GVW breakdown was applied to these VMT values to arrive at the percent VMT values by vehicle class (LDV, MDV, and HDV) given at the bottom of the table. It should be noted that the LDV class includes both autos and LDTs (under 6000-lb GVW).

Except for downtown Manhattan, the MDV contribution to VMT ranges from 2 to 4 percent. On the other hand, HDV VMT contributions steadily increase from 1.4 percent for the lightly-populated Phoenix-Tucson AQCR to 20.7 percent for downtown Manhattan. Vehicles above 6000-lb GVW (MDVs and HDVs) contribute from 5 percent to 28 percent of the daily VMT, with the percentage increasing as population density increases.

9. EMISSION INVENTORIES

Inventories of mobile source emissions were calculated for the New York City, Los Angeles, and Phoenix-Tucson AQCRs. These inventories included a breakdown by vehicle class (LDV, MDV, and HDV), and were projected to the year 1990 to reflect the effects of various possible MDV control strategies.

All control strategies assumed that the presently in force LDV exhaust emission regulations (including the 1976 LDV regulations) would remain unchanged. Strategy No. 1 further assumed that present Federal 1974 HDV emission standards would stay in effect through 1990. Strategy No. 2 assumed that MDV and HDV emission standards similar to California 1975 HDV standards would be implemented in the 1975 to 1977 period. Strategy No. 3 assumed that oxidation catalyst plus EGR systems would be added to MDVs only in the 1977 to 1979 period. Strategy No. 4 assumed that reduction catalysts would be added to MDVs only in the 1980 to 1982 period. The principal features of these emission control strategies and their corresponding LDV, MDV, and HDV emission levels are summarized in Table 9.

Figures 6, 7, and 8 illustrate typical results, in this case the HC, CO, and NO_x inventories, respectively, for the New York City AQCR. The overall trends are similar for the Los Angeles and Phoenix-Tucson AQCRs; only the absolute values vary somewhat.

With no further emission control beyond the presently established LDV regulations and the 1974 Federal HDV standards (for all vehicles over 6000-lb GVW), emissions in the 1985 to 1990 period are reduced to approximately 25 to 30 percent of 1970 levels. This is illustrated as Strategy No. 1 in Figures 6, 7, and 8.

Implementation of MDV and HDV emission standards equivalent to the California 1975 HDV standards in the 1975 to 1977 period (Strategy No. 2) results in a further sizeable reduction for all three pollutants. For example, as shown in Figure 6 the 1990 HC inventory is approximately 15 percent of 1970 values. This assumes, although it may well be not the case, that emission reductions for the current nine-mode HDV engine dynamometer procedure are representative of actual vehicle emission reductions.

The addition of oxidation catalysts (in 1977 to 1979) and reduction catalysts (in 1980 to 1982) to MDVs has relatively little effect on total emissions by 1990; this is illustrated as Strategies Nos. 3 and 4, respectively, in Figures 6, 7, and 8. This minimal effect occurs because only MDVs (and

Table 9. Control Strategy Emission Levels

STRATEGY NUMBER	EMISSION LEVEL ASSUMPTION								
	LDVs	MDVs				HDVs			
		BASIC FEATURE	EMISSION LEVEL,[1] gm/mi			BASIC FEATURE	EMISSION LEVEL,[1] gm/mi		
			HC	CO	NO_x		HC	CO	NO_x
1	CURRENT FEDERAL LDV REGULATIONS (including the 1976 LDV regulation), ALL FOUR STRATEGIES	1974 FEDERAL HDV STANDARDS	4.25	62.08	6.57	1974 FEDERAL HDV STANDARDS	17.9	179	12.6
2[2]		1975 CALIFORNIA HDV STANDARDS	1.33	38.08	2.06	1975 CALIFORNIA HDV STANDARDS	5.6	112	3.94
3[3][4]		OXIDATION CATALYST ADDED	0.40	4.20	2.06	1975 CALIFORNIA HDV STANDARDS	5.6	112	3.94
4[4][5]		REDUCTION CATALYST ADDED	0.40	4.20	0.45	1975 CALIFORNIA HDV STANDARDS	5.6	112	3.94

