SMOG

A REPORT TO THE PEOPLE

By Lester Lees · Mark Braly · Mahlon Easterling · Robert Fisher · Kenneth Heitner · James Henry · Patricia J. Horne · Burton Klein · James Krier · W. David Montgomery · Guy Pauker · Gary Rubenstein · John Trijonis

ENVIRONMENTAL QUALITY LABORATORY
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LIST OF ABBREVIATIONS

APCD	Air Pollution Control District
ARB	Air Resources Board
A.S.M.E.	American Society of Mechanical Engineers
CNG	Compressed natural gas
CO	Carbon monoxide
CTA	Chicago Transit Authority
CVS	Constant volume sampling
DOT	Department of Transportation
EPA	Environmental Protection Agency
EQSC	Environmental Quality Study Council
GSA	General Services Administration
HC	Hydrocarbons
LFG	Liquefied flammable gas
LNG	Liquid natural gas
LPG	Liquid petroleum gas
NO	Nitric acid
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
PCV	Positive crankcase ventilation
ppm	Parts per million
pphm	Parts per hundred million
scfm	Standard cubic feet per minute
TAC	Technical Advisory Committee
VSAD	Vacuum spark advance disconnect

FIGURES

FOREWORD

The Environmental Quality Laboratory (EQL) traces its origins to a series of discussions initiated by Caltech President Harold Brown on the feasibility of a Caltech Air Pollution Laboratory aimed at alleviating the smog problem in the South Coast Air Basin. In an address to the Institute for the Advancement of Engineering on February 28, 1970,[1] Dr. Brown summarized the main conclusions of a faculty-JPL study group on smog led by Professor Carver Mead that preceded the formation of the EQL. To quote from Dr. Brown's address, the most important conclusion "is that there are other factors which are as important or more important than the technological ones. . . . Unless expert social scientists are available—and I mean not only economists to examine the economic balance, but political scientists, sociologists, psychologists, and so on—the study will be done in too narrow a context. Although it will give the right answers to its own questions, it will prove to have overlooked questions more important than those which it asked."

Our experience in working on the smog problem over the past year fully confirms Dr. Brown's observations. The EQL team engaged in this study included social scientists, lawyers, engineers, and graduate and undergraduate students. Each of us had to learn that the social, cultural, legal, economic and technical factors interact strongly and therefore cannot be treated separately. In addition to innumerable internal debates, seminars and memos, we had the benefit of numerous discussions with people in industry, in environmental action groups, and in government at all levels who are concerned with air pollution.

At the outset of the EQL study we made the decision to consider only those air pollution control strategies that comply with the spirit (if not the letter) of the Clean Air Act of 1970. In the spirit of that act this report describes a "management standards" approach for achieving drastic reductions in the number of "smoggy" days in the South Coast Air Basin of California by the end of 1977. In order to illustrate the kinds of control measures that are required if the management air quality standards are to be satisfied, we chose one particular control strategy for detailed study. This strategy, called EQL Strategy #1, is based on new "technical" control measures on stationary sources and *used* motor vehicles, combined with a set of social and economic incentives and disincentives designed to encourage the shift to low-pollution motor vehicles, to encourage the use of multiple-occupancy vehicles (buses, carpools, etc.), and to halt or at least reduce the annual rate of increase in gasoline consumption in the Basin.[2] If EQL Strategy #1 is followed, we estimated that the average number of days per year on which the California

[1]Brown, H.: "The University and Environmental Research," *Bulletin of the California Institute of Technology,* Vol. 79, No. 1, March 7, 1970.

[2]Some of these technical control measures are also included in the Implementation Plan submitted by the State to the U.S. Environmental Protection Agency in February, 1972.

ambient air quality standard on photochemical oxidants is violated would be reduced from 241 days in 1970 to 50 days by the end of 1975, and to 25 days by the end of 1977.

The measures we propose are neither painless not inexpensive. We did not find any "magic solutions." For example, the cost of EQL Strategy # 1 for this Basin is estimated at about one billion dollars through the end of 1975, or about $100 per head. Whether or not the results that could be achieved are worth the effort and expense is up to the people of the South Coast Air Basin to decide.

An earlier version of this report called EQL Report # 4, dated January 15, 1972, consisted of Part I, which contained a summary of EQL Strategy 1, and Part II, which briefly outlined the legislative and administrative actions required. The present final edition of the EQL air pollution report contains a revised and updated version of Part I and a new Part II, entitled "Supporting Information and Analysis."

Our work on the short-term (1972-1977) air pollution control problem raised important and difficult questions about the long-range (1982-2000) problem of controlling air pollution in the South Coast Air Basin. Members of the EQL staff are studying new technologies, social and economic incentives, modes of transportation and patterns of land use and development in an attempt to formulate a long-range strategy.

LESTER LEES
Director, Environmental Quality Laboratory

Pasadena, California
June 15, 1972

SMOG—A REPORT TO THE PEOPLE

PART I

EQL STRATEGY NO. 1—A SUMMARY

PART 1: SUMMARY

In 1970, 25 years after California enacted its first air pollution control law, Los Angeles County still had air that did not meet state air quality standards for photochemical oxidants (such as ozone) on 65% of the days, for carbon monoxide on 55% of the days, and for nitrogen dioxide on 31% of the days. Clean air was three decades behind us, and state and local enforcement agencies estimated that it was two decades ahead—in 1990. The federal government said otherwise. With the enactment of the Clean Air Amendments of 1970 the timetable for clean air was moved ahead to 1975—or 1977, at the latest.

The California strategy, on one hand, and the federal requirements, on the other, seemed to represent two extremes. One was so slow that the time when economic and population growth would overtake control measures could be readily predicted. This would happen sometime in the middle of the 1980's. The other was so rapid that only a sudden and wrenching curtailment of transportation and economic activity could produce the required results. In the latter case, the cure might be worse than the disease.

An interdisciplinary team of researchers at the Environmental Quality Laboratory concluded that for air basins with critical air pollution problems—like that of Los Angeles and surrounding areas—a compromise was needed. The team put together a strategy that seemed practical and—when added to pollution control measures presently in effect or planned—would reduce the number of substandard, smoggy days 80% by 1975 and 90% by 1977.

EQL Strategy #1—so designated since it was only one of many possible combinations—would introduce several novel features to air pollution control. It would focus on the millions of motor vehicles presently on the road instead of relying, as has been the case heretofore, only on increasingly stringent control of new cars. Engine and evaporation emissions from the existing stock of cars would be reduced by a number of practical means: changing the fuel from gasoline to the cleaner-burning natural gas or propane; retrofit devices and engine modification; mandatory inspection and testing of vehicle emissions. Somewhat more radical were socio-economics policies that would reduce use of motor vehicles significantly and thus, for the first time, test the motorist's determination to reduce air pollution by asking of him a personal sacrifice of a measure of his freedom in deciding where, when, and how he would use his car. Stationary sources would be recognized as significant causes of pollution in the Basin and efforts to make further emission reductions at power plants, industry, and even service stations, would be redoubled.

The cost of such a program is not small—about $1 billion for those technical measures to which a dollar value can be attached. That's about $100 a head for everyone in the South Coast Air Basin, or, looked at another way, it's less than 35 miles of a new freeway in Los Angeles.

I/1 NEED FOR A NEW AIR POLLUTION CONTROL STRATEGY IN THE SOUTH COAST AIR BASIN

Twenty five years ago the California State Legislature passed its first air pollution control legislation. During the last quarter-century California has come to be recognized as a world leader in air pollution control. Yet in 1970 the California state ambient air quality standard on photochemical oxidants (including ozone), chosen so that it lies "below that (level) associated with aggravation of respiratory diseases,"[1] was violated on 241 days in the South Coast Air Basin. In that same year the standard on nitrogen dioxide was exceeded on 115 days and the standard on carbon monoxide (12 hour average) was violated on 203 days.[2]

Without the air pollution control measures on stationary sources and new motor vehicles now in effect the situation would be even worse. But if the State and local control program in effect in 1971 were to be followed for the rest of this decade, it would lead at best to a relatively slow improvement in air quality in this Basin. For example, it is estimated that the California standard on oxidents would still be violated on 140 days in 1975 and on 85 days in 1980. The two principal reasons for this slow progress are: (1) the low "death rate" of dirty old cars and the low "birth rate" of new motor vehicles that meet stringent exhaust emission and evaporative control standards; (2) the increase in gasoline consumption at a rate of about 4% per year. The EQL is certainly not the only group to conclude that a new air pollution control strategy that would deal effectively with these two problems is urgently needed (Section II/1.1).

While the EQL study of the "smog" problem was in progress, the federal government began to exert pressure for a much faster rate of improvement in air quality than the 1971 State and local strategy could possibly provide (Section II/1.2). On April 30, 1971, the Administrator of the Environmental Protection Agency, acting under the provisions of the Federal Clean Air Act of 1970 (as amended), published new federal air quality standards that are even more stringent than the California standards. Except for the standard on nitrogen dioxide, the federal standards are not to be exceeded more than once a year. These standards must be attained within three years of the date of final approval of the state plan, except that an extension of up to two years may be granted by the Administrator.

Thus, the South Coast Air Basin is required to meet the new federal ambient air quality standards by 1975, except in the case of photochemical oxidants, for which the EPA granted a two-year extension.

If the state agencies do not prepare a satisfactory implementation plan, the Act empowers the Administrator of EPA to develop such a plan, and if the states do not have the authority to carry out the plan, the Act has given broad authority to the Administrator. Even if the Administrator does not act,

[1] Air Resources Board, Annual Report to Governor Ronald Reagan and the Legislature, entitled *Air Pollution Control in California, 1970*, January, 1971, Table 1, p. 24.

[2] *Profile of Air Pollution Control*, Los Angeles APCD, 1971.

private citizens and groups can sue under the Act to force compliance with federal ambient air quality standards.

In contrast to these new federal requirements the Los Angeles County Air Pollution Control District stated in its 1971 annual report[3] that the present strategy would bring air quality up to the California state standards by 1990!

Thus, the present California control program places "clean air" so far in the future that any improvements in air quality might well be overtaken by population and economic growth long before the distant "target date" is reached. But to reduce violations of air quality standards from the present level of 241 days per year for photochemical oxidants (for example) to literally *one day per year* within the period allowed by the Clean Air Act would require drastic curtailments in the rates of consumption of gasoline, natural gas and residual oil in the Basin, and a sudden brake on economic activity. The most effective practical approach must lie somewhere in between these two extremes.

The approach adopted in this report occupies this "middle ground." We recognize that the South Coast Air Basin in California is faced with a uniquely difficult air pollution control problem. Because of its special meteorology and topography, and the enormous rate of consumption of fossil fuels,[4] even the best technology likely to be available in this decade would not reduce the average number of days per year on which State air quality standards on photochemical oxidants are violated below a lower bound of 10-15 days.[5] We chose for detailed study a particular control strategy (called EQL Strategy #1) designed to drive toward these lower limits as rapidly as feasible in the *spirit* (if not the letter) of the Clean Air Act of 1970 (as amended).[6] In summary, EQL Strategy #1 is based partly on new "technical" control measures to reduce emissions from stationary sources and *used* motor vehicles.[7] But even in the short run (1972-1977) we found it necessary to combine these technical measures with a set of social and economic incentives and disincentives designed to encourage the shift to low-pollution motor vehicles, to encourage the use of multiple-occupancy vehicles (buses, carpools, etc.), and to reduce the annual rate of increase in gasoline consumption in the Basin. These control measures are not supposed to be all-inclusive, and the "mix" is not optimized for minimum cost to achieve a given level of air quality.[8] But they are representative of the kinds of measures that are required.

[3]*Profile of Air Pollution Control,* Los Angeles APCD, 1971.

[4]List, E. J., *Energy Use in California: Implications for the Environment,* EQL Report #3, December, 1971.

