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Lead Industries Association, Inc.

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June 5, 1973

SUBJECT: DU PONT TECHNICAL PAPER
LEAD IN GAS

TO THE OFFICIAL MEMBERS OF THE
LEAD INDUSTRIES ASSOCIATION, INC.:

Attached is a copy of a paper recently presented to a body of the American Petroleum Institute by Du Pont personnel which, in considerable technical detail, explains the feasibility of the thermal reactor and trap device which would permit the continued use of leaded gasoline. The paper presents facts and figures on emission controls, and relates the penalties in fuel consumption resulting from them.

We feel this could be valuable information for company personnel who are asked questions about the lead in gasoline situation, the fuel shortage and the validity of the reactor-trap concept.

There are a limited number of additional copies available.

Sincerely,

PE Robinson

Philip E. Robinson
Executive Vice President

J F Smith

Jerome F. Smith
Secretary & General Manager

PER/JFS/lm

N 3538

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Paper for Presentation at a Session on Emission Control Systems and Fuel Requirements of 1975-76 Cars, II, During the 38th Midyear Meeting of the American Petroleum Institute's Division of Refining, in the Benjamin Franklin Hotel, Philadelphia, Pa., May 15, 1973.

A TOTAL VEHICLE EMISSION CONTROL SYSTEM

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ABSTRACT

Studies of ambient air quality levels from the CAMP stations, traffic flow in urban central business districts, and emission rates from vehicles on the road suggest that the automotive exhaust emission standards mandated by the Clean Air Act Amendments of 1970 may be more stringent than required to attain the national ambient air quality standards. Based on preliminary results from continuing studies, emission levels as measured by the 1975 Federal Test Procedure of 15 to 40 grams per mile of carbon monoxide, 0.4 to 0.8 gram per mile of hydrocarbons, and 1.5 to 3.0 grams per mile of nitrogen oxides appear to be adequate.

The application of emission control systems to date and the reduction of compression ratios have increased the fuel consumed by an average weight domestic sedan by 17 percent compared with pre-emission control vehicles. This consumption penalty is predicted to double if the emission control systems now contemplated are used to meet the current 1976 standards.

If vehicle emission standards were changed to the values suggested above as being adequate to attain ambient air quality standards, noncatalytic exhaust emission control systems based on thermal reactors, exhaust gas recirculation, and engine modifications could be employed. Such systems would permit the continued use of high octane leaded gasoline giving motorists the opportunity to use the lowest cost fuel in high compression, more efficient engines. The fuel consumption of cars using such control systems is less than 8 percent greater than corresponding 1970 production vehicles or approximately equivalent to the current 1973 production cars.

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A TOTAL VEHICLE EMISSION CONTROL SYSTEM

E. N. Cantwell, W. E. Bettoney, J. M. Pierrard

INTRODUCTION

Prior to 1970, control of automotive emissions first by the State of California and later by the U.S. government was based on the application of demonstrated technology. Future emission goals were based on the expected rate of development of improved technology to reduce emissions. However, with the passage of the Clean Air Act Amendments of 1970, Congress mandated (1)* by 1975, emissions of hydrocarbons and carbon monoxide must be reduced by 90 percent from the 1970 levels and (2) by 1976, emissions of nitrogen oxides must be reduced by 90 percent. Congress was concerned that public health and welfare might be affected by pollution caused by automobiles and thus felt that drastic action was necessary. The Clean Air Act of 1970 also directed the U.S. Environmental Protection Agency to determine national ambient air quality standards which would protect public health and welfare. Because emission levels were mandated first and air quality standards established later it is not unreasonable to expect that the degree of emission control legislated by Congress might not be consistent with what was needed to achieve national ambient air quality standards later promulgated by the EPA. Since the 1970 Clean Air Act Amendments were passed, additional data have been generated which are useful in assessing the adequacy of the emission reductions mandated by Congress. The need for carefully setting the automotive emissions standards arises from the fact that for most types of automotive engines fuel consumption increases with the degree of control which is imposed. Thus, the degree of emission control and the extent of the fuel consumption penalty must be considered at the same time. In view of the critical crude oil supply situation in this country, it is imperative that a balance be struck between the desirability of achieving ultra-low emission levels for automobiles and the desirability of minimizing fuel consumption penalties.

The purpose of this paper is to report on the progress being made in major programs being carried out by Du Pont in these areas of concern. The results of studies to date show that:

- Achievement of national air quality standards may be possible with automotive emission levels of hydrocarbons, carbon monoxide and oxides of nitrogen less stringent than mandated by Congress in the 1970 Clean Air Act Amendments.
- Noncatalytic total emission control systems have been developed which are capable of reducing automobile emissions to levels which should permit achievement of the national ambient air quality standards without suffering large fuel penalties.

*Numbers in parentheses refer to references on pages 36 and 37.

- In general, fuel consumption penalties of vehicles equipped with emission control systems are dependent on the degree of emission control. This penalty probably will vary with the type of emission control system which is used and with the relative amounts of control of hydrocarbons, carbon monoxide and nitrogen oxides. Vehicles meeting standards that will permit achievement of the ambient air quality standards are projected to have a much lower fuel consumption penalty than vehicles equipped to meet the 1976 emission standards mandated by the Clean Air Act Amendments of 1970.

AIR QUALITY AND EMISSION STANDARDS

The EPA published ambient air quality standards for six major atmospheric pollutants in 1971 (1). The standards for hydrocarbons, carbon monoxide, oxidants, and nitrogen dioxide associated with automotive usage are shown in Table 1. The adequacy of these national air quality standards has been vigorously debated. Some critics contend that some of these standards are too high to adequately protect the public health while others contend that they are lower than can be supported based on medical evidence. Still others point out that some of the standards approach or are below natural background levels and thus are extremely difficult or perhaps impossible to attain. For the purposes of this paper, the goal of meeting the ambient air quality standards will be accepted and only the question of what automotive emission standards are needed to meet these standards will be examined.

TABLE 1

NATIONAL AMBIENT AIR QUALITY STANDARDS FOR AUTOMOTIVE POLLUTANTS

Carbon Monoxide	9 ppm 35 ppm	8-Hour Average* 1-Hour Average*
Hydrocarbons	0.24 ppm C; (6-9 a.m.)	3-Hour Average*
Nitrogen Oxides	0.05 ppm NO_2	Annual Arithmetic Mean
Oxidant	0.08 ppm	1-Hour Average*

* Not to be exceeded more than once a year

Rollback Analysis

A crucial step in air resource management is to decide what emissions reductions are needed to meet air quality goals. To do this, knowledge of the relationship between pollutant emissions and ambient air quality is needed. Although there has been considerable effort directed to the development of mathematical models for prediction purposes the practical decisions on needed emissions reductions have been made in the past on the basis of the so-called "rollback" approach first used by California and later by EPA. This approach assumes that the pollutant concentration is proportional to the emission rate of the pollutant. The equation is:

$$R = \frac{(GF)\ (PAQ) - (DAQ)}{(GF)\ (PAQ) - (B)}$$

where: R = Fractional emission rate reduction required to achieve desired air quality
GF = Emission Growth Factor
PAQ = Present Air Quality
DAQ = Desired Air Quality
B = Background Air Quality

To illustrate, achievement of the national ambient air quality standard for carbon monoxide requires that the 8-hour average carbon monoxide concentration not exceed 9 parts per million (ppm) more than once per year. (Carbon monoxide is chosen as an example because in many large cities most of it can be ascribed to vehicular activity.) Then, by the reasoning of the rollback approach, if the 8-hour average carbon monoxide concentration exceeded once per year is 18 ppm, a reduction of emissions to half the current rate is expected to achieve the 9 ppm air quality standard level, assuming background to be negligible.

The Federal and State agencies have used the rollback approach to calculate the automotive emission standards required for achievement of ambient air quality standards for various combinations of assumed implementation dates and air quality standards. These calculations usually are made to estimate the emission reduction required to meet the air quality standard in the most polluted location, usually the central business district, at some future date. This degree of control is expected to guarantee achievement in less polluted places in the agency jurisdiction.