(1) VALUES IN gm/mi EITHER BASED ON TEST RESULTS, ON CONVERSION FROM gm/bhp-hr STANDARDS, OR ON ESTIMATES OF CATALYTIC CONVERTER EFFICIENCY

(2) IMPLEMENTED IN CALIFORNIA IN 1975; REST OF UNITED STATES IN 1977

(3) IMPLEMENTED IN CALIFORNIA IN 1977; REST OF UNITED STATES IN 1979

(4) ONLY MDVs ARE REGULATED TO LOWER LEVELS IN STRATEGIES 3 AND 4, i.e. HDVs REMAIN AT 1975 CALIFORNIA HDV STANDARD LEVELS

(5) IMPLEMENTED IN CALIFORNIA IN 1980; REST OF UNITED STATES IN 1982

not HDVs) are equipped with the catalysts and they represent a relatively small percent of the total number of vehicles in an AQCR (e.g., MDVs are only 1.5 percent of total vehicles in New York City AQCR), and contribute only a small amount of the total VMT (e.g., MDVs contribute 3.15 percent of the total daily VMT in the New York City AQCR).

The various control strategies examined do have a marked effect on the relative percentage contribution of the LDV, MDV, and HDV vehicle classes. Figure 9 illustrates the variation of LDV, MDV, and HDV