[5]The California ambient air quality standard states that the maximum daily one-hour average oxidant level should not exceed 0.10 ppm (parts per million).

[6]Later (Section II/1.1) this strategy is compared with a strategy that relies mainly on new car controls and does not meet the requirements of the Clean Air Act of 1970 (as amended) even in spirit.

[7]Some of these measures are included in the new State Implementation Plan (February, 1972)

[8]Cost optimization for a wide range of strategies is treated in some detail by Trijonis, John, *An Economic Air Pollution Model. Application: Photochemical Smog in Los Angeles County in 1975,* Summer, 1972.

I/2 EQL STRATEGY NO. 1

I/2.1 General Features

The EQL strategy depends on the concept of "management standards," based on technical, economic and social feasibility, that would serve as milestones enroute to the clean air required by both the California and federal ambient air quality standards. These management standards would set a first "target date," by which time significant *percentage reductions* are to be achieved in the number of days per year that ambient air quality standards are violated in the Basin. By the second "target date" substantial percentage reductions would have to be made in the *remaining* number of these "objectionable" days, etc. This approach provides the flexibility required, and allows for "feedback" from the public as it assesses the beneficial effects of specific control measures, measured against the economic and social costs of these measures.

The Clean Air Act of 1970 (as amended) appears to give the Administrator of the EPA discretionary authority to approve such an approach by a state during the period in which a time extension is in effect. Such extensions can be granted when (among other reasons) the necessary technology is unavailable; when the state has implemented reasonable alternatives (as would be the case if a strategy similar to EQL Strategy #1 were adopted); when reasonable interim measures are provided for (the basis of the EQL strategy). EPA regulations published in the Federal Register on August 14, 1971 encourage each state "to consider the socio-economic impact and the relative costs and benefits" of alternative strategies. Public welfare and productive capacity are to be weighed as well as public health.

Before discussing specific control measures contained in EQL Strategy #1, certain desirable main features of any such strategy are outlined as follows:

1. In order to be credible the "target dates" for the achievement of management standards ought to be set well within the present decade and not in the vague future one or two decades hence. December 31, 1975 is a reasonable first target date (corresponding roughly to the end of the 3-year period allowed under the Clean Air Act), and December 31, 1977 is a reasonable second target date (corresponding to the end of the 2-year extension period).

2. These management standards should be expressed in terms of percentage reductions in the average number of days per year on which the California (or federal) standards on oxidants, nitrogen dioxide and carbon monoxide are exceeded. For example, a reasonable goal is to reduce these "objectionable" days in the South Coast Air Basin from the 1970 level of 241 per year to a level of 50 days per year by the end of 1975 (a reduction of 80%). By the second target date, at the end of 1977, the objectionable days should be reduced to 25 (an additional reduction of 50%).[9]

[9]If desired a third target date could be set at the end of 1979 by which time a reduction of 50% in the remaining number of these "objectionable" days must be achieved (to about 13 days per year).

3. Because of the relatively short time periods involved, the "technical" control measures required to reach these management standards will have to be based mainly on existing technology that can be developed and introduced within the next 2-4 years.

4. Any strategy must rely on a number of different control measures, each of which provides a modest improvement. It is the cumulative effect which is significant. There is no one "magic solution."

One such strategy (EQL Strategy #1) is described in the next sub-section. The control measures that are proposed are not supposed to be all-inclusive, nor are control costs supposed to be minimized. Our purpose is to illustrate the kinds of measures that must be taken if the requirements listed above are to be met. In most of the discussion to follow we are making the "conservative" assumption that *new* motor vehicles for model years beyond 1974 will meet the 1974 California exhaust emissions standards, but not the more stringent 1975/76 federal standards. Some of the figures to be presented in Part II will show the additional benefits to be gained (at additional cost!) if new motor vehicles do in fact meet the federal standards beginning in 1975.

I/2.2 Specific Control Measures

The nature and extent of the specific control measures that are needed depend on the magnitude of the reductions in emissions of reactive hydrocarbons and nitrogen oxides that are required in order to meet the management air quality standards set forth in EQL Strategy #1. At present no general theory exists that would enable us to predict ambient air quality for photochemical oxidants, nitrogen dioxide and carbon monoxide in terms of the emissions level of the primary contaminants. In lieu of such a theory, the relationship between air quality and emissions levels is here established by means of a statistical analysis of air quality monitoring data obtained at the ground-level stations of the Los Angeles Air Pollution Control District over the last several years.[10] An important simplifying physical assumption is made that *for given meteorological conditions* the atmospheric concentrations of carbon monoxide and the "early morning"[11] concentrations of reactive hydrocarbons and nitrogen oxides are directly proportional to their respective emissions levels.

The application of this simple idea to the statistical data is best illustrated by dealing first with the contaminant nitrogen dioxide, which tends to be approximately proportional to the total input of nitrogen oxides. Statistical data is displayed in terms of the average number of days per year that the maximum atmospheric concentration exceeds a given level for at least one hour, plotted against the concentration (Figure 1). (The solid curve in

[10]This analysis was carried out by Mr. John Trijonis as part of his Caltech PhD thesis research on the economics of air pollution control.

[11]By "early morning" we mean before 9:30 A.M., in Los Angeles, or before photochemical reactions have begun.

Figure 1 corresponds to the 1969 average of about 1000 tons per day of nitrogen oxides emissions in the Basin.) As expected, "low" one-hour maximum concentrations of nitrogen dioxide around 10 pphm[12] are exceeded quite frequently, but "high" concentrations around 50 pphm are rarely exceeded at this emissions level. These observations correspond roughly to the relatively high frequency of occurrence of maximum mixing layer heights (or heights of the base of the infamous inversion layer) that are 3500 feet or less, compared to the infrequent appearance of maximum mixing layer heights that are 700 feet, or less. These relatively infrequent low inversion layers markedly concentrate the pollutants near the ground.

Suppose that by means of a set of control measures the level of emissions of nitrogen oxides in the Basin is reduced by 50% to 500 tons per day. For the *same meteorological conditions*, atmospheric concentrations of nitrogen dioxide are also cut in half (dashed curve in Figure 1). In other words, if emissions are reduced by 50%, the simple rule to follow is that the number of days per year on which a particular maximum one-hour concentration of nitrogen dioxide is exceeded is the same as the number of days per year on which twice this concentration was exceeded at twice the emission level (horizontal dashed line in Figure 1). By following this rule, we see that at the new emissions level, a concentration of 25 pphm for one hour (California state standard) is exceeded on the same number of days per year as a concentration of 50 pphm was exceeded at the old emissions level. A 50% reduction in emissions level leads to a 90-95% reduction in days per year of violations of the state standard (vertical dashed line in Figure 1).

The situation for photochemical oxidants is more complicated than for nitrogen dioxide because the peak one-hour oxidant level depends on "early-morning" concentrations of reactive hydrocarbons and nitrogen oxides, on sunlight intensity, temperature and other variables in a complex manner. In spite of this difficulty, by using the Los Angeles APCD data Trijonis was able to work out "summer" and "winter" correlations between daily one-hour average oxidant level and "early-morning" concentrations of reactive hydrocarbons and nitrogen oxides. The effect of reductions in emissions levels on the concentrations of these two substances is calculated just as nitrogen dioxide was analyzed in the simple illustrative example given earlier.[13]

Our calculations show that in order to reduce from 241 to 50 the average number of days per year on which the maximum daily one-hour average oxidant concentration of 0.10 ppm is exceeded[14] (first "target" of EQL Strategy #1) the total emissions of reactive hydrocarbons from all sources in the Basin must be reduced to 28% of *present levels,* and emissions of nitrogen oxides

[12]parts per hundred million.

[13]Estimates of the number of objectionable days per year for each pollutant were obtained for Central Los Angeles. The average number of days per year on which the California ambient air quality standards are violated at *some* station in the entire Basin is significantly higher. For photochemical oxidant the number of objectionable days for the entire Basin is 1.7 times higher on the average than in Central L.A., and for nitrogen dioxide the number of such days is 2.3 times higher on the average.

[14]California State ambient air quality standard.

must be reduced to about *45% of present levels.* If these reductions were made, the California ambient air quality standards for nitrogen dioxide of 25 pphm for one hour would be exceeded on 10 days per year as compared with 130 days in 1970. The "health warning"[15] level of a one-hour average oxidant concentration of 0.20 ppm (twice the State standard) for persons with coronary artery diseases or chronic respiratory diseases would be exceeded on 15 days per year, as compared with 150 days per year in 1970.

Thus, Phase 1 of EQL Strategy #1 is designed to reduce total emissions of reactive hydrocarbons to 28% of present levels and nitrogen oxide emissions to 45% of present levels by December 31, 1975.

These objectives would be accomplished by means of the following *Phase 1 control measures,* combined with the effects of the new cars introduced into the Basin.

A. Motor Vehicles

1. Mandatory conversion of all gasoline-burning commercial motor vehicles of model years 1970 and later in both small and large fleets (trucks, taxis, buses, cars) to burn a gaseous fuel, such as compressed natural gas or liquid propane gas, by *December 31, 1973,* in the South Coast Air Basin. This measure means that about 33% of the gasoline now burned in the Basin would be replaced by gaseous fuels.

2. (a) Mandatory installation on 1960-1965 gasoline-powered cars of a currently available control device that reduces hydrocarbon emissions by about 60% and NO_X emissions by about 35% on pre-1966 cars.[16]
   (b) Mandatory installation on 1966-1970 gasoline-powered cars of a control device that reduces nitrogen oxides emissions by a substantial amount.[17]

3. Mandatory installation of an evaporative control device on gasoline-powered 1966-1969 vehicles that reduces fuel tank evaporative emissions by 90%. (Starting with the 1970 models new cars have such controls.) Since this device is estimated to cost approximately $150 to purchase and install, some subsidy or cost-sharing would be required. (Less expensive retrofit devices are currently under study at the EQL.) If such a subsidy were to be paid to vehicle owners for installation of this device, an equal subsidy ought to be made available to vehicle owners who elect any other step that would reduce reactive hydrocarbon emissions in the

[15]Proposed by the Los Angeles County Medical Association.

[16]The State Air Resources Board has approved the General Motors vacuum spark advance disconnect device and the Air Quality Products capacitor discharge, ignition optimization system for these cars (Section II/3.4).

[17]In November 1971 Governor Reagan signed the Sieroty-Cologne Bill, which requires that beginning in 1973 all 1966-1970 cars must be equipped with a device that will "significantly" cut nitrogen oxide emissions. The certification that such a device is installed on the car is to be made on initial registration, on transfer of ownership, or on renewal of registration. A limit of $35 is set on the initial cost of such a device, including installation charges, and the bill specifies that it should not require maintenance more than once every 12,000 miles at a maximum cost of $15. The State Air Resources Board must now set the standards for such equipment.

Basin by a comparable amount. *Example:* purchase of a post-1969 vehicle to replace an older vehicle that is sold to a new owner who lives and works outside the Basin.

4. A mandatory vehicle emissions inspection system that would: (1) insure that new and used gasoline-powered vehicles meet the emissions standards set for them by present and proposed control measures; (2) insure that vehicles operating on gaseous fuels are properly tuned to achieve the low exhaust emissions levels qualifying them for the 7 cents/gallon (equivalent) State fuel tax remission;[18] (3) form the basis for a system of emissions taxes.