The amount of growth expected in emission sources has a significant effect on the reduction required in vehicle emission levels. As an example, EPA has calculated the degree of emission reduction required to achieve the ambient air quality standards for CO for the city of Chicago for two different time periods (2, 3). The first EPA calculation, Table 2, assumed that implementation of stringent emission standards would occur in 1980 while the second calculation assumed 1975. In both cases a vehicle growth rate of approximately 2.4 percent per year was assumed for the city of Chicago. Vehicle traffic in the central business district has been essentially constant for the past ten years based on data obtained from the city of Chicago, and shown in Figure 1. Thus, the use of a national or even a

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TABLE 2

ALTERNATIVE CO EMISSION STANDARDS COMPUTED BY ROLLBACK MODEL

CITY OF CHICAGO

	EPA (Ref. 2)	EPA (Ref. 3)
Worst-Case Ambient CO, ppm (occurred December, 1965)	46	46
Year of Implementation of Emission Standard	1980	1975
Emission Growth Factor	2.18	1.54
Background Air Quality, ppm	1	1
Desired Air Quality, ppm	9	9
Emission Reduction Required, % Based on Pre-1968 Vehicles	92	89
Emission Standard, g/Mile (CVS-75)	6.8	9.3
Future Worst-Case Ambient CO, ppm	9	9
Year Achieved	1990	1985

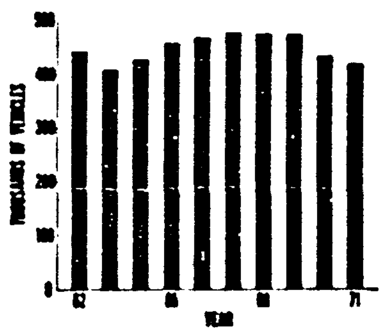

Fig. 1 – Daily Cordon Traffic Counts for the Central Business District of Chicago.

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regional vehicle growth rate may not be appropriate for the central business district in a major urban area. This condition of traffic saturation apparently exists in most major urban areas which are the regions of most concern since they have the highest levels of automotive derived air pollution.

Rollback calculations to determine needed automotive emission levels to meet the air quality standards are very dependent upon values used for vehicular growth factors and ambient air quality standards as illustrated in Table 3. With 1975 as the implementation date for stringent emission control, the allowable emissions of carbon monoxide range from 9 to 15 grams per mile and the hydrocarbons from 0.32 to 0.5 gram per mile depending on the value of the growth factor assumed. The threefold difference in allowable NO_x emissions between the first and second EPA calculations results from using different ambient air quality standards. The ambient air quality standards used in the first calculation was an NO_2 level of 0.1 ppm average for one hour not to be exceeded more than once per year. This standard, when applied in Los Angeles results in an allowable NO_x emission standard of 0.36 gram per mile. The second calculation was based on a national ambient air quality standard issued by EPA of 0.05 ppm NO_2 on an annual average basis. This standard, when applied in New York City resulted in an allowable emission standard for NO_x of 1.2 grams per mile. With the growth factor equal to unity the allowable emission rate of NO_x rises to 1.8 grams per mile. Also shown are the proposed California standards for 1975 vehicles which are predicated on the achievement of California air quality standards (4).

Allowable emission standards required to meet the ambient air quality standards when calculated using the rollback method are quite sensitive to assumed input values and in view of the economic impact of even small differences in these emission standards, a better method is needed.

TABLE 3

ROLLBACK MODEL IS SENSITIVE TO ASSUMED INPUT VALUES

Source	Year of Implementation	Growth Factor	Allowable Emissions To Meet Air Quality Standards Grams Per Mile* CO	HC	NO_x
EPA	1980	2.18	6.8	0.15	0.36
EPA	1975	1.54	9.3	0.32	1.2
Du Pont	1975	1.00	15.0	0.5	1.8
California	1975		17.3	0.9	1.5

* 1975 CVS Test Procedure

Analysis of Air Quality Trends

An alternative method of determining required emission reductions is to analyze the response of ambient air quality to the downward changes in vehicular emission rates which have taken place since emission control was instituted in California in 1966 and nationwide in 1968. This approach does not depend upon the development of adequate mathematical diffusion models and inherently accounts for the influence of atmospheric processes on the relationship between emissions and air quality. It also incorporates any growth that did take place and does not require the simplifying assumptions needed for the rollback analysis. Trend analysis of air quality is now possible because almost one-half of the cars on the streets are now equipped with some type of emission control system and the impact of the emission control should be readily apparent. Such was not the case in 1969-70, and as a result the only technique available for calculating required automotive emission reduction was the rollback method. A considerable body of air quality data is available for trend analysis. The first source is from the Continuous Air Monitoring Project (CAMP) being conducted by EPA (5). The second source is the air monitoring data gathered by the State of California Department of Public Health.

We are in the process of an extensive analysis of the air quality data which have been made available to us on magnetic tape by EPA and the State of California. Because carbon monoxide in urban areas is primarily associated with vehicular traffic and because this pollutant, at least on a short term basis is conserved, we have concentrated our initial studies on it. A more detailed and complete description of this analysis may be found in the forthcoming paper to be presented at the June 1973 meeting of the Air Pollution Control Association (6). This work is continuing and in addition we also have initiated analyses of ambient air quality data for hydrocarbons, nitrogen oxides, and oxidants to examine the relationships for these pollutants.

There has been a general improving trend in carbon monoxide air quality over the years at the six CAMP sampling sites near the centers of the cities listed as shown in Tables 4 and 5. Annual average CO values, as well as the percent of the time that the ambient air quality standard levels were exceeded, have decreased in all of the cities. The only exception to this decrease occurred in Denver during 1970 and 1971. We are examining the situation in Denver to explain this inconsistency.

A detailed study has been made for Chicago, the city cited by EPA as having the worst vehicular carbon monoxide problem, and the prototype case used in the EPA rollback calculations of required nationwide carbon monoxide emission rate reductions (2, 3). To date, three factors have been examined in some detail: the trend of vehicle CO emissions, the trend of motor vehicle use in the area surrounding the CAMP air sampling location, and the trend in maximum ambient CO levels.

The trend in CO emission rate for the vehicle population on the road has been steadily downward over recent years in response to reductions concurrent with

TABLE 4

CAMP CARBON MONOXIDE TRENDS

Year	Annual Average CO Concentration, ppm					
	Chicago	Denver	Washington	Cincinnati	St. Louis	Philadelphia
1962			5.3			
1963			6.9	7.1		
1964	12.1		5.7	6.1	6.4	7.2
1965	17.1	7.3	3.7	4.0	6.5	8.1
1966	12.5	7.9	3.3	4.9	5.8	6.8
1967	8.8	7.6	4.9	5.6	5.6	6.4
1968	6.2	5.4	3.4	5.7	4.6	8.7
1969	8.2	4.6	3.0	-	5.1	3.5
1970	6.9	6.5	3.8	-	4.4	4.1
1971	5.4	6.7	3.5	2.3	4.4	2.6

TABLE 5

CAMP CARBON MONOXIDE TRENDS

Year	Percent of Time the 8-Hour Federal CO Standard (9 ppm) Was Exceeded					
	Chicago	Denver	Washington	Cincinnati	St. Louis	Philadelphia
1962	21		11			
1963	37		20	29		
1964	67		5	29	16	23
1965	92	26	2	2	21	35
1966	71	34	2	3	12	18
1967	40	30	5	6	7	19
1968	18	11	2	6	2	39
1969	38	5	0	-	1	1
1970	24	16	2	-	0	2
1971	14	19	2	1	1	1

introduction of new model year vehicles. This trend based on EPA data (3) is shown in Figure 2. Cars were first required to meet national CO emission standards in 1968. Decreases in CO emission rate in earlier model years can be ascribed to engine modifications made in anticipation of the imposition of emission standards. The lag between the step reduction of CO emission rate from one model year to the next, and the decrease in the average CO emission rate for vehicles in use reflects the fact that only about 10 percent of the vehicle population is replaced each year.

As we have already shown in Figure 1, the traffic in the area surrounding the EPA Chicago CAMP air sampling station has been approximately the same over the last decade. Thus, the changes in ambient air quality should be proportional to the changes in emission rates.

Maximum 8-hour average CO levels reached each month in Chicago have been decreasing to about the same degree as vehicular CO emissions as shown in Figure 3. If the trend envelope established by the monthly maximum CO occurrences in the 1965-71 period, shown by the dashed line in Figure 3, is extended, it would indicate the 9 ppm air quality standard level should be achieved in 1974. As the air quality standard allows this level to be exceeded once per year, achievement of the level is more stringent than required. At the projected time of achievement of the 9 ppm level, in mid-1974, the vehicle population CO emission rate as indicated by the vehicle emission curve will be approximately 40 grams per mile. Obviously, the trend line drawn through the peak CO occurrence is drawn on the basis of limited input data but considering the remaining data, it appears reasonable.