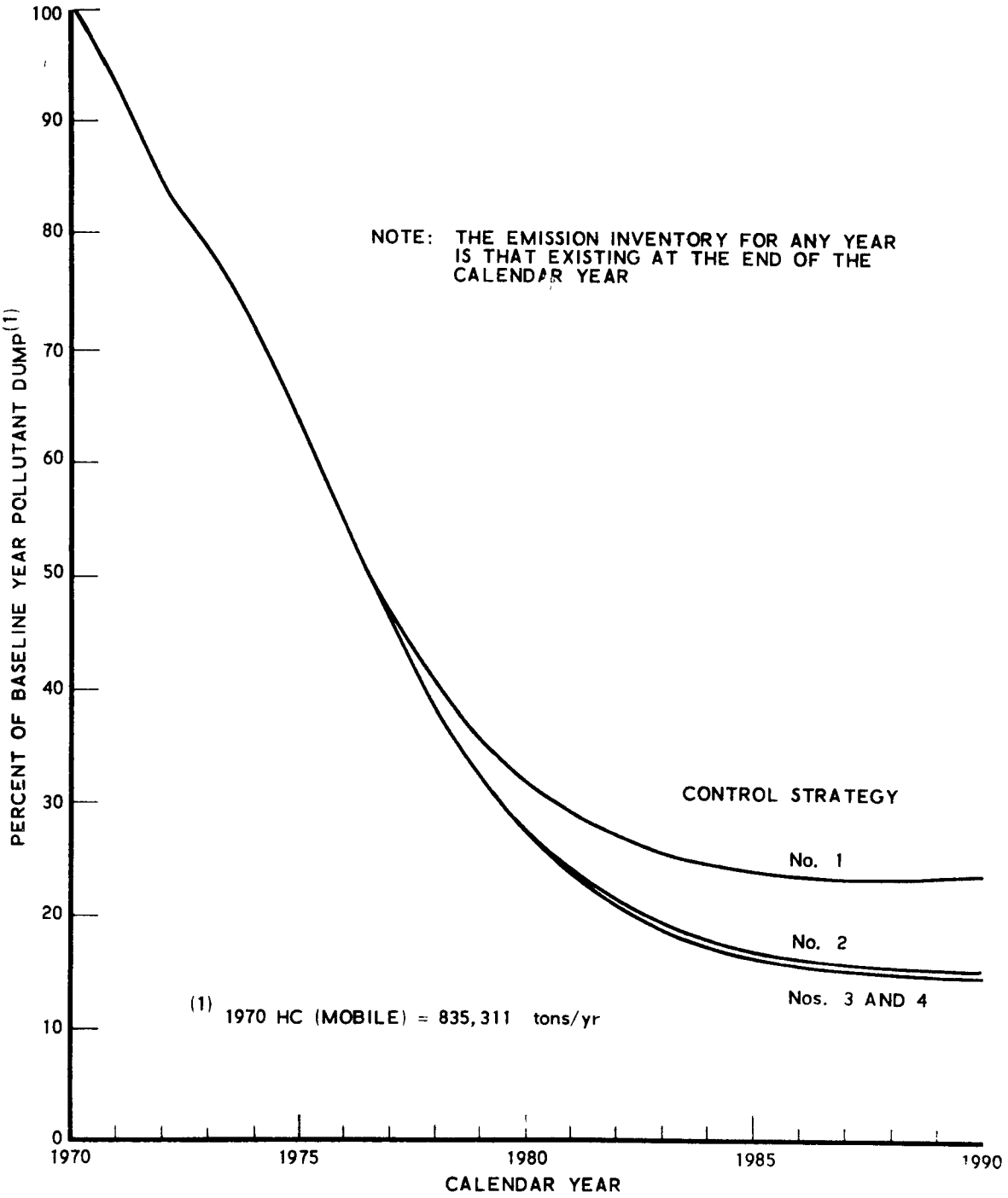

Figure 6. New York City AQCR -- Mobile Source HC Inventory (Determined using anticipated normal growth rates)