5. Social and economic incentives and disincentives designed to encourage the shift to low-pollution motor vehicles by motorists and vehicle manufacturers, to encourage the use of multiple-occupancy vehicles, and to halt or at least reduce the annual rate of increase in gasoline consumption. Such measures include: (1) emissions taxes assessed on car owners in proportion to the amount of emissions their cars discharge into the air; (2) reserved "fast lanes" on freeways for buses and carpools; (3) controlled access to freeways so that buses and carpools are given priority during rush hours; (4) free or subsidized parking for carpoolers; (5) buses and demand-jitneys partially subsidized by revenues collected from emissions taxes; (6) as a last resort, additional gasoline taxes and/or a limit on the total consumption of gasoline in the Basin at 2.7 billion gallons per year by a system of freely auctioned coupons, giving motorists in the Basin gasoline purchase rights up to this total amount, but no more.[19]

   In our calculations we assumed that by December 31, 1975, the combined effect of all the measures under #5 amounts to a 20% reduction in the motor vehicle pollution remaining after measures #1-4 are put into practice.

B. Stationary Sources

1. *Nitrogen Oxides.* Mandatory installation of two-stage combustion and/or gas recirculation (or other control devices) designed to cut NO_X emissions by 50% by the end of 1973 in all fossil-fuel power plants.[20] Mandatory use of low "excess" air in industrial boilers and heaters using natural gas with a rating in excess of 30 million BTU/hour (about 8.5 megawatts).

[18] California law presently exempts vehicles operating with propane or natural gas conversion systems approved by the Air Resources Board from the State tax on vehicle fuel.

[19] According to E. J. List, the actual rate of gasoline consumption in 1969 was 4 billion gallons a year. The figure of 2.7 billion gallons represents what is left after one-third of current gasoline demand is converted to gaseous fuels.

[20] Such control devices are now being installed in the large electric power plants of Southern California Edison and the Los Angeles Department of Water and Power.

2. *Hydrocarbons.* (a) Substitution of nonreactive materials by users of organic solvents emitting "high reactivity" HC (as defined by the Los Angeles APCD) in order to cut these emissions by 50% by 1973.[21] (b) Mandatory recirculation of vapors from gasoline storage tanks in filling stations back to tanker trucks during filling operations.

C. Phase Two

Phase 2 of EQL Strategy #1 consists of a limited number of "smog alerts" to be called in the Basin during the period July through September when the oxidant level exceeds 0.20 ppm at any station in the Basin, or when early morning inversion layer height and temperature indicate a high probability that this level will be exceeded.[22] Beginning in 1973 two or three such alerts would be called, and by 1975 the number of such alerts would be increased to 6-8.

Although we do not attribute any specific reduction in the number of "objectionable" days to Phase 2, it seems clear that the two phases of EQL Strategy #1 are mutually reenforcing. Incentives for reducing emissions are created by calling smog alerts that shut down or curtail emission sources, while reductions in emissions require fewer smog alerts. If our target of about 15 days per year for an oxidant level of 0.20 ppm is reached by the end of 1975, these smog alerts could be discontinued.

1. During these smog alerts only "low emission" vehicles,[23] vehicles with two or more passengers, and buses and jitneys would be permitted on the freeways.
2. During an alert all stationary sources of "high reactivity" HC emissions would be shut down.

Rough estimates indicate that the cost of Phase 1 of EQL Strategy # 1 for the South Coast Air Basin is about one billion dollars through December 31, 1975, which amounts to about $100 per head, or $300 per household ($25 per head per year or $75 per household per year). The cost breakdown is as follows: (1) loss of federal and State tax revenues by conversion to gaseous fuels—$400 million; (2) Vacuum Spark Advance Disconnect—$70 million; (3) evaporative control retrofit—$225 million; (4) mandatory motor vehicle

[21]Approximately 100 tons/day of "high reactivity" HC are emitted by these sources. Another 550 tons/day of "low reactivity" HC emissions from stationary sources would not be affected by this program.

[22]At present first stage smog alerts are called when the oxidant level exceeds 0.50 ppm (five times the State air quality standard). No emissions sources are curtailed during these alerts.

[23]These vehicles could be identified by means of special windshield stickers.

inspection program—$200 million; (5) controls for stationary sources—$100 million.[24]

By the second target date of December 31, 1977, EQL Strategy #1 calls for no more than 25 days per year on which the California ambient air quality standards for oxidants is violated in the Basin. Our calculations show that in order to achieve this objective the total emissions of reactive hydrocarbons in the Basin must be reduced to about 22% *of present levels* and nitrogen oxides emissions must be reduced to about 38% *of present levels*. If the Phase 1 control measures are successful in reaching their targets by the end of 1975, it turns out that the *additional* reductions in total emissions that are required by the end of 1977 could be achieved by means of two specific control measures: (1) continued conversion of gasoline-burning commercial vehicles to burn a gaseous fuel, as long as emissions from new vehicles are significantly higher than emissions from gaseous-fueled vehicles (maintaining the level of one-third of the gasoline replaced by gaseous fuels at all times); (2) continuation of mandatory vehicle emissions inspection program (A.4 of Phase 1). The social and economic incentives and disincentives listed under A.5 of Phase 1 would almost certainly be necessary in the long run (Section I/3), but no additional reductions in emissions after 1975 are attributed to these measures in the present "conservative" calculations. The *additional* cost of this program from the end of 1975 to the end of 1977 is estimated at about $380 million. (The total cost of the emission controls for new cars for 1976 and 1977 is estimated at about $300 million in this Basin.)

In Section II/2 of this report the reductions in emissions from motor vehicles and stationary sources that can be achieved by each of the control measures in EQL Strategy #1 are discussed in detail. In Figures 3 and 4 we show the breakdown in reductions in reactive automotive hydrocarbons and nitrogen oxide emissions for L.A. County. Figures 5 and 6 show the contribution from stationary sources and the reductions in *total* reactive automotive hydrocarbons and nitrogen oxide emissions. Based on these reductions the projected improvement in ambient air quality for photochemical oxidant and nitrogen dioxide are calculated by methods already outlined and described in detail in Section II/2.2. In Figures 7 and 8 the results of these calculations are illustrated for the "present strategy" (1971) and for EQL Strategy #1. Figure 9 shows the projected reductions in the number of "health warning" days (proposed by the Los Angeles County Medical Association for persons suffering from coronary artery diseases or chronic respiratory diseases).

Control measures A.1 and A.5 on motor vehicles will also greatly reduce carbon monoxide emissions into the atmosphere of the Basin, as shown in

[24]The costs to the buyers of new cars that meet the California exhaust emission standards is estimated at approximately $400 million over this same period. This estimate is based on an additional cost of pollution controls of $50/car in 1972, $150/car in 1973 and $300/car in 1974 and 1975. Detailed cost calculations contained in Trijonis' thesis based on "harder" data later shows that the cost of Phase I in the South Coast Air Basin is about $1.8 billion, including new car controls. This cost amounts to about $45 per capita per year, or about 1.2% of disposable income per capita after taxes.

Figure 10. In Figure 11 we show the corresponding projected improvements in ambient air quality for carbon monoxide according to the "present strategy" and EQL Strategy #1. By 1977 EQL Strategy #1 would virtually eliminate the carbon monoxide problem in L.A. County.

In Sections II/3 and II/4 the feasibility of the "technical" control measures A.1-A.4 and B.1 and 2 for motor vehicles and stationary sources is examined. By feasibility we mean supply, distribution and marketing of gaseous fuels; economics of conversion to gaseous fuels; safety, insurance and reliability of gaseous-fueled motor vehicles; economics and performance of "retrofit" devices on used cars; availability and performance of control devices for stationary sources. No important technical or economic difficulties were uncovered in this study. However, a considerable amount of "risk capital" and organizational effort is required to put these control measures into effect on the time schedule adopted in EQL Strategy #1. On the other hand, the program provides some attractive opportunities for profitable business ventures and for employment of presently under-employed or unemployed skilled people in the Los Angeles area.

In Section II/3 the controversial question of the conversion of commercial motor vehicles to burn a gaseous fuel is discussed in some detail. The supply problems for compressed natural gas (CNG) and propane (LPG) in this Basin were studied carefully, not only by the EQL staff but also independently by a well-known oil and gas consulting firm retained by the EQL—The Pace Company of Houston, Texas. The Pace Company report concluded that supplies of CNG and LPG are adequate to replace up to 33% of the gasoline burned in the Basin.[25] The report recommended a "mix" of 25% CNG and 8% LPG to make up the figure of 33%. This amount of CNG is equivalent to 250 million cubic feet per day. In the "smoggy" summer months "firm" customer demand for natural gas is about 500 million cubic feet per day, leaving about 2.5 billion cubic feet per day for "interruptible" users (Figure 12). About 10% of the "interruptible" supply would have to be diverted from electric power plants and industrial users to motor vehicles. Such a diversion could be accomplished by means of a small price differential. In the relatively "smog-free" winter months natural gas is in short supply because of large "firm" customer demand. Thus motor vehicles converted to CNG are almost always equipped with "dual-fuel" systems that allow them to switch to gasoline in the winter months, or when they are outside the Basin.

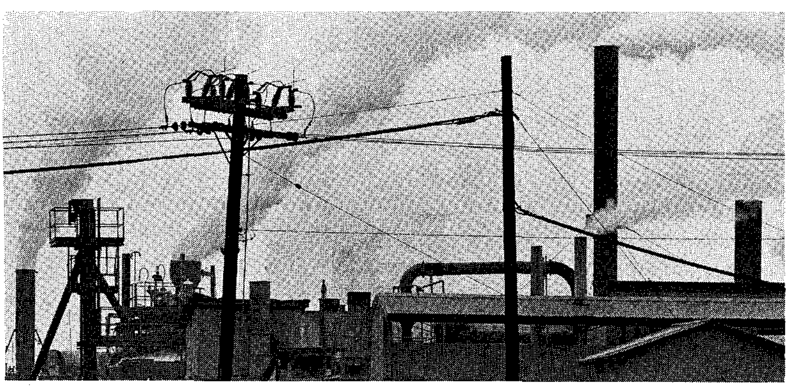
If 8% of the projected gasoline consumption in the Basin is replaced by propane by 1975, the requirement for propane amounts to about 10 million barrels per year, a quantity equal to the total consumption of propane in California in 1970 (Figure 13). However, propane supply is increasing rapidly in the 1970's, Canadian propane supplies are available, and the figure of 8% is regarded by the Pace Company as a reasonable initial target that would not place too great a strain on refineries and other sources (mainly natural gas fields).

[25]The major conclusions of the Pace Report are discussed in Section II/3.1.

So far as distribution of CNG is concerned commercial fleets generally would have their own fueling facility, including compressor and storage tank. Recently the Union Oil Co. and Pacific Lighting Corp. announced a cooperative pilot program whereby two service stations in Riverside, California, will sell CNG to motor vehicles.[26] This system could be expanded rapidly to include a certain fraction of the service stations in the Basin. Propane, on the other hand, is already available at about 64 stations in the Los Angeles area, and a number of other stations now selling propane to campers could easily obtain the necessary permit to sell this fuel to motor vehicles. This distribution system could also be expanded once the demand was established.

Similar conclusions about feasibility were reached regarding the possible rate of conversion of motor vehicles to burn a gaseous fuel. After several days of training, a good mechanic can convert one vehicle in about one working day. Thus 1000 mechanics working 250 days per year could convert the estimated 500,000 commercial fleet vehicles in the Basin in about two years.

In contrast to these technical-economic measures, the detailed effects of the social and economic measures listed under A.5 (and discussed in detail in Section II/5) are very difficult to forecast. The whole purpose of this set of incentives and disincentives is to provide alternate modes of transportation and to influence human behavior. Lacking a predictive theory of human behavior we need to introduce demonstration or "pilot" programs in order to obtain "feedback" from the public in a reasonably short time period. In the case of the emissions tax, for example, an iterative procedure could be utilized, in which a certain reasonable tax schedule is set and the effects observed for one year, after which the schedule is revised as needed. These pilot and iterative programs are necessary first steps toward a long-range strategy for the post-1982 period.