Alternate Automotive Emission Standards

In view of disagreement among the emission standards calculated by the various rollback techniques and implied by the analysis of historical air quality trends, further reexamination of the national vehicle emission standards would appear warranted. Although much work remains to be done in this area, it is possible to suggest a range of automotive emission standards which apparently would meet ambient air quality standards as highlighted in Table 6.

The rollback analysis applied to Chicago suggests that carbon monoxide levels between 9 and 15 grams per mile would be appropriate, whereas the analysis of the air quality trends for Chicago suggests a CO value of 40 grams per mile. Certainly the value of 15 grams per mile for CO as derived by the rollback method is a conservative level.

In the case of hydrocarbon levels the rollback equation suggests 0.3 to 0.5 gram per mile. In the absence of conclusive analysis of the relationships between the trends of ambient oxidant levels and exhaust hydrocarbon emission levels it would seem appropriate to retain a hydrocarbon emission standard at the average value of 0.4 gram per mile. On the other hand, if the two- to threefold differences between CO values calculated by rollback analysis and air quality trend analysis also applies to hydrocarbons, then a hydrocarbon standard of at least two times greater or 0.8 gram per mile would be appropriate.

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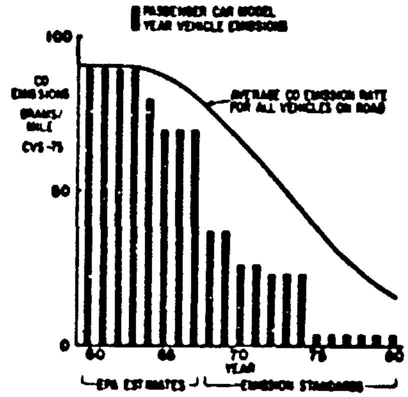

Fig. 2 – Carbon Monoxide Emission Rates of Light Duty Passenger Cars by Model Year and Average Carbon Monoxide Emission Rates for All Motor Vehicles on the Road in Each Year.

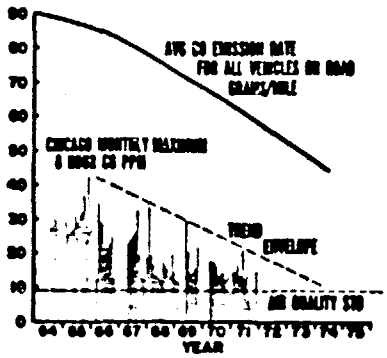

Fig. 3 – Monthly Maximum Ambient Carbon Monoxide Concentrations from the CAMP Station in Chicago and the Carbon Monoxide Emission Rates of All Vehicles on the Road.

TABLE 6

ALTERNATE AUTOMOTIVE EMISSION STANDARDS

	Emission Levels, Grams Per Mile 1975 CVS Test Procedure		
	CO	HC	NO_x
Suggested Levels Needed to Attain Air Quality Standards			
Rollback	15	0.4	1.5
Air Quality Trend Analysis	40	0.8*	2 to 3**
1973-74	28	3	3.0
1975 Nationwide (7)	15	1.5	3.1
1975 California (7)	9	0.9	2.0
1976	3.4	0.41	0.4

* Rollback value adjusted for estimated differences between rollback and air quality trend analyses observed with carbon monoxide.

** Rollback value adjusted for anticipated upward revision due to errors in measurement of ambient NO_2 levels.

In the case of nitrogen oxides, the rollback equation suggests nitrogen oxide emission standards ranging between 1.2 and 1.8 grams per mile or an average of 1.5 grams per mile. However, the EPA has stated that the ambient levels of NO_2 were measured incorrectly because of faulty analytical techniques and that they will suggest to the Congress that the emission standard should be revised upward (7). If such an upward revision were to take place, the allowable automotive emission standard would increase from 1.5 to a value of perhaps 2 to 3 grams per mile. This also would appear reasonable in light of the experience with CO.

When the levels of automotive emission standards needed to achieve ambient air quality standards are compared with the current automotive emission standards shown in Table 6 it can be seen that they correspond most closely to the 1975 interim standards for the State of California recently announced (7). The hydrocarbon and nitrogen oxides standards are in excellent agreement while the 1975 California standard for carbon monoxide may be lower than needed.

EFFECT OF EMISSION CONTROLS ON FUEL CONSUMPTION

In the absence of any other considerations it would be desirable to attain the lowest emission levels from automobiles that are technologically achievable. However, available information indicates that fuel consumption increases with increasing stringency of emission control. Preservation of our natural resources such as crude oil is very important so it is imperative to achieve a balance between gasoline utilization and the degree of air quality achieved. Therefore, the goal should be to set automotive emission standards at those levels which will just achieve the ambient air quality standards in the worst urban areas since this approach will minimize gasoline consumption.

To assess the fuel consumption penalty of achieving low, and perhaps unnecessarily stringent, emission levels in the future it is necessary to quantify the effect of emission control systems already installed on vehicles and predict what the penalties will be when more stringent emission control systems are used. Two studies on the effect of emission control systems on vehicle fuel consumption have been used. First, trends in fuel consumption and performance of car models produced since the 1970 model year have been determined at Du Pont. Second, a report detailing the fuel economy of more than 2,000 vehicles spanning the model years from 1957 to 1973 has recently been released by EPA (8). Data from these two studies are examined in this section and are used as a basis to assess the penalties which have occurred and to project anticipated fuel consumption penalties through the year 1976.

Test Fleet and Procedures

The Du Pont Petroleum Laboratory has purchased a fleet of representative, current model cars each year for the past 20 years to determine the road octane quality of fuels and the octane requirements of cars. Since 1970, we have purchased each year a group of six cars of the same make and model, and equipped with the same accessories. We have determined fuel consumption and acceleration performance for these cars each year after they have been operated at least 5,000 miles. Information on the individual cars is summarized in Table 7.

From 1970 to 1971 the compression ratio of most engines decreased significantly with some additional reduction in the average for all cars for 1972 and 1973 models. As shown in Table 8, the average compression ratio declined 0.9 unit from 1970 to 1971 and 0.1 additional unit in both 1972 and 1973. Averages for the six cars were within 0.1 ratio of weighted U.S. average car based on studies of Coordinating Research Council Octane Number Requirement Surveys for 1970, 1971, and 1972 (9, 10, 11).

TABLE 7

CARS USED IN FUEL ECONOMY PROGRAM

V-8 Automatic Transmissions
1970 to 1973 Models

Car Make	Air Conditioning	Displacement CID	Carburetor Barrels
A	Yes	350	2
C	Yes	455	4
D	Yes	400	2
E	Yes	351	2
F	No	302	2
G	No	318	2

TABLE 8

COMPRESSION RATIO OF CARS USED IN PROGRAM

Manufacturer's Published Ratios

Car Make	Model Year 1970	1971	1972	1973
A	9.0	8.5	8.5	8.5
C	10.0	8.5	8.5	8.5
D	10.0	8.2	8.2	8.0
E	9.5	9.0	8.5	8.6
F	9.5	9.0	8.5	8.0
G	8.8	8.6	8.6	8.6
Average	9.5	8.6	8.5	8.4
Weighted CRC Average*	9.4	8.7	8.6	-

* Based on analysis of data in CRC Octane Number Requirement Surveys for 1970, 1971, and 1972.

The weight of the vehicles increased each model year with the average increasing 291 pounds from 1970 to 1973 as shown in Table 9. About half of this increase (148 pounds) occurred between the 1972 and 1973 models and is associated primarily with safety standards involving bumpers. A change in construction of Make F from unit body to frame and body coincided with an increase of 510 pounds for that car from 1971 to 1972. There were no significant changes in rear axle ratios, tire sizes, or automatic transmission characteristics. Changes affecting carburetion, ignition timing, valve timing, and exhaust gas recirculation were made to the vehicles throughout the period to meet the successively more stringent U.S. vehicle emission standards.

Performance was measured in terms of time, in seconds, to accelerate from 25 to 60 miles per hour and 0 to 60 miles per hour. Speed and time were plotted automatically from a speed sensor on a fifth wheel. Six repeat accelerations were run, three in each direction, on a straight and level section of a public highway. Results are based on the average of the times in seconds for the six accelerations.

Fuel consumption was measured by driving over a 26 mile urban-suburban course which included approximately nine miles of city traffic and 17 miles of suburban and interstate highways. A summary of the test course is outlined in Table 10. More time was spent in city traffic than on the highway. The test vehicles were fueled from auxiliary tanks located in the trunk and the fuel consumed was determined by weight difference.