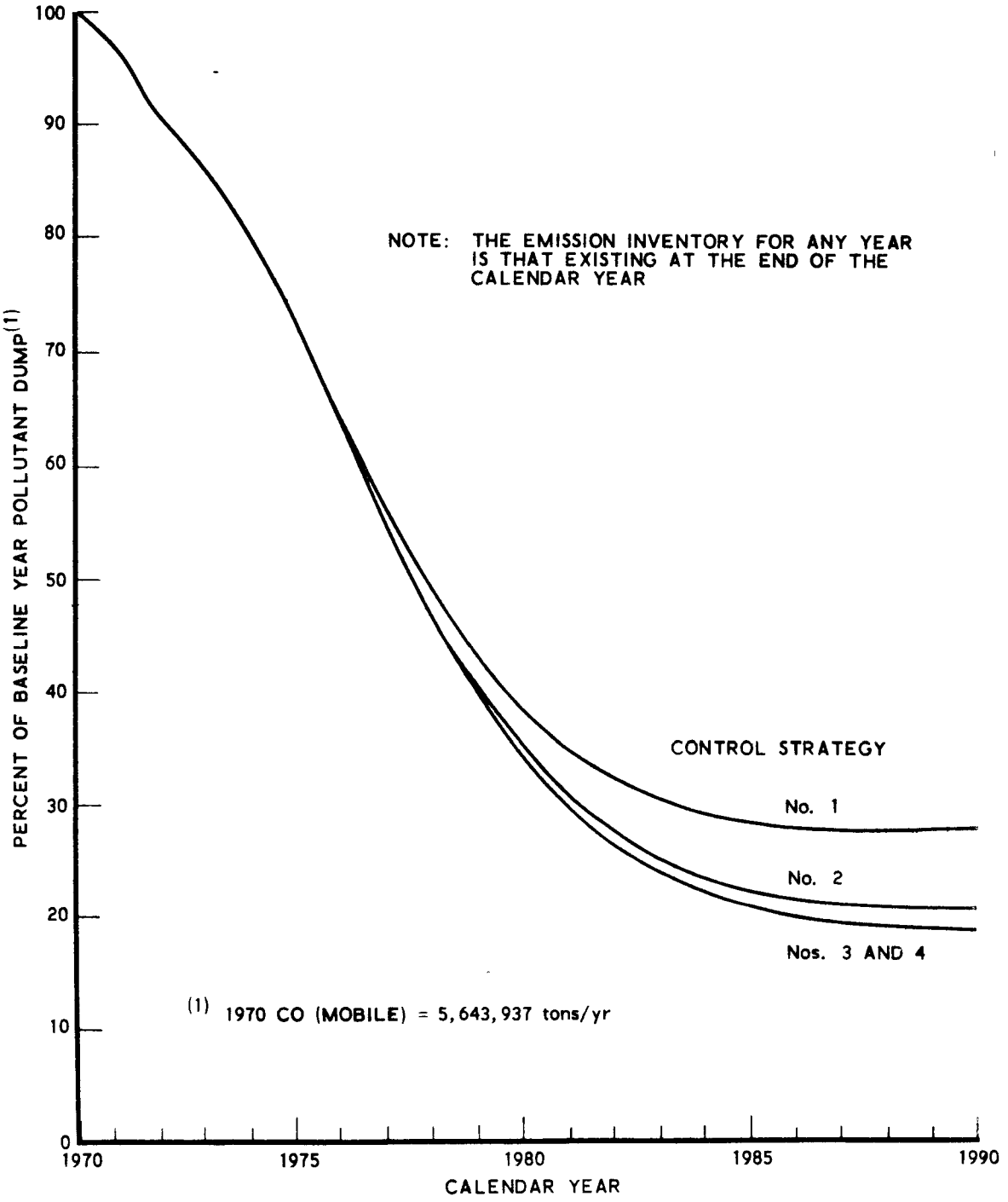

Figure 7. New York City AQCR -- Mobile Source CO Inventory (Determined using anticipated normal growth rate)