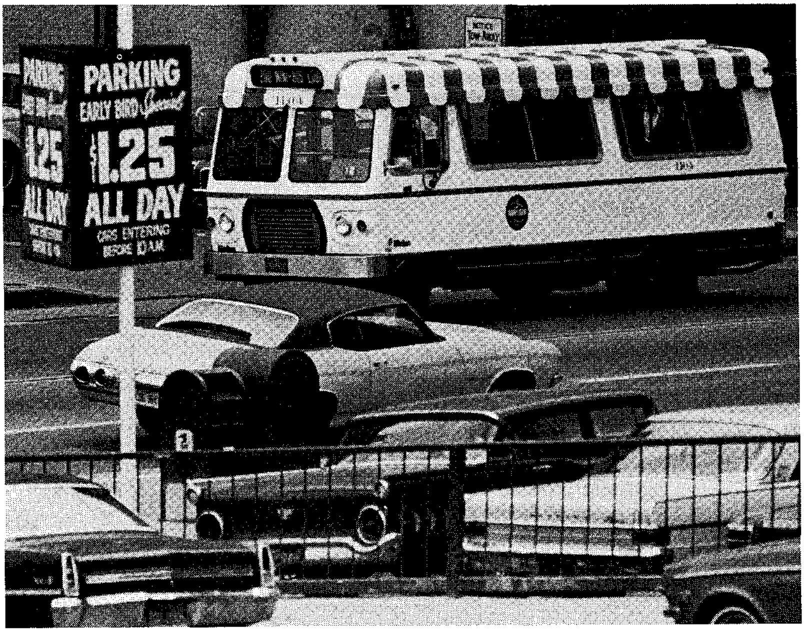
[26]These stations began selling CNG to motor vehicles in May, 1972.

I/3 A GLIMPSE AT THE POST 1982 PERIOD AND LONG-RANGE NEEDS

Sometime in the early 1980's emissions of reactive hydrocarbons, nitrogen oxides and carbon monoxide into the atmosphere and the number of smoggy days in the Basin will begin to increase again, even if EQL Strategy #1 is fully implemented (Figure 14). The projected growth in population and in the rate of consumption of gasoline, natural gas and oil in the Basin makes this outcome inevitable—*if no new steps are taken.* Section II/6 of this report contains a brief discussion of some possible approaches to the long-term air pollution problem in the Basin, including (1) introduction of new technology, e.g., electric commuter cars, replacement of natural gas and oil-fueled industrial burners by electric-powered devices, replacement of electric power plants inside the Basin by new power plants located outside the Basin; (2) limitations on population, industry and commerce in the Basin, provision for a balanced transportation system, and important changes in life-style.

PART II

SUPPORTING INFORMATION AND ANALYSIS


PARKING
EARLY BIRD Special
$1.25
ALL DAY
CARS ENTERING
BEFORE 10 A.M.

PART II: SECTION II/1

These days one hears much of what Alvin Toffler has called "future shock." Change comes at an accelerating rate—faster than many can assimilate it.

Such cannot be said of California's efforts to control air pollution. There "future shock" gives way to "slow history." The consensus that the automobile is the principal source of pollution in the Basin was slow to emerge, and it was not until the mid-sixties that the first effective exhaust emission controls were required for new cars. By 1970 hydrocarbons and carbon monoxide automotive emissions had declined about 20% from their 1965 peak, but oxides of nitrogen were not controlled until the 1971 model year. Hopefully official projections are correct and we are now on the down side of the 1971 NO_X peak. From now until 1976 California and Federal automotive emissions control requirements become progressively tighter until 1976 levels are down 90% from the 1970. This would seem to take care of the air pollution problem, so can't we stop worrying?

Even if we assume that the complicated and cumbersome control technology for new cars is completely successful, there are two reasons why the answer to the question above must be "no." One is that it takes so long to replace the present motor vehicle population with the new clean cars. (About 7% of all cars in California retire to the junkyard every year, and they are replaced by new cars that account for about 11% of the car population in the state every year.) The other reason is growth. The consumption of gasoline is increasing about 4% every year. (Look at the difference in the death rate of old cars and the birth rate of new ones.)

The present control strategy for the South Coast Air Basin—relying as it does on controlling only the new cars as they are built and holding the line on stationary source emissions—will reduce the 241 days of violating the state oxidant air quality standard to 140 in 1975 and 85 in 1980. It will reduce the days of exceeding the state nitrogen dioxide air quality standard from 115 in 1970 to 50 in 1975 and 12 in 1980. This assumes our best hopes for clean new cars are realized.

The EQL study proposes some ways of accelerating clean air history by using the best available, practical technology for controlling emissions of cars presently on the road; by reducing the use of those cars; and by further reductions in emissions from stationary sources. The result in 1975 would be 50, instead of 140 days of violating the state oxidant air quality standards, and by 1977, 25 days instead of 85. This is 24 days more than the Environmental Protection Agency says that its own air quality standards—which are slightly lower than the California standards used in this report—can be exceeded. The accelerated results outlined in this report represent a good faith effort which, in the judgement of the EQL team, is probably as far as the South Coast Air Basin can go within the time allowed by the Clean Air Amendments.

This conservative program should be kept in mind by those who find the measures proposed in the EQL program radical and disturbing.

II/1 A NEW AIR POLLUTION CONTROL STRATEGY FOR THE SOUTH COAST AIR BASIN

II/1.1 The Present Control Strategy and Its Deficiencies

The Mulford-Carrell Air Resources Act of 1967 created the State Air Resources Board (ARB) and charged it with the responsibility for setting and enforcing exhaust emission standards for all new motor vehicles sold in California.[1] By 1970 the control measures established by the Board on tail-pipe, crankcase and evaporative emissions had reduced total hydrocarbon (HC) and carbon monoxide (CO) emissions in the South Coast Air Basin by 20% from the peak values reached in 1965. This reduction was achieved in spite of an increase in gasoline consumption of about 4% per year in the Basin. In 1970 the ARB established exhaust emission standards for oxides of nitrogen (NO_X) for all new light-duty motor vehicles, beginning with the 1971 model year. Total NO_X emissions in the Basin should begin to decline from the peak reached in 1971 as older motor vehicles are replaced year by year by new vehicles meeting the increasingly stringent California standards.

Stationary sources in the South Coast Air Basin are controlled fairly strictly. They account for about 10% of the "reactive" hydrocarbon emissions and about 35% of the nitrogen oxides (NO_X) emissions at 1971 levels. In mid-1971 the Los Angeles Air Pollution Control District (APCD) announced that it would formulate a program to cut emissions from stationary sources in half by the end of 1973.

These are impressive programs and important accomplishments. Yet, if the present course of action is followed for the rest of the decade, it will lead at best to a relatively slow rate of improvement in ambient air quality. (Dr. Burton Klein of Caltech refers to this type of strategy as "slow history".) According to our predictions (Section II/2) the average number of days per year on which various California State standards are exceeded at some location in the South Coast Air Basin will still be discouragingly high by the year 1975, as shown in Table 1. Even as late as the year 1980, thirteen years after the passage of the Mulford-Carrell Act, the maximum daily one-hour average oxidant level (including ozone) of 0.10 ppm, chosen so that it lies "below that associated with aggravation of respiratory diseases,"[2] will be exceeded an average of 85 days per year at some location in the South Coast Air Basin. The two principal reasons for this slow rate of improvement in ambient air quality are: (1) the slow rate of attrition of "dirty" old cars (about 7% of all cars "die" each year in California), and the slow birth rate of new "cleaner" cars (about 11% of the car population per year); (2) the

[1]Until 1970 exhaust emission standards were adopted only for new light-duty motor vehicles under 6000 pounds gross weight. In that year the ARB established standards and test procedures for hydrocarbons, oxides of nitrogen and carbon monoxide exhaust emissions from heavy-duty, diesel-powered and gasoline-powered vehicles over 6000 pounds gross weight, to become effective in the 1973 model year.

[2]Air Resources Board, Annual Report to Governor Ronald Reagan and the Legislature, entitled *Air Pollution Control in California, 1970,* January, 1971 [Table I, p. 24].

TABLE 1
Present Strategy (1971)[3]

YEAR STANDARD	1970	1975	1980
Nitrogen dioxide concentration 0.25 ppm for 1 hr.[4]	115/days/year	50	12
Maximum daily 1 hr. average oxidant level			
0.10 ppm[4]	241	140	85
0.20 ppm[5]	150	35	20
Eye Irritation	130	50	15

increase in gasoline consumption at the rate of about 4% per year. Beyond 1980 the average number of days per year on which the California State standard on photochemical oxidant is exceeded reaches a *minimum* of about 80 days per year in 1982, and then increases again because of the expected increase in annual gasoline consumption.

The EQL is certainly not the first group to call attention to deficiencies in the present air pollution control strategy. In September, 1970, the Technical Advisory Committee (TAC) of the ARB concluded that the present strategy is wholly inadequate to meet State ambient air quality standards on oxidants and nitrogen dioxide (NO_2) in the foreseeable future.[6] The TAC report recommended drastic changes that would "have direct and jarring effects on residents of the South Coast Air Basin." These changes included suggestions to limit the number and use of automobiles, trucks and aircraft, to remove or make essentially emission-free all industries and fossil-fuel power plants in the Basin, and to limit the growth of population, industry and commerce.

In February, 1971, the State Environmental Quality Study Council (EQSC), acting on the basis of its own studies and the TAC report, called for an Emergency Air Quality Measure to be enacted by concurrent resolution of the State Legislature. This measure would "direct the ARB to conduct intensive studies to determine means of bringing the earliest possible emergency relief to the most critical air basins, and to determine what long-term continuing measures are necessary to deal with air pollution imperiling health."[7] In recommending long-term measures of its own, the EQSC adopted all of the suggestions made by the TAC report, and added another—development of clean sources of energy.

[3]Based on the "conservative" assumption that new motor vehicles for model years beyond 1974 meet the California 1974 exhaust emission standards, but not the more stringent 1975/76 federal standards. "Present Strategy (1971)" refers to the 1971 California strategy before the adoption of the State Implementation Plan submitted to the Environmental Protection Agency (EPA) in February, 1972.

[4]California State ambient air quality standard.

[5]"Health Warning" level recommended by Los Angeles County Medical Association for persons with coronary artery diseases or chronic respiratory diseases.

[6]*Recommended Ambient Air Quality Standards Applicable to All Air Basins,* a report to the California Air Resources Board by the Technical Advisory Committee, September, 1970.

[7]State of California, Environmental Quality Study Council, *Progress Report,* February, 1971.

On November 12, 1970, the highly respected legislative analyst, Mr. A. Alan Post, called attention to the TAC report in a lengthy statement on the ARB submitted to the Subcommittee on Air Pollution of the Assembly Transportation Committee. Mr. Post drew a distinction between short-term *management* standards based on technical, economic and social feasibility, and ambient air quality standards defined as goals to be reached over a longer period of time. While he did not go as far as the TAC report, Mr. Post recommended important changes in the organization and functions of the ARB, and he concluded that "logically the Board should undertake an intensive effort to reduce the emissions of *used* vehicles (emphasis ours) in California . . . We now know that control of new car emissions is not capable of producing significant improvement in air quality in the Los Angeles and San Francisco areas within a matter of years[8] . . . If any significant short-term improvement is to be made in air quality during the next several years, it will have to be accomplished by controls on vehicles *now* in operation" (emphasis Mr. Post's).

The ARB itself recognizes the importance of older cars in urban areas. Following the guidelines set by the California Legislature in the Pure Air Act of 1968, as amended in 1969, the Board in 1970 accredited one exhaust control device for 1955-1965 cars.[9] In cooperation with the Division of Highways, the ARB is also testing motor vehicles burning liquid petroleum gas or natural gas as a fuel. Several such systems were approved as meeting the Board's 1974 exhaust emission standards, and therefore eligible for exemption from the 7-cent per gallon State tax, as provided by the Legislature in 1970.