The vehicles were tested in matched pairs so that they drove the course in an identical time to insure that variations in traffic and thus variations in average speed on the course did not unduly influence the results. The drivers and the position of the cars were rotated and replicate tests of at least four determinations on each matched pair were made. Due to changes in traffic lights in the city portion of the test course the average speed has decreased from a value of 28.6 mph in 1970 to a current average value of 24.4 mph. Thus, it was not possible to compare data obtained several years ago with current data because the fuel consumption was affected by speed. A minor change has been made recently in the city portion of the driving to avoid some of the more congested streets and the average speed over the course is now about 30 mph or much closer to the value obtained when the course was originally set up in 1970. To compensate for these variations in speed in recent tests, the relationship between speed and fuel usage was determined by linear regression analysis and all fuel consumption data were normalized to an average course speed of 24.4 mph.

Performance and Fuel Consumption of 1970 to 1973 Cars

Performance in terms of acceleration times for the six car fleet has deteriorated in the past four model years as shown in Table 11. An increase of 13 percent in acceleration time occurred between the 1970 and 1971 models. This increase probably is associated with the reductions in compression ratio and other changes made to meet the emission standards. Small increases were seen also between

1971 and 1972 models and 1972 and 1973 models. When the cumulative increase from 1970 to 1973 was calculated based on the individual changes in each year, the acceleration times apparently increased 23 percent. In view of this rather large change in vehicle performance, the 1970 vehicles which had been retained at Du Pont were run in direct match against the 1973 vehicles in early 1973. These evaluations showed that the differences between the 1970 and 1973 fleets were only 10 and 11 percent rather than 22 and 23 percent. Although the vehicles were checked thoroughly and adjusted to meet manufacturer's specifications, no explanation was found for the fact that the 1970 vehicles were not capable of repeating the acceleration times that they had displayed when they were relatively new. Perhaps

TABLE 9

MEASURED WEIGHT OF CARS USED IN PROGRAM

Weight Determined With Full Fuel Tank
and a Constant Allowance For Driver

	Model Year			
Car Make	1970	1971	1972	1973
A	4,350	4,470	4,520	4,610
C	4,840	5,050	5,070	5,280
D	4,640	4,690	4,660	4,820
E	4,360	4,400	4,450	4,680
F	3,760	3,600	4,110	4,230
G	4,220	4,210	4,220	4,300
Average	4,362	4,403	4,505	4,653

TABLE 10

URBAN-SUBURBAN FUEL CONSUMPTION ROAD COURSE

	City	Suburbs	Overall
Miles	9	17	26
Time, Minutes	44	20	64
Speed, mph	12.3	51.0	24.4

TABLE 11

ACCELERATION TIME CHANGES 1970 TO 1973

Year Of Test	Models Tested	Acceleration Time 0-60	Acceleration Time 25-60
1970	1970	10.7	7.8
	1971	12.2	8.8
Increase, Percent		13	13
1971	1971	12.0	8.5
	1972	12.2	8.8
Increase, Percent		2	3
1972	1972	12.6	9.6
	1973	13.6	10.1
Increase, Percent		7	6
Cumulative Increase 1970 to 1973, Percent		23	22
1973	1970	11.4	8.6
	1973	12.6	9.5
Increase, Percent		10	11

the accumulation of approximately 30,000 miles had caused some deterioration in engine performance which was not detectable by conventional diagnostic techniques. However, it is clear that there has been a significant decrease in vehicle performance between the years 1970 and 1973 and the acceleration times of vehicles have increased by at least 10 percent. Approximately 5 percent of this increase is due to the increase in weight of the cars from 1970 to 1973 and the remainder is due to decreased power.

In this report we have chosen to express fuel usage in terms of fuel consumption. The expression fuel economy or miles per gallon has been commonly used in the past but fuel consumption or the amount of fuel used per mile is a more meaningful measure of the effect of various vehicle changes on the demand for gasoline and relates directly to the utilization of natural resources. Fuel consumption is expressed as grams per mile because of the familiarity of this term in reference to exhaust emission measurements.

Fuel consumption of the 1973 cars is greater than for the corresponding 1970 cars as shown in Table 12. Fuel consumption increased each year, ranging from 6 to more than 9 percent more. The cumulative fuel consumption increase between 1970 and 1973 calculated based on the individual changes for each year was 24 percent. Because of the implications of changes of this magnitude it was decided to make a direct check between the 1970 and 1973 model cars.

The fuel consumption of 1973 cars was 14 percent greater than 1970 cars on a direct match basis. All of the fuel consumptions were regressed against average test speed and all data normalized to an average vehicle speed of 24.4 mph. The fleet average fuel consumption data are given in the lower part of Table 12. To further check these measurements, triplicate emission tests were made on each of the vehicles and the fuel consumption calculated based on exhaust emission analysis while conducting the 1975 CVS Federal emission test procedure. These data are shown in Table 12. Again, the fuel consumption increase was 14 percent for the 1973 models when compared with the 1970 model vehicles.

TABLE 12

FUEL CONSUMPTION BY MODEL YEAR

Year Of Test	Speed mph	Models Tested	Fuel Usage: Economy Miles/Gal	Fuel Usage: Percent Loss	Fuel Usage: Consumption Grams/Mile	Fuel Usage: Percent Increase
1970	25.6	1970	14.1		199	
		1971	13.1	7	214	8
1971	24.9	1971	13.1		214	
		1972	12.4	5	226	6
1972	24.4	1972	12.7		221	
		1973	11.6	9	242	9.5
Cumulative 1970 to 1973				19		24
1973	24.4	1970	13.0		215	
		1973	11.5	12	245	14
1973*		1970	13.3		211	
		1973	11.7	12	239	14

* Calculated from exhaust analysis during CVS 1975 Test Procedure

The discrepancy between the direct determinations of the fuel consumption of the 1970 and 1973 vehicles and the calculated cumulative effect based on individual model year comparisons has not been explained at this time. However, it is believed that the most recent data, because of the greater number of tests and the fact that direct match tests were made, are more accurate.

About one-third of the increase in fuel consumption of the six cars between 1970 and 1973 was determined to be due to increased weight. The other two-thirds of the increase was due to other changes which had been made to control emissions. The effect of increased weight on fuel consumption was determined directly. The weight of the 1970 vehicles was increased approximately 500 pounds by placing weights, equally distributed, in the front and rear passenger compartments. Replicate, direct match fuel consumption measurements were made with the 1970 vehicles with and without the additional weights. The average fuel consumption data for the individual 1970 and 1973 vehicles were normalized to an average speed of 24.4 mph and are shown in Table 13 and Figure 4. The fuel consumption for the 1970 vehicles plus a sufficient amount of weight so that they equalled the weight of the 1973 vehicles is given also. The increase in fuel consumption of the individual 1973 cars ranged from -2 percent to 15 percent greater than for the 1970 cars at equal vehicle weights. The six-car fleet average increase in fuel consumption at equal weight was 9.4 percent for the 1973 cars compared with the 1970 cars.

The 9 percent increase in fuel consumption and the 10 percent increase in acceleration time can be attributed to the reduction in compression ratio and other engine changes to meet emission standards. If vehicle performance had been held constant, the increase in fuel consumption would have been even greater.

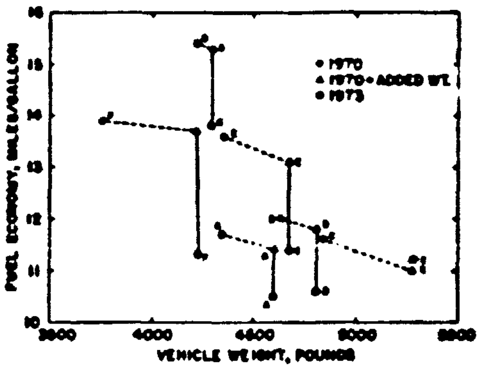

Fig. 4 – Fuel Economy Measured on Urban–Suburban Road Course of 1970 Vehicles, 1970 Vehicles with Enough Added Weight to Equal 1973 Vehicles, and 1973 Vehicles.