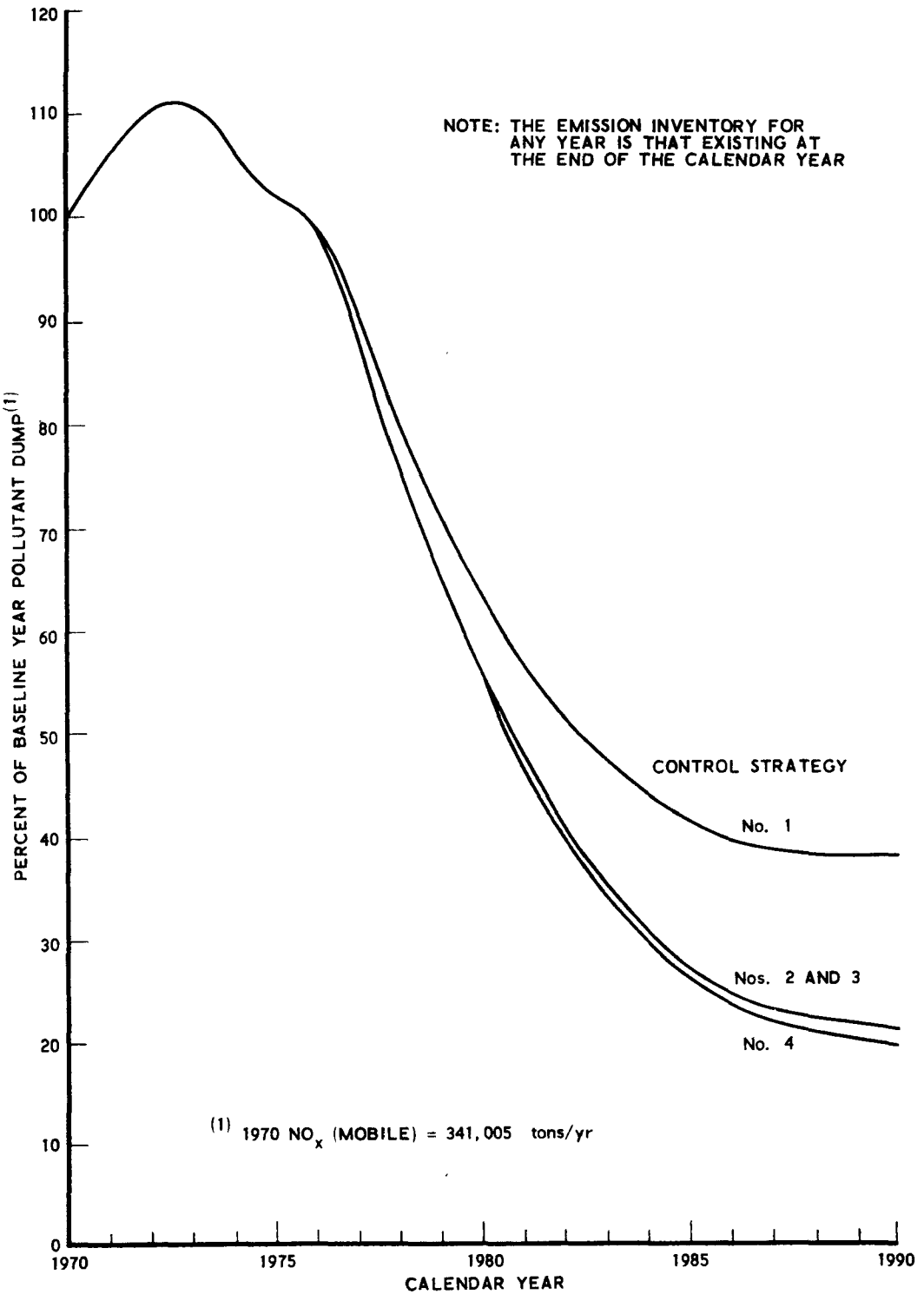

Figure 8. New York City AQCR -- Mobile Source NO_x Inventory (Determined using anticipated normal growth rate)