The drive to control exhaust emissions from older cars was given additional weight by Governor Reagan's Special Message to the Legislature on "Smog" (March 11, 1971). The Governor's message called for "authority to require immediate installation of a device to control nitrogen oxide discharges in 1966-1970 model cars when it becomes available,"[10] and asked also for "realistic emission standards and pollution control device requirements for 1955-1965 used cars."[11]

Meanwhile, impetus to clean up the air we breathe came from a new direction. On April 30, 1971, the Administrator of the Environmental Protection Agency, acting under the provisions of the Federal Clean Air Act of 1970 (as amended), published new federal ambient air quality standards that are

[8]On the basis of observations made on a recent air shuttle between Los Angeles and San Francisco, several members of the EQL staff concluded that Mr. Post's statement applies as well to the whole region between the two cities.

[9]Unfortunately, certain difficulties with this device, developed by Air Pollution Controlled (Denver, Colorado), led Norris Industries to withdraw from its manufacturing and marketing agreement with the Denver firm.

[10]In November 1971 Governor Reagan signed the Sieroty-Cologne Bill, which requires that beginning in 1973, all 1966-1970 cars must be equipped with a device that will "significantly" cut nitrogen oxide emissions. (See footnote on page 23, Part I). It is expected that the first such devices will be available by September, 1972.

[11]The ARB has approved both the General Motors device and the Air Quality Products device for these cars (see Section II/3.4).

even more stringent than the California standards (Table 2). Except for the standard on NO_2 the federal standards listed in Table 2 are not to be exceeded more than once a year.

TABLE 2
Comparison of California State Ambient Air Quality Standards and Federal Standards (April 30, 1971)

POLLUTANT	CALIFORNIA	FEDERAL (Primary and Secondary)
Nitrogen Dioxide	0.25 ppm for 1 hr.	0.05 ppm (annual average)
Photochemical Oxidant	0.10 ppm for 1 hr.	0.08 ppm for 1 hr.
Carbon Monoxide	40 ppm for 1 hr. and 10 ppm for 12 hrs.	35 ppm for 1 hr. and 9 ppm for 8 hrs.

The Clean Air Act now requires "prompt and effective action" by the states to develop an air pollution abatement plan that will meet these standards. This law is bound to have a profound effect not only on air pollution control strategy, but on life in the South Coast Air Basin.

II/1.2 Implications of the Clean Air Act of 1970 for Air Pollution Control Strategy in the South Coast Air Basin

The Clean Air Act of 1970, 42 USC 1857-1857 1 as amended by Public Law 91-604,[12] is an exacting federal statute which requires every state to develop an adequate air pollution abatement plan by 30 January, 1972. The plan must provide for the implementation, enforcement and maintenance of national ambient air quality standards promulgated by the Administrator of the EPA (Table 2). These air quality standards must be attained within three years of the date of approval of such plan or any revision thereof.[13] The Administrator of the EPA may, in his discretion, grant an extension of up to two years in time allowed for the attainment of the primary standards.[14].

Under Final EPA Requirements for preparation, adoption, and submittal of implementation plans,[15] states must develop a far-reaching control strategy for attaining the national primary ambient air quality standards. "Control strategy" means a combination of measures designated to achieve

[12]Hereafter referred to as "the Act."

[13]Section 110(a)(2) of the Clean Air Act (1970); 40 CFR (Code of Federal Regulations) 51.10(b)

[14]Section 110(e)(1) of the Act; 40 CFR 51.30(a) (1971).

[15]40 CFR 51 (1971), 36 Fed. Reg. 22398-22417 (25 November 1971).

the aggregate reduction of emissions necessary for attainment and maintenance of a national standard, including, but not limited to, measures such as:

1. Emission limitations.

2. Federal or State emission charges or taxes or other economic incentives or disincentives.

3. Closing or relocation of residential, commercial or industrial facilities.

4. Changes in schedules or methods of operation of commercial or industrial facilities or transportation systems, including, but not limited to, short-term changes made in accordance with standby plans.

5. Periodic inspection and testing of motor vehicle emission control systems, at such time as the Administrator determines that such programs are feasible and practicable.

6. Emission control measures applicable to in-use motor vehicles, including, but not limited to, measures such as mandatory maintenance, installation of emission control devices, and conversion to gaseous fuels.

7. Measures to reduce motor vehicle traffic, including, but not limited to, measures such as commuter taxes, gasoline rationing; parking restrictions, or staggered working hours.

8. Expansion or promotion of the use of mass transportation facilities through measures such as increases in the frequency, convenience and passenger-carrying capacity of mass transportation systems or providing for special bus lanes on major streets and highways.

9. Any land use or transportation control measures not specifically delineated herein.[16]

In regions where national standards will not be met by application of the federal motor vehicle emission standards alone, ". . . the control strategy shall provide for application of such other measures as may be necessary for attainment and maintenance of such national standard."[17]

Each plan must show that the State has legal authority to carry out the plan, including authority to:

1. Adopt emission standards and limitations and any other measures necessary for attainment and maintenance of national standards.

2. Enforce applicable laws, regulations, and standards, and seek injunctive relief.

3. Abate pollutant emissions on an emergency basis to prevent substantial endangerment to the health of persons, i.e., authority comparable to that available to the Administrator under section 303 of the Act.

[16] 40 CFR 51.1(n)(1971).

[17] 40 CFR 51.14(b)(1971).

4. Prevent construction, modification, or operation of any stationary source at any location where emissions from such source will prevent the attainment or maintenance of a national standard.

5. Obtain information necessary to determine whether air pollution sources are in compliance with applicable laws, regulations, and standards, including authority to require record keeping and to make inspections and conduct tests of air pollution sources.

6. Require owners or operators of stationary sources to install, maintain, and use emission monitoring devices and to make periodic reports to the State on the nature and amounts of emissions from such stationary sources; also authority for the State to make such data available to the public as reported and as correlated with any applicable emission standards or limitations.[18]

The plan must also provide for public availability of emission data reported by source owners or operators or otherwise obtained by a State or local agency.[19]

Regions such as Los Angeles, where existing ambient levels of pollutants exceed the levels specified by applicable national standards, must develop a plan that ". . . shall set forth a control strategy which shall provide for the degree of emission reduction necessary for attainment and maintenance of such national standard, including the degree of emission reduction necessary to offset emission increases that can reasonably be expected to result from projected growth of population, industrial activity, motor vehicle traffic, or other factors that may cause or contribute to increased emissions."[20]

The Administrator has ample powers of enforcement under the Act. The Administrator may issue orders requiring any person to comply with an implementation plan whenever he finds that such person is in violation of any requirement of an applicable implementation plan under the Act, Section 113(a). He may also order any state to enforce the plan effectively if he finds that the state has failed to act 30 days after being notified of such failure by the Administrator. Instead of issuing an order, the Administrator may bring a civil action for appropriate relief, including a permanent or temporary injunction.

The Act provides penalties of up to $25,000 per day of violation and one year in prison for persons knowingly violating requirements of the Act more than 30 days after notification of the violation by the Administrator. These penalties apply also to persons acting in violation of an order of the Administrator. Subsequent violations may subject the wrongdoer to a fine of $50,000 per day and two years in prison.

[18] 40 CFR 51.11(a)(1971).

[19] 40 CFR 51.10(c)(1971).

[20] 40 CFR 51.12(a)(1971).

The Act provides emergency powers for the Administrator under Section 303. Upon receipt of evidence that a pollution source presents an imminent and substantial endangerment to the health of persons, and that the appropriate state or local authorities have not acted to abate such sources, the Administrator may bring suit in the name of the United States to restrain immediately any person causing or contributing to the pollutant.

Any person may bring a civil action in his own behalf under Section 304 of the Act against any person who is alleged to be in violation of an emission standard or limitation under the Act, or an order of the Administrator or a State with respect to such a standard or limitation. A person may also bring suit against the Administrator for failure to perform an act which is not discretionary. Any person may also intervene as a matter of right in an action brought by the Administrator or a State.

Thus, the Act, administered by Mr. William Ruckelshaus, requires prompt and effective action to develop a viable air pollution abatement plan for the South Coast Air Basin. If the State ARB and the Los Angeles APCD do not develop an imaginative and comprehensive plan, the Federal Government will develop such a plan. Even if the Administrator does not act, private citizens and groups can sue under the Act to force compliance with federal emission standards and limitations [(sec. 304(a)(1))].

II/1.3 Short-term (1972-1977) Objectives and Management Air Quality Standards

The California and federal ambient air quality standards (Table 2, Section II/1.1) are *absolute* standards, in the sense that certain prescribed pollutant levels must not be exceeded more than once a year. No attempt is made to assess the damage to health, property or esthetic values if these standards are exceeded more often, nor is there any analysis of the control costs associated with measures designed to reduce the number of violations to one day per year. No "middle ground" is recognized between the present unsatisfactory situation (Table 1) and the attainment of ambient air quality standards.

The approach adopted in this report occupies this "middle ground." We recognize that the South Coast Air Basin in California is faced with a uniquely difficult air pollution control problem. Because of its special meteorology and topography, and the enormous rate of consumption of fossil fuels,[21] even the best technology likely to be available in this decade cannot reduce the average number of days per year on which State air quality standards on photochemical oxidants are violated below a lower bound of 10-15 days.[22] Drastic curtailments in the rates of consumption of gasoline, natural

[21]List, E. J., *Energy Use in California: Implications for the Environment,* EQL Report #3, December 1971.

[22]The California ambient air quality standard states that the maximum daily one-hour average oxidant level should not exceed 0.10 ppm (parts per million).

gas and residual oil, and sharp reduction in economic activity would be needed in order to bring the number of "objectionable" days down to (literally) *one day per year* within a five-year period, as required by the Clean Air Act Amendments of 1970. However, the fact that the federal standards are unattainable within this Basin by the end of 1977 should in no way excuse us from making a maximum effort to drive toward the lower bound of 10-15 objectionable days per year as rapidly as feasible.

Our strategy for air pollution control is based on the concept of "management standards" that take into account the technical, economic and social feasibility of achieving substantial improvements in air quality. These management standards are stated in terms of a series of definite "target dates," by which times certain percentage reductions are to be achieved in the average number of days per year on which the California ambient air quality standards for oxidants, nitrogen dioxide and carbon monoxide are violated. For example, our proposed goal is to reduce the number of these "objectionable" days for photochemical oxidants in the South Coast Air Basin from the 1970 level of 241 days per year to a level of 50 days per year by the end of 1975 (a reduction of 80%). By the second target date, at the end of 1977, these objectionable days should be reduced to 25 days per year (an additional reduction of 50% and an overall reduction of 90%).[23]

The Clean Air Act appears to give the Administrator of the EPA discretionary authority to approve an alternative approach similar to the one we propose during the period in which a two-year time extension is in effect (from 1975 to 1977). Such extensions can be granted when (among other reasons) the necessary technology is unavailable; when the State has implemented reasonable alternatives (as would be the case if a strategy similar to EQL Strategy #1 were adopted); when reasonable interim measures are provided like those in EQL Strategy #1. EPA regulations published in the Federal Register on August 14, 1971, encourage each state "to consider the socio-economic impact and the relative costs and benefits" of alternative strategies. Public welfare and productive capacity are to be weighed as well as public health.

While the management standards approach honors what we believe to have been the intent of Congress, it also responds in a rational and justifiable way to a serious shortcoming found in the Clean Air Act: the imposition of uniform standards. The Clean Air Act's provision for uniform air quality standards is a serious shortcoming in the near term. Uniform standards, because they overlook the fact that air pollution costs and control costs vary from area to area, have been criticized for their gross inefficiencies. See, for example, the article by Teller, "Air Pollution Abatement: Economic Rationality and Reality," in Volume 96 of *Daedalus,* page 1082 (1967); and the book by J. H. Dales, *Pollution, Property and Prices* (University of Toronto Press, 1968).