TABLE 13

EFFECT OF EMISSION CONTROLS ON FUEL CONSUMPTION, 1970 TO 1973

Average Speed 24.4 mph

	Economy Miles/Gal	Percent Loss*	Consumption Grams/Mile	Percent Increase
1970 A	11.7		240	
1970 A + 260 Lbs	11.4		246	
1973 A	10.5	7.9	267	8.5
1970 C	11.6		242	
1970 C + 440 Lbs	11.0		255	
1973 C	11.2	- 1.8	250	- 2.0
1970 D	12.0		234	
1970 D + 180 Lbs	11.8		238	
1973 D	10.6	10.2	265	11.3
1970 E	13.6		206	
1970 E + 320 Lbs	13.1		214	
1973 E	11.4	13.0	246	15.0
1970 F	13.9		202	
1970 F + 470 Lbs	13.7		205	
1973 F	11.3	17.5	248	21.0
1970 G	15.4		182	
1970 G + 80 Lbs	15.3		184	
1973 G	13.8	9.8	203	10.3
Avg 1970	13.0		215	
Avg 1970 + 291 Lbs	12.5		224	
Avg 1973	11.5	8.0	245	9.4

* At equal vehicle weight

Comparison of Du Pont and EPA Data

Another source of data showing the effect of emission control systems on fuel consumption is the previously mentioned EPA report (8). These fuel economy data were calculated, we understand, by the EPA from carbon monoxide and carbon dioxide measurements made during the 1972 CVS Federal emission test procedure. More accurate results would have been obtained if allowance were made for the hydrocarbons emitted -- this is particularly true for the pre-emission control cars which emitted substantially higher hydrocarbon levels than the 1970 and 1973 cars. The data from Table I of Reference 8 are illustrated graphically in the upper part of Figure 5 and the data corrected for hydrocarbon emissions are shown in the lower part of Figure 5. The fuel economies for the model years 1964 through 1967 were averaged to give representative fuel economies for the model years immediately prior to the institution of Federal exhaust emission controls in 1968. Also shown are the fuel economy data for the years 1970 and 1973. In their report, the EPA averaged the data for all vehicle weights and concluded there were no significant differences between 1970 and 1973 vehicles other than a weight effect. However, there are significant differences in the fuel economies of the 1970 and 1973 vehicles when compared with the pre-controlled vehicles at all vehicle weights above 3,500 pounds. In our opinion, the scatter in the data for vehicle weights below 3,500 pounds precludes any conclusion as to the effect of model year on fuel economy for these lighter cars. This scatter may be due to the lack of a sufficient number of data points for these lighter weight vehicles and the wide differences in the types of vehicles represented. Above 3,500 pounds, most of the vehicles are the conventional U.S., standard size sedans equipped with a relatively large displacement engine and an automatic transmission.

The Du Pont data showing a fuel consumption increase of 9.4 percent from 1970 to 1973 for a nominal 4,500 pound vehicle appears to be in reasonably good agreement with the EPA data. The fuel consumption data from the EPA study obtained from the faired curves corrected for hydrocarbon emissions shown in Figure 5 are given in Table 14. Also shown are the data from the Du Pont road test at a vehicle weight of 4,653 pounds which was the average weight of the 1973 test fleet. The fuel consumption of the 1973 vehicles compared with the 1970 vehicles increased from just under 4 percent for the 3,500 pound vehicles to more than 9 percent for the 5,500 pound vehicles. The EPA data corrected for hydrocarbon emissions comparing the

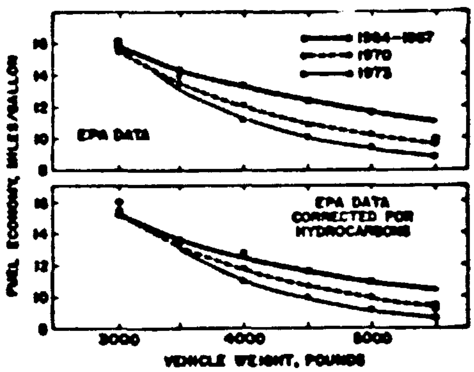

Fig. 5 — Fuel Economy of 1964 to 1973 Vehicles Calculated from Emission Test Results by the EPA.

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TABLE 14

EFFECT OF EMISSION CONTROLS ON FUEL CONSUMPTION, 1970 TO 1973

Analysis of EPA Report (8)
Corrected for Unburned Hydrocarbons

	Fuel Usage					
	Economy Miles/Gal		Percent	Consumption Grams/Mile		Percent
Weight, Lbs	1970	1973	Loss	1970	1973	Increase
3,500	13.2	12.7	3.7	213	221	3.8
4,000	11.7	11.0	6.0	240	255	6.2
4,500	10.6	9.9	6.6	265	283	6.8
4,653*	12.5	11.5	8.6	224	245	9.4
5,000	9.9	9.1	8.1	283	308	8.8
5,500	9.4	8.6	8.5	298	326	9.4

*Du Pont road tests, average weight of 1973 fleet

1973 vehicles with the pre-emission control 1964 to 1967 vehicles are shown in Table 15. Fuel consumption increased from 7 to 20 percent dependent on vehicle weight. These data illustrate the effect of reduced compression ratios and emission control systems on fuel consumption because the comparisons are made at equal weight.

TABLE 15

EFFECT OF EMISSION CONTROLS ON FUEL CONSUMPTION, 1964-67 TO 1973

Analysis of EPA Report (8)
Corrected for Unburned Hydrocarbons

	Fuel Usage					
	Economy Miles/Gal		Percent	Consumption Grams/Mile		Percent
Weight, Lbs	1964-67	1973	Loss	1964-67	1973	Increase
3,500	13.6	12.7	6.6	206	221	7.3
4,000	12.4	11.0	11.3	226	255	12.8
4,500	11.6	9.9	14.7	242	283	16.9
5,000	10.9	9.1	16.5	257	308	19.8
5,500	10.3	8.6	16.5	272	326	19.9

Estimated Fuel Consumption Losses from Pre-1968 Through 1976 Models

The information from the previous section can be used to quantify the effect of compression ratio reductions and emission control systems on fuel consumption for systems already in use. Information provided by the automotive companies and various study groups commissioned by the EPA to study future control systems can be used to project the effect on fuel consumption of future emission control systems which meet the U.S. 1976 emission standards.

The fuel consumption increases from the previous section have been plotted for Figure 6 for an average 4,500 pound vehicle. The penalties would be greater for a heavier vehicle and would be less for a lighter vehicle. The cumulative increase in fuel consumption through 1973 model year as compared with pre-emission control cars is 17 percent. This increase is due to many factors such as changes in carburetion, spark timing, compression ratio, valve timing, and the introduction of exhaust gas recirculation in the 1973 model cars. The increase however does not contain any component related to vehicle weight. Projections of increases in fuel consumption beyond the 1973 model years are difficult in that prototype 1975 and 1976 vehicles are not available for test at this time. However, during testimony at the recent remand hearings before the EPA, the automobile manufacturers discussed the fuel economy losses that would be encountered in their best effort 1975 prototype vehicles (12, 13, 14). Their estimates for the fuel economy loss for the 1975 models when compared with the 1973 models ranged from 0 to 10 percent. We have assumed an average value for the loss between 1973 and 1975 of 5 percent in terms of fuel economy. This loss, coupled with previous penalties results in a cumulative increase in fuel consumption from pre-1968 models to the 1975 models of 24 percent. The imposition of stringent nitrogen oxide emission controls in 1976 will bring about a further increase in fuel consumption. It has been estimated that the decrease in fuel economy would range from 5 to 20 percent comparing the 1976 models with the 1975 models (15, 16, 17). Again, we have assumed a median value of 10 percent economy loss between the 1975 and 1976 vehicles. This penalty results in an overall increase in fuel consumption of 42 percent for the 1976 vehicles compared with pre-emission

The foregoing discussion illustrates the extent of the increased fuel consumption penalties that reduced compression ratios and emission controls have caused and are anticipated to cause in the future. Current model full size American built cars use approximately 17 percent more fuel than pre-emission control models and it is anticipated that by the time hydrocarbons and carbon monoxide have been decreased to the 1975 interim California levels the total penalty in terms of increased fuel consumption will rise to approximately 24 percent. Imposition of the very stringent NO_x standard in 1976 as mandated by the Clean Air Act Amendments will cause the increase in fuel consumption to total 42 percent when compared with pre-emission control vehicles. The amount of the increase probably will be somewhat different with different kinds of emission control systems but the major change will take place with the scheduled imposition of the more stringent standards in 1976 as shown in Figure 6.

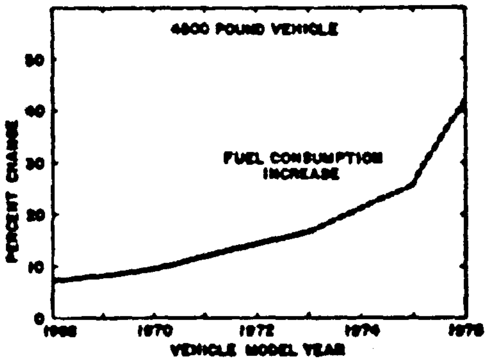

Fig. 8 – Estimated Increase in Fuel Consumption Due to the Application of Emission Control Systems.