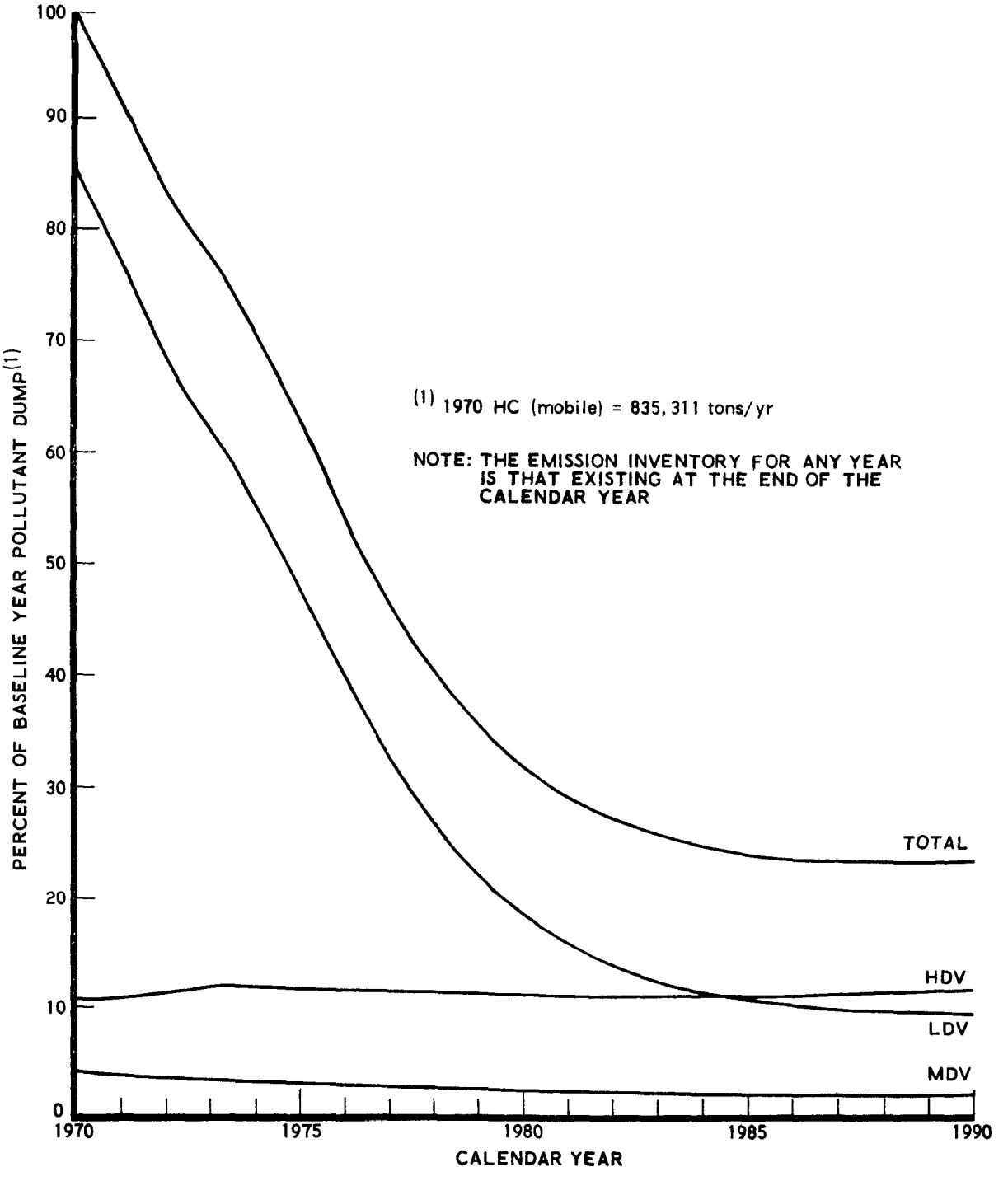

Figure 9. New York City AQCR HC Inventory Contribution by Vehicle Class -- Control Strategy No. 1 (Determined by using anticipated normal growth rates)

HC percentage contribution from 1970 to 1990 for Strategy No. 1 based on the 1970 total HC inventory representing 100 percent. Figure 10 is a replot of Figure 9 and similar plots of the other control strategies that expresses percentage HC contribution variation where 100 percent represents a different total HC emission inventory value each year. Figures 11 and 12 are similar plots for CO and NO_x, respectively. Table 10 compares 1990 and 1970 HC values for all four emission control strategies.

Under Strategy No. 1, HDVs would be contributing as much emissions as LDVs by 1985. Strategy No. 2 would appreciably reduce the HDV contribution, but it would still be several times higher in 1990 than in 1970. Strategies Nos. 3 and 4 do not further reduce HDV emission levels (apply only to MDV emissions levels); thus these strategies would have to be expanded to include HDVs to significantly alter the HDV percentage contribution.

In the case of MDVs, their percentage contribution of total emissions rises steadily from 1970 to 1990 under Strategy No. 1. For example, HC increases from 4 percent to 9 percent as shown in Table 10. Strategy No. 2 reduces 1990 MDV contributions to approximately 6 percent, while Strategies Nos. 3 and 4 (oxidizing and reducing catalyst in MDVs only) reduce 1990 MDV HC values to slightly below (about 3 percent) 1970 percentage levels.

Combined MDV and HDV emissions (vehicles above 6000-lb GVW) exceed LDV HC emissions by approximately 50 percent in 1990 under Strategy No. 1 (See Table 10). Under all other strategies examined, the combined percentage of MDV and HDV emissions in 1990 are approximately two times their 1970 percentage levels.