[23]If desired, a third target date could be set at the end of 1979, by which time an additional reduction of 50% in the number of the remaining "objectionable" days (to about 13 days per year) must be achieved.

Adoption of management standards provides for an individualized approach to California's unique set of problems.

In order to remove a possible ambiguity in the interpretation of the Clean Air Act, we have suggested[24] that the Act be amended to give the EPA Administrator the option in each air basin EITHER to enforce the national primary and secondary air quality standards, which are not to be violated more than one day per year as the Act presently provides, OR to enforce management standards in selected problem air basins as follows:

For each air basin in the U.S. in which one or more of the ambient air quality standards announced by the Environmental Protection Agency on April 30, 1971, was violated on more than ten days during calendar year 1970 or 1971, the EPA Administrator shall require that

1. *An 80% reduction* in the number of "objectionable" days below the 1970 or 1971 level must be achieved by *December 31, 1975;*

2. *An additional 50% reduction* in the *remaining* number of such days must be achieved by *December 31, 1977.*

Adoption of these management standards would require equal levels of effort for all sections of the country, without imposing an unrealistic, uniform nationwide standard of a certain fixed number of "objectionable" days per year.

In California, for example, such an approach is applicable not only to the South Coast Air Basin, but also to the San Diego County Air Basin, the Sacramento Valley Air Basin, and the San Francisco Bay Area Basin.

In all of the EQL studies the assumption is made that the California State ambient air quality standards are adequate. Our studies have convinced us that no useful purpose is served by the current differences between the California and federal ambient air quality standards on nitrogen dioxide, photochemical oxidants and carbon monoxide (Table 2). The California oxidant level was chosen so that it lies "below that associated with aggravation of respiratory diseases." No new medical evidence has come to light that would suggest that any lower level is justified. The controversy over the differences between the California and federal ambient air quality standards tends to obscure the fact that *both* of these standards are being violated at least two-thirds of the year in this Basin, and that a major effort is required to reduce the number of "objectionable" days by 90% by 1977. Similar remarks apply to the nitrogen dioxide and carbon monoxide standards.

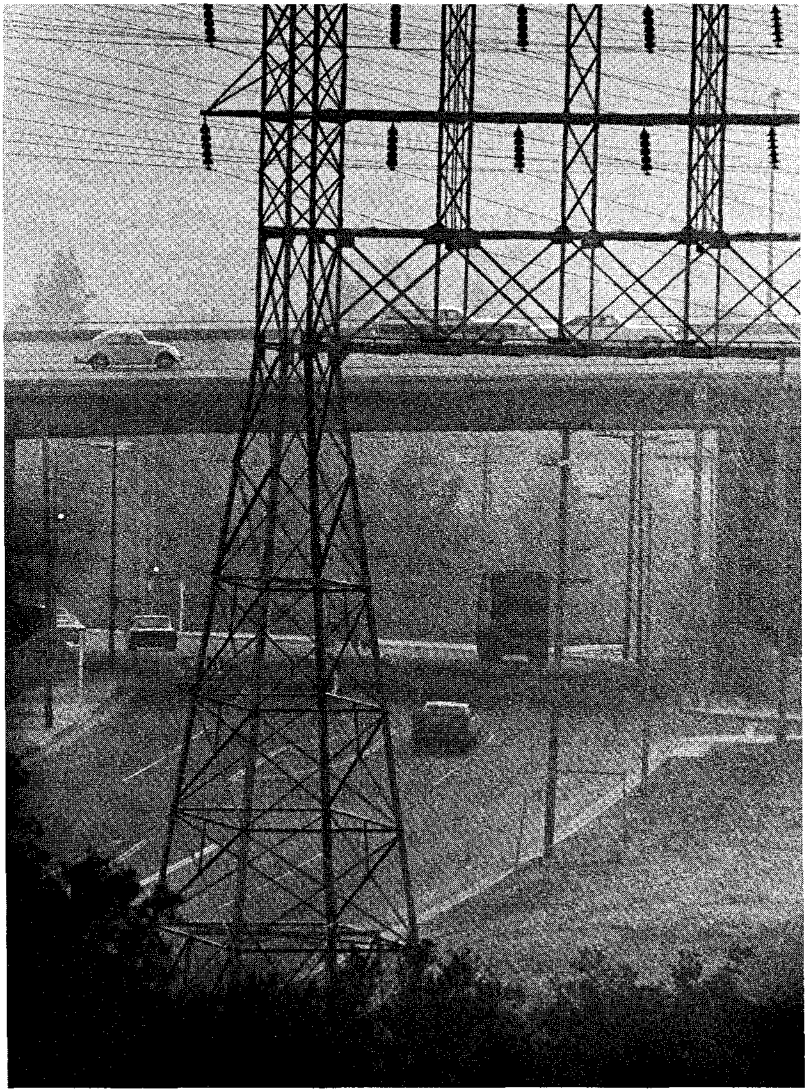
One set of specific control measures that would enable the South Coast Air Basin to achieve the management air quality standards just described are listed in Section I/1.2 and are discussed in detail in Sections II/3 and II/4. In summary, EQL Strategy #1 is based partly on new "technical" control measures to reduce emissions from stationary sources and *used* motor vehicles.[25]

[24]Lees, L.: *Statement on Implementation of Clean Air Amendments of 1970* to Subcommittee on Air and Water Pollution of the Senate Committee on Public Works at hearing in Los Angeles, California on March 25, 1972.

[25]Some of these measures are included in the new State Implementation Plan (February, 1972).

But even in the short run (1972-1977) we found it necessary to combine these technical measures with a set of social and economic incentives and disincentives designed to encourage the shift to low-pollution motor vehicles, to encourage the use of multiple-occupancy vehicles (buses, car pools, etc.), and to reduce the annual rate of increase in gasoline consumption in the Basin. These control measures are not supposed to be all-inclusive, and the "mix" is not optimized for minimum cost to achieve a given level of air quality.[26] But they are representative of the kinds of measures that are required to reach the proposed management standards.

[26]Cost optimization for a wide range of strategies is treated in some detail by Trijonis, John, *An Economic Air Pollution Model. Application: Photochemical Smog in Los Angeles County in 1975,* Summer, 1972.



PART II: SECTION II/2

Emissions of various pollutants from all sources determine air quality, but it is not easy to predict from emissions what the quality of the air will be at different times in different places. Normally, emissions don't change radically from day to day but air quality does because it is affected by meteorological variables like temperature, winds, rain, and inversion layer.

Despite these complications, in order to plan an air pollution control strategy we must know what "clean air" means in terms of reducing emissions. For the EQL work, this was done by comparing statistics for emissions, pollutant concentrations, and weather conditions for a number of years. For carbon monoxide, which does not change when exposed to sunlight, it was fairly simple to discern the patterns of emissions/air quality relationships. For photochemical oxidants, which result from the reaction of two types of emissions—reactive hydrocarbons and oxides of nitrogen—in sunlight, the problem was quite complex.

The calculations based on the statistical model showed that in order to reach the air quality goals set out in EQL Strategy #1 it would be necessary to reduce total emissions of reactive hydrocarbons in the Basin 72% by 1975 and 78% by 1977, and oxides of nitrogen 55% by 1975 and 62% by 1977. Fortunately, the model showed that the pay-off for reducing emissions is somewhat greater than might be expected. The 78% reduction in reactive hydrocarbon emissions and the 72% reduction in oxides of nitrogen, lead to a 90% reduction in days when the oxidant air quality standard is exceeded and a 96% reduction in the nitrogen dioxide violations by 1977.

Using the same model, it was also possible to estimate roughly how the various proposed means of reducing emissions would contribute to clean air. You will recall that in 1970 the Los Angeles Basin recorded 241 days on which the state standard for oxidants was exceeded. The present strategy would reduce this to about 140 by 1975. The goal proposed by EQL was 50 days—90 days less than the present strategy would deliver. The 90 days would be distributed generally as follows: conversion to gaseous fuels, 16 days; reduced vehicle use, 15 days; control of gasoline vapors from used cars (evaporative retrofit), 32 days; vacuum spark advance disconnect, 4 days; additional controls of stationary sources, 23 days. A similar breakdown for the contribution of various measures to reduced violations of the nitrogen dioxide standard would attribute a much greater share of the results to the vacuum spark advance disconnect. Figure 22 shows graphically the break-down for oxidant air quality in Downtown Los Angeles, where violations were somewhat less than for the whole Basin.

Such break-downs of the strategy indicate the truth of a remark by Dr. A. J. Haagen-Smit, chairman of the California Air Resources Board and pioneering investigator of photochemical smog: "Progress against smog comes in tiny steps."

II/2 EFFECTS OF EQL STRATEGY NO. 1 IN REDUCING EMISSIONS AND IMPROVING AIR QUALITY

II/2.1 Introduction

In order to link the air pollution control measures required in this Basin to the management air quality standards proposed in Section II/1.3, we need to work out the relations between total pollutant emissions and air quality. In the absence of a general theory, these relations are established by means of a statistical model based on air quality monitoring data obtained at the ground-level stations of the Los Angeles Air Pollution Control District over the last several years (Section II/2.2).[1]

In Section II/2.3 the contribution made by each control measure in EQL Strategy #1 to the reduction in pollutant emissions from motor vehicles or stationary sources is discussed in detail. The cumulative effect of all these measures over the period 1972-1982 is compared with projections of the reductions in emissions that can be achieved by following the present strategy. By combining the results obtained in Sections II/2.2 and II/2.3, improvements in air quality are projected for the period 1972-1982 in terms of reductions in the average number of days per year on which the California ambient air quality standards on oxidants, nitrogen dioxide and carbon monoxide are violated (Section II/2.4). Long-range projections of air quality in the South Coast Air Basin up to 1995 are also made in Section II/2.4, based on a *fixed technology* and growth rates in total emissions of 2% per year and 4% per year. (See also Section II/6.)

In Section II/2.5 we examine the additional improvements in air quality that might be realized after 1975 if new motor vehicles do in fact meet the stringent 1975/76 federal exhaust emission standards, instead of the 1974 California exhaust emissions standards utilized in the calculations of Sections II/2.3 and II/2.4.

Finally in Section II/2.6 a few brief observations are made about the air quality problems for sulfur dioxide and particulate matter in the South Coast Air Basin.

II/2.2 Relations Between Air Quality and Emissions Levels

II/2.2.1 Statistical Model

Air quality monitoring data obtained by the Los Angeles APCD over the past few years corresponds to a rather limited range of emissions levels for the major pollutants.[2] In order to utilize this data to predict air quality at any other emissions levels certain simplifying physical assumptions must

[1]Trijonis, John, *An Economic Air Pollution Model. Application: Photochemical Smog in Los Angeles County in 1975*, Summer, 1972.

[2]*Profile of Air Pollution Control*, Los Angeles APCD, 1971.

be introduced. The most crucial (but reasonable) assumption is that *for given meteorological conditions* the atmospheric concentrations of carbon monoxide and the "early-morning" concentrations of reactive hydrocarbons and nitrogen oxides are directly proportional to their respective emissions levels.

This assumption implies that changes in emission levels are made in the same proportion at all points in the Basin, and at the same time. We are also making the assumption that the meteorological statistics in the Basin change very slowly over the years, if at all, compared to the time scale for significant changes in emissions levels.

II/2.2.2 CO and NO_2

For the case of carbon monoxide (CO) the assumptions of the model appear to be well met. CO is very nearly inert over a time span of a day or two, which is the normal residence time of an air mass in this Basin. More than 98% of the CO emitted comes from motor vehicles, and major reductions in CO emissions are expected to result from controls on each vehicle.