Increases up to 42 percent in the gasoline consumed by vehicles require that the need for such stringent automotive exhaust emission standards as mandated by the Clean Air Act Amendments of 1970 be examined critically. If the ambient air quality standards can be met with less stringent emission control, great savings in domestic crude oil and decreased demand for imported crude oil will be realized.

TOTAL EMISSION CONTROL SYSTEMS

Automobile exhaust emission standards sufficiently stringent to achieve ambient air quality standards are significantly lower than the current U.S. standards (for 1973) thus requiring some form of exhaust treatment device for conventional engines. Both catalytic and thermal reactor emission control systems can provide the required degree of control. However, most catalytic systems require lead-free gasoline and this restriction results in increased crude oil use. If lower octane unleaded fuel is used, the compression ratio of the engines must be reduced resulting in higher fuel consumption. If current octane quality is maintained with unleaded fuel, more crude is required to produce a given volume of gasoline. On the other hand, emission control systems based on thermal reactors are compatible with leaded fuel, and high compression ratios which results in minimum fuel consumption. Thus, if both systems can meet the necessary standards and both impose an equal fuel consumption penalty due to the modifications to the engine that must be made to enable the control system to function properly, the thermal system used with leaded gasoline will result in the lowest overall energy consumption. Also, the thermal system can be engineered to last the life of the car without added maintenance such as catalyst replacement. The development of the first and second generation total emission control systems or TECS I and TECS II was described in an earlier publication (18). The TECS I vehicles were designed in 1969 and 1970 to meet the then existent exhaust emission standards for the 1975 model year as set forth by the U.S. government and by the State of California. After the passage of the Clean Air Act Amendments of 1970 a second generation system, TECS II, was developed in an attempt to meet the more stringent levels for 1975-1976 mandated by the Act. Recently, the TECS III system has been developed to meet emission levels compatible with the attainment of the ambient air quality standards while minimizing the fuel consumption penalty.

TECS I - the first generation vehicles were successful in meeting the goals of the former 1975 U.S. and California standards. Six TECS I vehicles of Car Make A were operated in a 10-month field test by the California Air Resources Board. The fleet average emission levels remained below the former 1975 standards throughout this test. Extended operation of the TECS I vehicles revealed two major problems. First, fuel consumption was significantly higher than comparable unmodified production 1970 vehicles. During the 10-month test conducted in California the TECS I vehicles used 17 percent more fuel than did the unmodified production vehicles. The second problem was excessive wear on various parts of the engine caused by the recirculation of metal oxides from the exhaust system back into the engine with the exhaust gas recirculation gases. Two solutions to this excessive wear problem were proposed in our previous publication (18) but neither solution had been demonstrated in extended vehicle durability tests.

TECS II - the second generation vehicles included Car Make A, a full size sedan equipped with a V-8 engine and automatic transmission, and Car Make B, a sub-compact equipped with a small four-cylinder engine and manual transmission. The TECS II vehicles approached but did not meet the emission levels required by the 1976 standards. Hydrocarbon levels were below 0.25 gram per mile but carbon monoxide levels were about 6 grams per mile and nitrogen oxide levels were about 0.6 gram per mile. To meet the very low nitrogen oxide levels, carburetors were operated very rich which increased fuel consumption. Car Make A used 34 percent more fuel and Car Make B 20 percent more fuel when compared with respective unmodified production vehicles.

TECS III - In light of the studies showing that less stringent emissions standards than those mandated by the Clean Air Act probably would achieve national ambient air quality standards and the growing concern over the increased utilization of fuel by low emission cars, it was decided to develop a third generation total emission control system or TECS III. The goal of this program was to achieve emission levels considered adequate to meet national ambient air quality standards in major urban areas while minimizing the fuel consumption penalty which usually accompanies the attainment of such low emission levels. An additional goal was that the components selected for the system demonstrate the potential to operate for the life of the vehicle with no significant added maintenance and with virtually no deterioration in emission control.

These criteria resulted in the selection of the same general systems used for the TECS I and TECS II vehicles. Exhaust manifold thermal reactors were used to control hydrocarbon and carbon monoxide levels because of their demonstrated potential to meet low emission levels for long periods of time. Exhaust gas recirculation was used in combination with modified carburetion and ignition timing to control nitrogen oxide levels because EGR had been shown to be effective in controlling nitrogen oxide levels, to be compatible with the use of exhaust manifold reactors, and to operate satisfactorily for extended mileages. The final component chosen was a muffler lead trap also previously described in an earlier publication. The exhaust lead trap would permit the use of less expensive, high octane leaded gasolines enabling the continued use of higher compression ratio, more efficient engines, while significantly reducing the emission of lead compounds to the environment (19). In addition to the control system components just described, all vehicles were equipped with production, closed positive crankcase ventilation systems and evaporative emission control systems.

Design of TECS III

Car Makes A and B were chosen for the development of TECS III because of our experience with these vehicles and the fact that they represented both current production standard size vehicles equipped with V-8 engines and automatic transmissions as well as the sub-compact cars representative of both domestic and foreign production. A description of the TECS III vehicles and the type of control system installed is summarized in Table 16.

TABLE 16

TECS III VEHICLES

	Car Make A	Car Make B
Vehicle	Four-door sedan 4,500 pounds	Two-door hardtop 2,250 pounds
Engine	350 CID V-8	1600 cc In-line 4 cylinders
Transmission	3 Speed automatic	4 Speed manual
Thermal Reactor	Modified Type VIII insulated with air injection	Type V shielded with air injection
EGR	Below throttle, ~ 10 percent	Above throttle, 13 percent
Traps	None	Muffler lead trap
Carburetion	Moderately enriched, fast release choke	Moderately enriched, fast release choke
Spark Timing	Modified vacuum advance on start up	Modified vacuum advance on start up

TECS III for Car Make A is shown schematically in Figure 7. The exhaust manifold reactors shown in Figure 8 were modifications of the Type VIII insulated reactor previously described (18). The interior core of the reactor is a large diameter open chamber with a single baffle located across the extended outlet pipe. The exhaust gases enter the core through extended exhaust ports and exit from these ports through rectangular slots which contain directional vanes. The core consisted of concentric, double walled cylinders to reduce the heat loss from the inner core to the outer shell of the reactor. To further reduce heat loss the outer shell and outlet pipe from the reactor were covered with one-half inch of fibrous ceramic insulation. Secondary air was injected into the exhaust ports and into the ends of the reactors to provide an overall oxidizing atmosphere.

The exhaust gas recirculation system for the Make A TECS III vehicle utilized two 1973 production EGR valves for this make vehicle. Exhaust gas was taken from the exhaust pipe ahead of the muffler on one side of the dual exhaust system, routed through the two EGR valves in parallel, and introduced below the secondary throttle plates of the four-barrel carburetor. The EGR valves were operated by manifold vacuum obtained from a port in the carburetor and were turned off at idle and at wide-open throttle.

A modified version of the production four-barrel carburetor normally used for this engine was employed. Metering was set to give a maximum vacuum air-fuel ratio at idle and a gradual leaning of the air-fuel ratio at higher speeds reaching an air-fuel ratio during cruising speeds of 50 to 60 mph somewhat in excess of 13 to 1. The production intake manifold was replaced with a dual-passage Offenhauser manifold and the intake system heat was supplied by engine coolant routed directly from the outlet of the engine through the internal passages in the intake manifold. A production 1970 distributor was used but the basic timing was advanced 4° from the manufacturer's specifications for 1970 to improve fuel economy.

The TECS III installed on Car Make B is shown schematically in Figure 9. The thermal reactor, shown in Figure 10, was a Type V exhaust manifold reactor modified to fit the Car Make B engine. This reactor contained an inner core to promote mixing of the air and the exhaust gases and a double walled heat shield to reduce heat loss to the outer shell. No external insulation was used.

The exhaust gas recirculation system for Car Make B is shown schematically in Figures 10 and 11. The exhaust gas was withdrawn from the exhaust ports in the immediate vicinity of the exhaust valve. The individual lines from each of the four ports were manifolded together to take advantage of the exhaust blowdown process to force the exhaust gas through the EGR line. A vacuum operated, on-off valve prevented exhaust gas recirculation during cold start up. Exhaust gas was delivered to the carburetor below the venturi and above the throttle plate.

The carburetor used on Car Make B was selectively enriched throughout the metering range to aid in the control of nitrogen oxide emissions. A vacuum spark advance control system sensitive to coolant temperature was incorporated to prevent manifold vacuum advance during cold starts until the coolant reached normal operating temperatures.