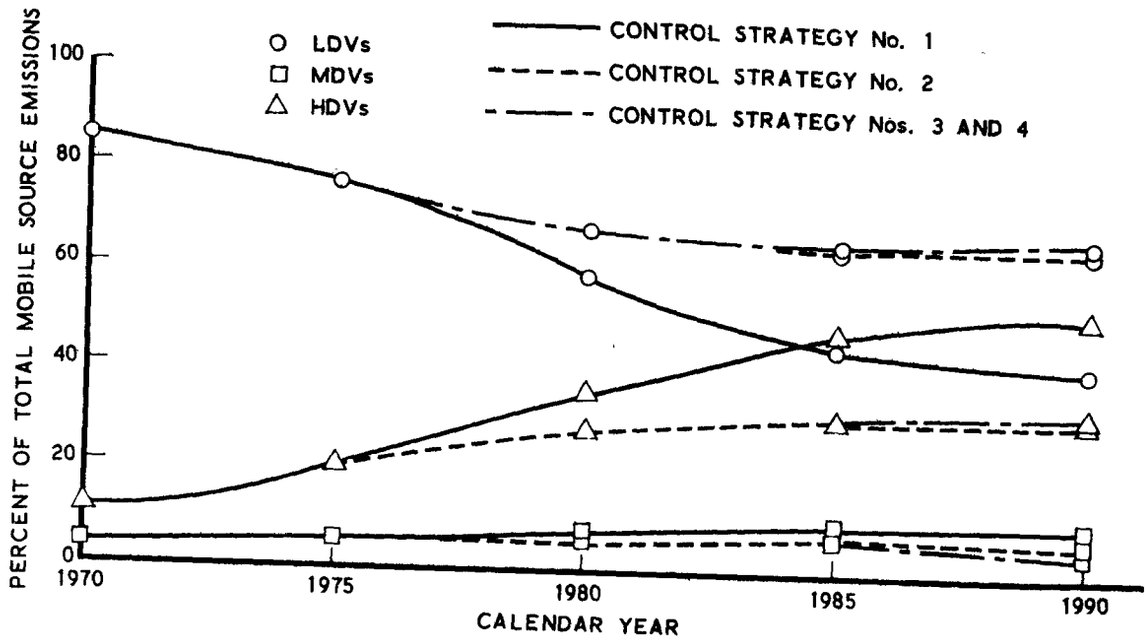

Figure 10. New York City AQCR -- HC Percentage Contribution of Vehicle Class (Normal Growth Rates)

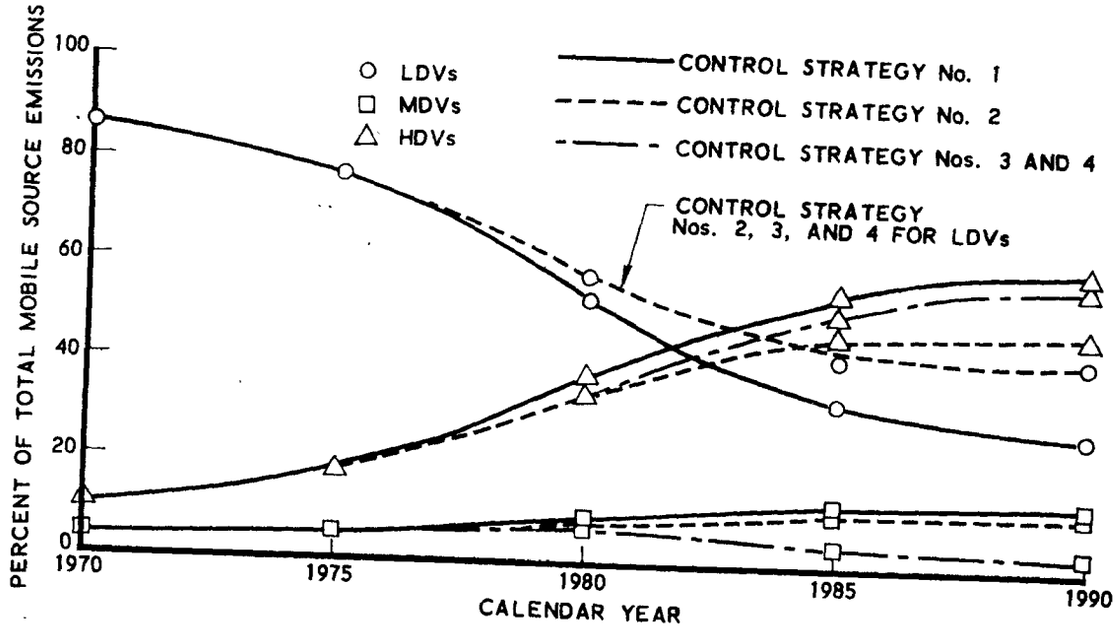

Figure 11. New York City AQCR -- CO Percentage Contribution of Vehicle Class (Normal Growth Rates)