In the case of nitrogen dioxide (NO_2) the validity of the main assumption is by no means obvious. In fact NO_2 is not inert; it is produced mainly by atmospheric reactions between nitrogen oxide emissions and hydrocarbons. Fortunately, available experimental data and photochemical reaction theory indicate that the maximum NO_2 concentrations tend to be roughly proportional to total NO_X input. This proportionality is the basic assumption utilized in the calculation of NO_2 air quality.

The assumption that reductions in NO_X emissions occur in the same proportion at all points in space and time will not be accurate if motor vehicles and stationary sources are not equally controlled. However, EQL Strategy #1 calls for controls on both types of sources in almost equal proportion. (Section I/2.2)

The application of the basic assumptions of the statistical model to the air quality data has already been illustrated in Section I/2.2 in terms of NO_2, which tends to be approximately proportional to the total input of nitrogen oxides. The solid curve in Figure 1 corresponds to the air quality date at the 1969 average level of about 1000 tons per day of nitrogen oxides emissions in the Basin, while the dashed curve labelled "500" corresponds to a new emissions level of 500 tons per day. Figure 2 shows typical improvements in air quality.

The simple idea (illustrated in Figure 1) is easily generalized: If the original emissions level is E° and the new emissions level is $E = \alpha E^\circ$, then the average number of days per year that a given concentration X_S is exceeded at the new emissions level E is just the average number of days per year that X_S/α was exceeded at the old level E°. By following this rule air quality for NO_2 in terms of the California standard of 25 pphm[3] for one hour is projected over a wide range of emission levels for several typical stations in L.A.

County (Figure 2). Evidently the number of "objectionable" days becomes very small if NO_X emissions are reduced by 50% from the 1969 levels.[4]

The federal ambient air quality standard for NO_2 (0.05 ppm) is stated in terms of an annual average instead of a maximum concentration for one hour (Section II/1.1, Table 2). At the reference (1969) emissions level of 1,000 tons per day Burbank had an annual average NO_2 concentration of 0.088 ppm. In order to achieve the desired air quality level at Burbank, a 43% reduction in NO_X emissions is required.

For CO there are two important air quality standards (Section II/1.1, Table 2): (1) a "peak" concentration of 40 ppm for one hour; (2) an "average" concentration of 10 ppm for 12 hours. By applying the same procedure utilized for NO_2 to the Los Angeles APCD air quality data for CO, the predictions of air quality vs. emissions shown in Figures 15 and 16 are worked out. If CO emissions are reduced by 60% from the 1968 level, the number of "objectionable" days based on the 12-hour average is reduced by about 90%.

II/2.2.3 Photochemical Oxidants

The maximum average one-hour atmospheric concentrations of photochemical oxidants depend (among other things) on the "early-morning" concentrations of reactive hydrocarbons and nitrogen oxides. By "early-morning" we mean before 9:30 A.M. in Los Angeles, or before photochemical reactions have caused significant changes in reactive hydrocarbon and NO_X concentrations. The dependence of "early-morning" reactive HC and NO_X on their respective emissions levels is worked out along the same lines as the treatment of CO and NO_2. However, the relation between photochemical oxidant air quality and emissions is more complicated than for NO_2, because the peak one-hour oxidant level depends not only on "early-morning" concentrations of reactive hydrocarbons and nitrogen oxides, but also on sunlight intensity, temperature and other meteorological variables. John Trijonis was able to overcome this difficulty by working out separate "summer" and "winter" correlations[5] between the "mid-day" one-hour average oxidant level in "Central L.A." and the "early-morning" concentrations of reactive hydrocarbons and nitrogen oxides in Downtown L.A., and by assuming that the distribution of the meteorological variables was independent of the distribution of the morning concentrations for these periods. By "mid-day" we mean until 1:00 P.M. and by "Central L.A." we mean the Downtown L.A.-Burbank-Pasadena Area.[6] An average of the maximum mid-day oxidant levels measured at the APCD stations in these three locations was utilized. In computing this average the data was weighted according to

[4]The situation in the South Coast Air Basin as a whole is discussed in Section II/2.2.4.

[5]The principal difference between summer and winter situations lies in the difference in sunlight intensity.

[6]The peak one-hour average oxidant level is almost always reached by 1:00 P.M. in this area of the Basin.

wind speed and direction so as to correspond as closely as possible to the air mass that had been in Downtown L.A. in the early morning.

A key concept in this analysis is the notion of a "probability function." This probability function is defined as follows: Suppose that at given emissions levels one knows the average number of days per year on which the early morning concentrations of HC and NO_x lie within certain small ranges around the values x and y, respectively. The probability function,

$$P^{(w)}_{O_{z_S}}(x,y) \text{ or } P^{(s)}_{O_{z_S}}(x,y)$$

is simply a number lying between 0 and 1 that measures the fraction of those days on which the maximum one-hour average oxidant concentration exceeds the standard for oxidants (z_S). (The superscripts "w" and "s" refer to "winter" and "summer", respectively.) Typical values of this probability function for summer conditions are shown in Figure 17 for the case z_S = 10 pphm $\equiv$ 0.10 ppm.[7] The probability is plotted against the early-morning NO_x concentration (y) for various (constant) values of the early-morning HC concentration (x) in parts per million of carbon (ppmC).

These probability values are derived from the Los Angeles APCD air quality data at the Downtown L.A., Burbank and Pasadena stations at the reference (1969) levels of hydrocarbon and nitrogen oxide emissions. *Now the important assumption is made that this probability function depends on x and y in the same way regardless of any changes in the emissions levels.* In other words, we are assuming that the early-morning concentrations x and y and the meteorological factors (sunlight intensity, temperature, etc.) that produce the oxidant from these concentrations are independent of one another. This assumption is credible only when separate "summer" and "winter" correlations are employed, because of the difference in sunlight intensity between the two seasons.

Suppose that the emissions levels are changed to new values

$$E_{HC} = \alpha E^{\circ}_{HC}$$

and

$$E_{NO_x} = \beta E^{\circ}_{NO_x}.$$

Then the early-morning concentrations of HC and NO_x will lie within a small range of the values αx and βy, respectively, on the same average number of days per year on which these concentrations were found in certain small ranges around x and y, respectively, emissions levels. The new probability

$$P^{(w)}_{O_{z_S}}(\alpha x,\beta y) \text{ or } P^{(s)}_{O_{z_S}}(\alpha x,\beta y)$$

is found by referring to a diagram such as Figure 17 and picking off the value of the probability for the pair of concentration values [HC] = αx, [NO_x] = βy. By multiplying this new probability by the average number of days per year

[7] 10 pphm happens to be the California standard.

on which the early-morning concentrations of HC and NO_X lie within certain small ranges around the values x and y, repeating this calculation for all possible pairs of (x,y) values, and summing up all the results, one finally obtains the total number of days per year on which the maximum one-hour average oxidant level exceeds z_S.[8] The calculations were performed for three oxidant standards—0.10 ppm, 0.15 ppm and 0.20 ppm; the results are shown in Figures 18, 19 and 20.

What Dr. Guy Pauker of the RAND Corporation and the EQL calls the "perverse nature" of NO_X in photochemical smog is well illustrated by Figures 17, 18 and 19. At very high NO_X concentrations nitric oxide (NO) soaks up the oxidants. At very low NO_X concentrations not much NO_2 can be produced, so not much atomic oxygen can be generated by photolysis of NO_2, and ozone and oxidant concentrations are low. In the intermediate region of NO_X concentrations the hydrocarbon concentration plays the dominant role in determining the level of photochemical oxidants in the L.A. atmosphere. This behavior is especially striking for the maximum one-hour average oxidant level of 0.20 ppm (Figure 20).

II/2.2.4 Air Quality—Emissions Relations for the South Coast Air Basin

All of the air quality/emissions relations obtained so far apply only to the Central L.A. area. However, we want to deal with improvements in air quality for the entire South Coast Air Basin. For CO and NO_2 the results for Downtown L.A. appear to be representative of the entire Basin in the sense that other stations seem to have similar air quality/emissions relations. A simple multiplication factor might be appropriate to translate the results for Downtown L.A. into Basin-wide criteria. For example, the number of days per year on which the California NO_2 standard of 25 pphm for one hour was violated was about 50 in Downtown L.A. in 1970 and about 115 at *any* station in the Basin, so the multiplication factor is 2.3. For CO the factor is close to unity, except possibly in special areas on or adjacent to freeways.

The problem of predicting the air quality/emissions relation for photochemical oxidant in the entire Basin is very difficult. The Basin acts like a large chemical reactor with the pollutants constantly being added to the air and constantly reacting as the air mass moves inland from the ocean. Especially in the eastern portion of the Basin pollutants probably originate in widely separated regions lying to the west and southwest. The mid-day oxidant level in the Central L.A. area is considerably lower than values observed at stations downwind of this area. Thus a single multiplication factor may not be adequate over a wide range of emissions levels. Photochemical reaction times may be lengthened when HC levels are reduced. This effect may reduce mid-day oxidant levels preferentially as compared to oxidant levels reached later

[8]The details of the procedure are discussed in Trijonis' thesis, where the calculation is expressed in the succinct language of the integral calculus.

in the afternoon, corresponding to peak values at inland stations. These limitations should be kept in mind when using the oxidant air quality/ emissions relations.

In spite of these reservations, as an interim measure we are going to apply a simple multiplication factor in order to indicate important trends. For photochemical oxidant these factors are as follows:

1970

OXIDANT LEVEL	DOWNTOWN L.A.	BASIN	MULTIPLICATION FACTOR
10 pphm	150 days/year	241	1.6
15 pphm	90 days/year	180	2
20 pphm	45 days/year	150	3.3

The procedure to be utilized in Section II/2.4 on projected improvements in air quality is to apply the emissions reductions to be discussed in Section II/ 2.3 first to the Central L.A. area, and then to use the multiplication factors listed above (and the factor 2.3 for NO_2) to predict improvements in air quality for the entire Basin.

II/2.3 Reductions in Emissions in the South Coast Air Basin (1972-1982)

II/2.3.1 Reductions in Motor Vehicle Emissions

Extensive data is available on the characteristics of the motor vehicle population of Los Angeles County, including the fraction of the population in each model year, average mileage per year as a function of model year, pollutant emissions in grams per mile as a function of model years, evaporative losses, etc. (Appendix A)[9] However, it must be kept in mind that the emissions figures are not precise, but that these numbers represent the best available estimates. Vehicular emissions are based on typical values measured from automobiles in the seven-mode driving cycle. Although this cycle is supposed to be representative, other "representative" cycles give other absolute results differing by as much as 50%. Professor List has pointed out that a similar ambiguity of ±30% exists for stationary sources.[10] This ambiguity is caused mainly by uncertainties in the emissions factors, and partly by uncertainties in total fuel consumption. The numbers used in this report usually follow those used by the Los Angeles APCD. In certain cases different projections have been made where it was felt justifiable, but the APCD figures seem to be representative of what is occurring.[11] Fortunately, improvements in air

[9] *Control of Motor Vehicle Emissions After 1974,* TAC of the ARB Report.

[10] List, E. J., *Energy Use in California: Implications for the Environment,* EQL Report #3, December 1971.

[11] *Profile of Air Pollution Control,* Los Angeles APCD, 1971.

quality depend on the *percentage* reductions in emissions from their 1969 or 1970 base levels (Section II/2.2 and Figures 2, 15, 16, 18-20), rather than on the *absolute magnitude* of emissions.

The contributions made by each individual control measure to the reduction in motor vehicle reactive hydrocarbon, nitrogen oxides and carbon monoxide emissions are illustrated in Figures 3, 4 and 10. The curves labeled "present strategy" include only the effect of new cars replacing older vehicles. The projections used in EQL Strategy #1 for the period 1972-1982 are based on the following control measures:

A. Conversion to Gaseous Fuels

Vehicles converted to gaseous fuels, such as natural gas and propane, have demonstrated emissions levels lower than the California 1974 standards and approaching the 1975/76 Federal standards (Table 3).