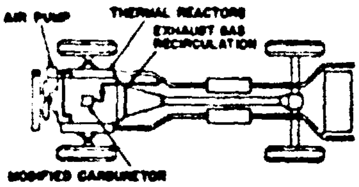

Fig. 7 – TECS III on Car Make A.

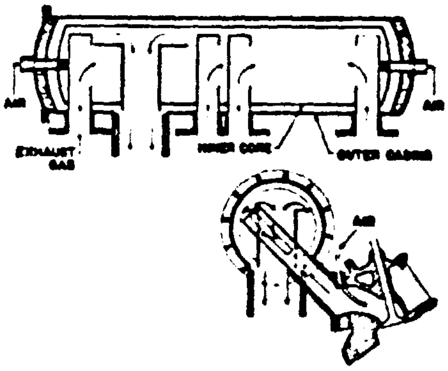

Fig. 8 – Modified Type VIII Thermal Reactor for Car Make A.

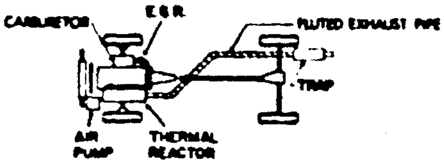

Fig. 9 – TECS III on Car Make B.

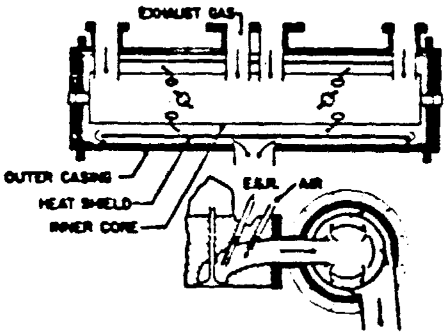

Fig. 10 – Type V Thermal Reactor for Car Make B.

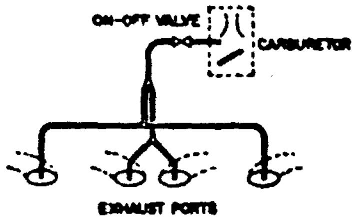

Fig. 11 – EGR System for Car Make B.

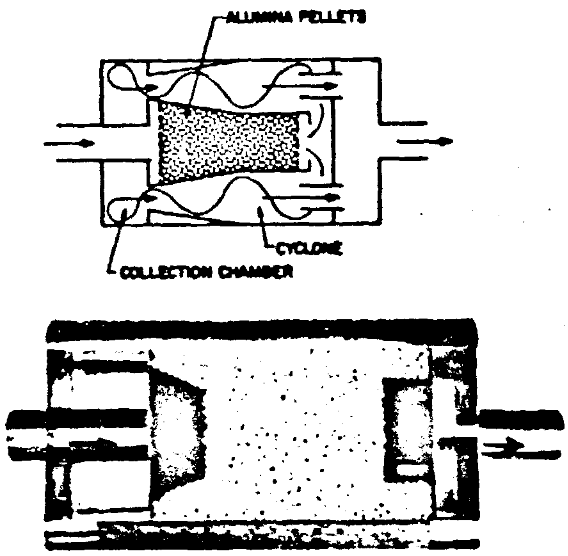

Fig. 12 – Muffler Lead Trap for Car Make B.

The trapping system installed on Car Make B contained fluted pipe from the outlet of the exhaust manifold reactor to the rear of the car to help cool the exhaust gases. The conventional muffler was replaced by the muffler lead trap shown in Figure 12 (19). The trap was the same size and shape as the production muffler and was located in the same place. The trap contained the bed of alumina pellets which agglomerated lead particles in the exhaust stream into large particles which could be separated from the exhaust gas stream by the twin cyclone separators and stored in collection chambers. The chambers had sufficient capacity to hold all the lead salts collected during 100,000 miles of operation on conventional leaded gasolines.

Emission Control with TECS III

Car Make B equipped with TECS III has recently completed a 50,000-mile durability test involving both road and laboratory chassis dynamometer operation. The road mileage accumulation consisted first of a 4,000-mile, cross-country trip from the east coast to Denver, to the continental divide, and back to the east coast. For the remainder of the mileage accumulation test the vehicle was driven during the daytime on an urban-suburban driving route in the South Jersey area. During the evening and nighttime hours mileage was accumulated on the programmed chassis dynamometer following a simulated turnpike driving schedule with speeds varying between 40 and 60 mph with an average speed of 50 mph. An unmodified production version of Car Make B was run as a companion car with all of its mileage being accumulated in a similar manner except that it did not make the cross-country road trip. Commercial gasoline containing 2.2 grams of lead per gallon and conventional multigrade lubricating oils meeting the manufacturer's specifications were used for these tests. Emission levels of both the unmodified vehicle and the vehicle equipped with TECS III were obtained at periodic intervals.

The hydrocarbon, carbon monoxide, and nitrogen oxide levels from both vehicles throughout the 50,000-mile test are shown in Figures 13, 14, and 15. The average emission levels for the 50,000-mile test are shown in Table 17.

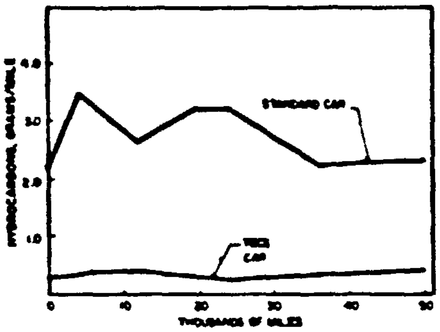

Fig. 13 – Hydrocarbon Emissions for Car Make B During 50,000–Mile Test.

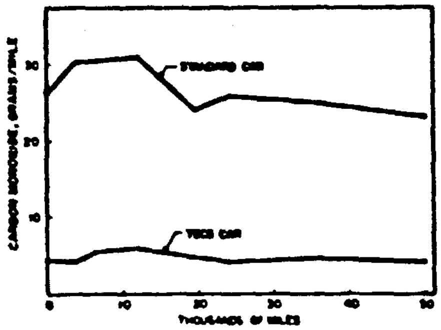

Fig. 14 – Carbon Monoxide Emissions for Car Make B During 50,000–Mile Test.

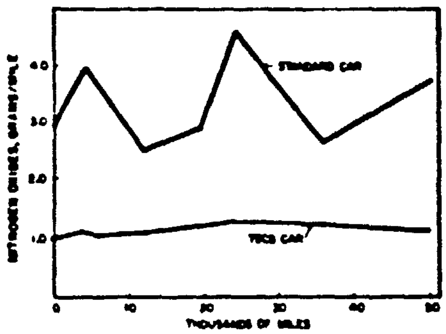

Fig. 15 – Nitrogen Oxide Emissions for Car Make B During 50,000–Mile Test.

TABLE 17

EMISSION LEVELS OF CAR MAKES A AND B WITH TECS III

	Emission Levels, Grams Per Mile 1975 CVS Test Procedure		
	CO	HC	NO_x
Car Make A	10.6	0.75	1.2
Car Make B	4.7	0.31	1.2
Suggested Emission Levels Needed To Attain Air Quality Standards	15–40	0.4–0.8	1.5–3.0

The average emission levels from replicate tests conducted with Car Make A equipped with TECS III are shown in Table 17. Also included are the emission levels previously indicated to be needed to attain the ambient air quality standards.

The emission levels from Car Makes A and B with TECS III are below the needed emission levels and it is clear that the emission control system technology represented by the TECS III vehicles is capable of reducing all of the exhaust emission pollutants to very low levels. Also, exhaust emission levels well below those indicated as being needed to achieve the ambient air quality standards can be maintained for at least 50,000 miles.

Fuel Consumption and Vehicle Performance

Improvements in carburetion and ignition timing incorporated in the TECS III vehicles have greatly reduced the fuel consumption and performance penalties that were associated with the earlier first and second generation total emission control systems. The fuel consumption for the TECS III vehicle of Car Make A is given in Table 18. These values were obtained from replicate measurements made during

TABLE 18

FUEL CONSUMPTION OF CAR MAKE A WITH AND WITHOUT TECS III

Average Speed 30 mph

	Fuel Usage			
	Economy Miles/Gal	Percent Loss*	Consumption Grams/Mile	Percent Increase*
Unmodified 1970 Production	14.3		196	
Unmodified 1973 Production	13.2	7.6	212	8.2
TECS III	13.2	7.6	212	8.2

*Compared with 1970

direct match tests over the urban-suburban road driving course as previously described. The fuel consumption penalty for Car Make A equipped with TECS III was 8.2 percent when compared with the 1970 unmodified production vehicle. This improvement in fuel consumption is all the more significant when it is compared with the unmodified 1973 production vehicle since the fuel consumption for the TECS III was equivalent to that of the 1973 production vehicle.