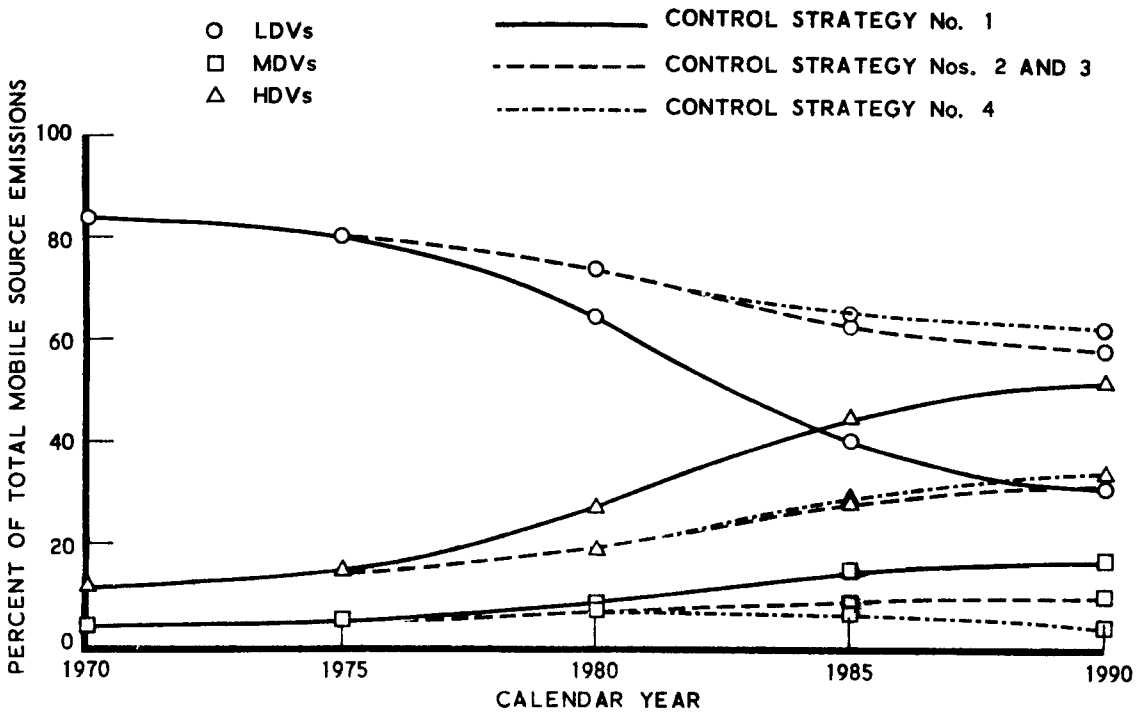

Figure 12. New York City AQCR -- NO_x Percentage Contribution of Vehicle Class (Normal Growth Rates)

Table 10. New York City AQCR Mobile Source HC Distribution of Vehicle Class (1970 to 1990

CONTROL STRATEGY NUMBER	PERCENT OF TOTAL MOBILE SOURCE HC INVENTORY							
	1970				1990			
	LDV	MDV	HDV	MDV AND HDV	LDV	MDV	HDV	MDV AND HDV
1	85	4	11	15	40	9	51	60
2(1)	ALL FOUR STRATEGIES HAVE SAME 1970 BASELINE VALUES			15	64	6	30	36
3(2)				15	66	3	31	34
4(3)				15	66	3	31	34

(1) IMPLEMENTED IN 1977 IN NEW YORK CITY AQCR

(2) IMPLEMENTED IN 1979 IN NEW YORK CITY AQCR

(3) IMPLEMENTED IN 1982 IN NEW YORK CITY AQCR

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16. ABSTRACT

A comparative analysis was made of the emission control cost factors (expressed as dollars expended per ton of pollutant removed) of medium duty vehicles (MDVs--6000 to 14000-lb GVW), light duty vehicles (LDVs--less than 6000-lb GVW), heavy duty vehicles (HDVs--greater than 14000-lb GVW), utility power plants, and a number of other stationary sources. Mobile source emission inventories were calculated for the New York City, Los Angeles, and Phoenix-Tucson Air Quality Control Regions. The results indicate that, in the mobile source area, emission control cost factors ($/ton) in general decrease in numerical value as the vehicle weight increases; i.e., MDVs are more cost-effective than LDVs, and HDVs are more cost-effective than MDVs. This same size effect was noted in stationary source cost factor comparisons, where the cost factors decreased in numerical value as the system size (or flow rate of the product being controlled) increased. Further, stationary sources have lower control cost factors (for the same pollutant specie) than the smaller mobile sources.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13B
Automobiles	Mobile Sources	13F
Trucks	Stationary Sources	14A
Boilers	Emission Inventories	21G
Utilities	Emission Control Systems	
Costs	Control Cost Effectiveness	

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