The performance of Car Make A unmodified and equipped with TECS III is shown in terms of wide-open-throttle acceleration times in Table 19. The TECS III vehicle was almost equivalent to the unmodified 1970 production vehicle in acceleration performance.

The fuel consumption of Car Make B equipped with the TECS III system is compared with the unmodified production vehicle in Table 20. Again, the results

TABLE 19

PERFORMANCE OF CAR MAKE A WITH AND WITHOUT TECS III

	Wide-Open-Throttle Acceleration Times, In Seconds, Level Road	
	0-60 mph	50-70 mph
Unmodified 1970 Production	12.3	9.0
TECS III	12.8	9.4
Increase, Percent	4.0	4.4

TABLE 20

FUEL CONSUMPTION OF CAR MAKE B WITH AND WITHOUT TECS III

Average Speed 24.4 mph

	Fuel Usage			
	Economy Miles/Gal	Percent Loss	Consumption Grams/Mile	Percent Increase
0 Miles				
Unmodified 1971 Production	25.0		112	
TECS III	22.4	10.4	125	11.6
24,000 Miles				
Unmodified 1971 Production	25.3		111	
TECS III	24.2	4.4	116	4.5
56,000 Miles				
Unmodified 1971 Production	24.0		117	
TECS III	22.8	5.0	123	5.1
Average for TECS III		6.6		7.1

represent replicate match tests on the urban-suburban road course. Improvements in the TECS III system in terms of carburetor metering and ignition timing resulted in an average fuel consumption penalty of 7.1 percent as compared with the unmodified production vehicle. It is expected that additional improvements in carburetor metering and ignition timing will reduce this penalty to an even smaller value.

The performance of Car Make B in terms of acceleration times with the TECS III is compared with the unmodified production vehicle in Table 21. Minor improvements in ignition timing, carburetion, and, most importantly, a significant reduction in the pressure drop across the muffler lead trap when compared with the lead trap incorporated in the TECS II vehicle resulted in a significant improvement in acceleration time for the TECS III vehicle. When compared with the unmodified vehicle the TECS III car had an 11 percent increase in wide-open-throttle acceleration time.

TABLE 21

PERFORMANCE OF CAR MAKE B WITH TECS III

	Wide-Open-Throttle Acceleration Times, In Seconds, Level Road 0-60 mph
Unmodified 1971 Production	21.9
TECS III	24.3
Increase, Percent	11

Based on these results it is clear that emission control systems which are capable of reducing emission levels on both large and small vehicles to values which apparently are compatible with meeting the national ambient air quality emission standards have been developed. Furthermore, these emission control systems impose only minor penalties in terms of both fuel consumption and vehicle performance when compared with unmodified production vehicles. These systems are compatible with the continued use of leaded gasoline and thus the motorist can gain the benefits of less expensive gasoline and higher compression, more efficient engines.

Performance of Lead Traps

Lead traps can be used in conjunction with thermal reactor based emission control systems to reduce the emission of lead to the environment. Total lead emissions can be reduced by 80 to 90 percent and airborne lead particles by 65 to 75 percent with the systems developed by Du Pont (19).

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TABLE 22

TOTAL LEAD EMISSION RATE FROM CAR MAKE B WITH AND WITHOUT TECS III

	Average Total Lead Emission Rate During 50,000-Mile Tests	
	Grams Per Mile	Reduction, %
Unmodified 1971 Production	0.0348	
TECS III	0.0063	82

Lead emission rates from both the unmodified Make B vehicle and the vehicle equipped with TECS III were measured throughout the 50,000-mile test according to procedures previously described (20). The average total lead emission rate for the two vehicles is shown in Table 22. The muffler lead trap system produced an 82 percent reduction in the total amount of lead emitted over the 50,000-mile test. Lead size distribution measurements were made on both cars at approximately the mid-point and the end-point of the test. The lead emission rates in the different particle size categories for the two vehicles are shown in Table 23. The muffler lead trap was extremely effective reducing the larger size particles by better than 97 percent. More importantly, it was also very effective in reducing the size particles which would be expected to remain airborne for significant lengths of time. Even for the finest particles, those below 0.3 microns in diameter, the lead trapping system effected a 77 percent reduction in lead emissions.

TABLE 23

SIZE DISTRIBUTION OF LEAD EMISSIONS FROM CAR MAKE B WITH AND WITHOUT TECS III

	Lead Emission Rate, Grams Per Mile — Size Range in Micrometers			
	> 9.0	1.0 to 9.0	0.3 to 1.0	< 0.3
Unmodified 1971 Production				
20,000 Miles	0.019	0.018	0.024	0.036
51,000 Miles	0.013	0.016	0.037	0.051
Average	0.016	0.017	0.030	0.044
TECS III				
26,000 Miles	0.0005	0.0016	0.0024	0.0075
51,000 Miles	0.0003	0.0029	0.0049	0.0129
Average	0.0004	0.0022	0.0036	0.0102
Reduction, Percent	97.5	87	88	77

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The muffler lead traps have been evaluated on unmodified production versions of Car Make A. Traps were installed on two vehicles and they were operated for 50,000 miles on a conventional leaded gasoline containing 2.2 grams of lead per gallon under the modified AMA mileage accumulation cycle on a programmed chassis dynamometer. The average lead emission rate for the cars equipped with the muffler lead traps and for the unmodified vehicles equipped with only the standard muffler are shown in Table 24. The traps reduced total lead emissions by 87 percent. Lead size distribution measurements were made from the vehicles equipped with the muffler lead trap at approximately 25,000 miles and the data along with corresponding data from an unmodified production vehicle are shown in Table 25. As in the case of Car Make B, the muffler lead traps were extremely effective, reducing the larger particle sizes by 98 percent and reducing the smallest size particles by 61 percent.

TABLE 24

TOTAL LEAD EMISSION RATE FROM CARS OF MAKE A WITH AND WITHOUT MUFFLER LEAD TRAP

	Average Lead Emission Rate During 50,000-Mile Tests	
	Grams Per Mile	Reduction, %
Unmodified 1970 Production	0.108	-
Two 1970 Production Vehicles With Muffler Lead Trap	0.014	87

TABLE 25

SIZE DISTRIBUTION OF LEAD EMISSIONS FROM CAR MAKE A WITH AND WITHOUT MUFFLER LEAD TRAP

	Lead Emission Rate, Grams Per Mile Size Range in Micrometers			
	> 9.0	1.0 to 9.0	0.3 to 1.0	< 0.3
Unmodified 1970 Production	0.038	0.023	0.019	0.028
Two 1970 Production Vehicles Vehicles with Muffler Lead Trap	0.00063	0.0030	0.004	0.010
	0.00084	0.0020	0.002	0.011
Average	0.00073	0.0025	0.003	0.011
Reduction, Percent	98	89	85	61

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CONCLUSIONS

The automotive exhaust emissions standards mandated by the Clean Air Act Amendments of 1970 appear to be more stringent than necessary to attain the ambient air quality standards in major urban areas. Based on trends in ambient air levels, traffic, and automotive emission rates the following exhaust emission standards based on the 1975 CVS Federal Test Procedure appear to be adequate to meet the ambient air quality standards:

Carbon Monoxide	15 to 40 Grams Per Mile
Hydrocarbons	0.4 to 0.8 Gram Per Mile
Nitrogen Oxides	1.5 to 3.0 Grams Per Mile

Current 1973 model standard size cars use from 7 to 20 percent more gasoline per mile than comparable pre-emission control cars. This penalty in fuel consumption is predicted to double if emission controls meeting the 1976 standards mandated by the Clean Air Act are used.

If vehicle emission standards were changed to the values suggested above as being adequate to attain ambient air quality standards, noncatalytic exhaust emission control systems based on thermal reactors, exhaust gas recirculation, and engine modifications could be employed. Such systems would permit the continued use of high octane leaded gasoline giving motorists the opportunity to use the lowest cost fuel in high compression, more efficient engines. The fuel consumption of cars using such control systems is less than 8 percent greater than corresponding 1970 production vehicles or approximately equivalent to the current 1973 production cars. Exhaust particulate traps could be used to control lead particle emissions, if needed.

The current strategy of requiring all cars to meet very stringent emission standards even though less stringent standards appear to be sufficient to attain the ambient air quality standards even in the worst areas in the country should be reexamined. The critical crude oil supply situation demands that a strategy be developed which assures clean air but is least wasteful of our natural resources.

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