TABLE 3
Emissions Levels for Gaseous Fuels

	AVERAGE MEASURED VEHICLE EMISSIONS[12]	STANDARDS CAL. 1974	STANDARDS FED. 1975-76[13]
Hydrocarbons	0.50 gm/mi	1.5 gm/mi	.25 gm/mi
Carbon monoxide	4.00 gm/mi	23.0 gm/mi	2.30 gm/mi
Oxides of nitrogen	0.75 gm/mi	1.3 gm/mi	.27 gm/mi

The conversion projection is based on a uniform rate of replacement of gasoline used in Los Angeles County by gaseous fuels over the period 1972-1975, until one-third of the gasoline is so replaced by the target date of December 31, 1975.[14] The conversions probably would be a mix of 75% natural gas and 25% propane, given present supply realities. (See Section II/3.1 for a discussion of gaseous fuels supply.) Conversions are assumed to begin with 1970-1972 model year vehicles, and to continue indefinitely year by year after 1975 in order to maintain the ratio of two-thirds gasoline to one-third gaseous fuels, so long as emissions from new gasoline-powered vehicles are significantly higher than emissions from gaseous-fueled vehicles (Table 3).[15] These converted vehicles stay on the road for some years after they are converted (Appendix), and they account for a significant portion of

[12]ARB and Pacific Lighting data (vehicles tuned for low emissions).

[13]Measured according to California seven-mode cycle.

[14]This projection is a conservative one; EQL Strategy #1 (I/2.2) calls for mandatory conversion of all *commercial fleet* vehicles by the end of 1973.

[15]If new motor vehicles do in fact meet the Federal 1975/76 exhaust emission standards after 1974 there would be no point in converting these vehicles. (See Section II/2.5).

the differences in emissions between EQL Strategy #1 and the present strategy (Figures 3, 4 and 10).

Conversions have begun for car and truck fleets, which typically burn larger amounts of fuel than the average vehicles and are already being attracted by the economic benefits of gaseous fuels. Since fleet vehicles burn more gasoline per vehicle, the number of vehicles that would have to be converted to reduce gasoline consumption by one-third is actually somewhat less than one-third.

The emissions figures do not show the full potential air quality benefits of burning gaseous fuels instead of gasoline. Unburned hydrocarbons in the exhausts of natural gas and propane vehicles have been found to be less photochemically reactive than those in gasoline exhausts. The hydrocarbons in gaseous fuels react so slowly with sunlight that they play almost no role in the formation of smog. Present vehicle emission standards do not distinguish between "high" and "low" reactivity hydrocarbons, so that the natural-gas or propane-driven vehicle which meets or approaches standards is really much "cleaner" than a gasoline-driven vehicle with similar emission characteristics. Unburned propane hydrocarbons are only about half as reactive as those contained in gasoline, and natural gas only about one-fifth as reactive."[16]

B. Vacuum Spark Advance Disconnect (VSAD)

The vacuum spark advance disconnect is a retrofit device which can be installed in all used cars up to and including 1970. It disconnects the vacuum spark advance except when a thermostatic switch senses that the car is tending to overheat. In that case the advance is reconnected until the engine cools down.[17] (See Section II/3.4 for additional discussion.) The effects of the VSAD on emissions is summarized in Table 4. The most important effect is the reduction by almost half in oxides nitrogen from 1966-1970 vehicles, which characteristically emit 6 grams per mile. The retrofit also provides some reduction in the hydrocarbon emissions, but almost no effect on carbon monoxide.

In our calculations we assumed that the VSAD retrofit would take place at a uniform rate over the period 1972-1975, and that by the end of 1975 all motor vehicles of model years prior to 1971 would be so retrofitted. Actually the new State law on 1966-1970 vehicles requires the installation of a device to reduce nitrogen oxide emissions "substantially" by 1973.

[16]Based on literature survey by John Batchelder using data on photochemical smog, especially that of A. P. Altshuller.

[17]At the EQL, the undergraduate students in the Clean Air Car Project are investigating the operating characteristics of a simple disconnect of the vacuum spark advance without the thermostatic switch. The cost of such a "fix" is estimated at $10.

TABLE 4
Percentage Changes in Emissions for Vacuum Spark Advance Disconnect (VSAD)[18]

Pre-1966	
Hydrocarbons	-10%
Carbon monoxide	+ 7
Oxides of nitrogen	-24
1966-70 Venicles	
Hydrocarbons	-23%
Carbon monoxide	- 6
Oxides of nitrogen	-44

C. Evaporative Control Retrofit

As indicated in Figure 21, even with the introduction of more effective evaporative controls in new vehicles in 1970, evaporation losses of hydrocarbons from older vehicles remain significant through the late 1970's. Usually about two-thirds of this loss is considered to be reactive hydrocarbons. For this reason it is desirable to try to reduce at least part of the contribution to reactive hydrocarbon emissions by the used vehicle population with an evaporative control system retrofit. The EQL calculations rest on a 50% reduction in the total evaporative emissions by fitting newer used cars with a control device similar to the device used in 1970 and later model vehicles. This step would require retrofitting all 1966 to 1969 vehicles by 1975 (Section II/3.4). In our calculations the retrofit is assumed to begin in 1972 and proceed at a uniform rate until all 1966-1969 vehicles are so retrofitted by the end of 1975.

D. Vehicle Emissions Inspection

Mandatory vehicle emissions inspection is an essential part of the EQL Strategy #1. Without it, the assumption that vehicles meet the standards in effect for their model year is questionable. The Northrop report to the California Air Resources Board indicated that tune-up reduced hydrocarbon emissions by 20-25%.[19] Presumably the vehicles had on the average declined at least this much from the standards of their model year if, indeed, they ever met them.

The inspection system would, therefore, provide a form of insurance that we are getting the emissions reductions which we are counting on for improved air quality. Such assurance will be increasingly important as standards become more stringent and devices more elaborate. Sophisticated control devices such as catalytic or manifold type reactors will probably be used on

[18]Based on ARB data. These performance estimates are very conservative. Recent data indicates the VSAD plus the "Clean Air Car tune-up" will reduce HC by about 50% and NO_X and CO emissions by about 30% on pre-1966 cars.

[19]*Mandatory Vehicle Emissions Inspection and Maintenance, Part A, Feasibility Study,* by Northrop Corporation for the ARB, June 21, 1971.

new motor vehicles. Some of the systems being proposed involve complicated auxiliary devices to preheat the catalyst bed, control mixture ratios, etc. The experience with the deterioration of the relatively simple devices now in use indicates that we can expect greater deterioration of the more sophisticated systems, unless a mandatory vehicle inspection system plus an emissions tax exerts pressure on automobile manufacturers to guarantee these devices and on motorists to maintain them in good working order (Section II/5). The mandatory vehicle emissions inspection system is assumed to begin in this Basin in 1972.

E. Reductions in Emissions Produced by Social and Economic Incentives

The main purposes of the social and economic incentives and disincentives to be discussed in Section II/5 are to encourage the shift to low-pollution motor vehicles, to encourage the use of multiple-occupancy vehicles, and to halt or reduce the annual rate of increase in gasoline consumption. For our present purposes the total effect of all these measures is regarded as a "lumped" 20% reduction in emissions by the end of 1975. Note that this 20% reduction is imposed after the conversion of one-third of the gasoline to gaseous fuels, so that the net reduction in emissions is 13% of the initial (1970) emission levels.

At present, gasoline consumption grows at the rate of about 4% per year in L.A. County. If all of this 20% reduction in emissions had to be achieved by reductions in gasoline consumption by gasoline-powered vehicles, it would amount to holding this consumption constant at its 1970 level for about five years. However, as discussed in Section II/5, a wide variety of other measures and interesting interactions between measures need to be considered.

If these social and economic measures are successful, they would almost certainly be continued after 1975. However, in the present calculations we have made the "conservative" assumption that no *additional* reductions in emissions are to be attributed to those measures after 1975.

II/2.3.2 Reduction in Stationary Source Emissions

Stationary sources of air pollution have been regulated by the Los Angeles Air Pollution Control District for nearly 25 years. Hydrocarbon emissions from petroleum refining and chemical industries have been regulated by rules that limit the total hydrocarbons emitted or substitute unreactive or "low reactivity" hydrocarbons as much as possible. A similar procedure has been applied to the use of organic solvents in industry and in commerce. The result has been that the stationary source load of total hydrocarbons is about 750-800 tons per day and has been constant for several years. The APCD has concentrated on the approximately 150-160 tons per day of reactive hydrocarbons. It has promised to reduce this to about 75 tons per day, probably by substitution of low reactivity solvents. These reductions could be made by tighter controls on evaporative losses from petroleum marketing, elimination of hydrocarbon solvents entirely in situations where nearly complete solvent recovery or control is not possible, etc. (Section II/4). In Figure 5 the planned reductions in reactive hydrocarbon emissions are assumed to occur at a uniform rate over the period 1972-1975, and these emissions are held constant at the new level thereafter.

Oxides of nitrogen result from combustion of fuels in power plants and industrial, commercial and residential furnaces. Limitations on emissions from new sources and some reductions of existing sources have stabilized the NO_X emissions at about 280-300 tons per day. Additional reductions of about 100 tons per day of NO_X could be made by application of existing and new rules (Section II/4). This reduction is indicated in Figure 6.

II/2.3.3 Overall Emissions

The combined emissions contributions from motor vehicles and stationary sources for Los Angeles County are summarized in Figures 5 and 6. Reactive hydrocarbon emissions are cut to 28% of 1970 levels by 1975 if EQL Strategy #1 is followed, as compared with a reduction to 52% of 1970 levels resulting from the present strategy (Figure 5). By 1975 nitrogen oxide emissions are reduced to 44% of 1970 levels by EQL Strategy #1 as compared to a reduction to 78% of 1970 values that can be achieved by following the present strategy (Figure 6).

II/2.4 Projected Improvements in Air Quality

By combining the results obtained in the two preceding sections, improvements in air quality are projected for the period 1972-1982 in terms of reductions in the average number of days per year on which the California ambient air quality standards on oxidants, nitrogen dioxide and carbon monoxide are violated. For photochemical oxidant we also calculated the projected improvements in air quality based on two higher levels of 0.15 ppm and 0.20 ppm, respectively, in order to illustrate the sensitivity of the average number of "objectionable" days per year to the pollutant level that is selected as "objectionable."[20]

Figure 22 shows a breakdown of the projected improvements in oxidant air quality (State standard) for Downtown L.A. according to the present strategy and according to EQL Strategy #1. Each specific control measure in

[20]The Los Angeles County Medical Association has proposed a maximum one-hour average oxidant level of 0.20 ppm as a "health warning" for persons with coronary artery diseases or chronic respiratory diseases.

EQL Strategy #1 makes a modest contribution towards cleaner air, but the *summation* of all these steps is impressive. No better illustration could be found of the statement often made by Dr. Arie Haagen-Smit, chairman of the ARB, that progress toward clean air is a painstaking step-by-step business in which there are no "magic solutions." By using Figure 22 the incremental short-term cost of each specific control measure can be weighed against the reduction in "objectionable" days that can be achieved by that measure.

In Figures 23 and 24 we show the reductions that can be achieved in the average number of days per year on which the two higher oxidant levels of 0.15 ppm and 0.20 ppm are exceeded in Downtown L.A. Similarly, Figures 25 and 11 illustrate the predicted improvements in air quality in Downtown L.A. based on the State nitrogen dioxide and carbon monoxide standards.

By using the multiplication factors for photochemical oxidant and nitrogen dioxide levels discussed in Section II/2.2.4, projections can be made of improvements in air quality for the entire South Coast Air Basin. Figures 7, 9 and 26 show the situation for photochemical oxidant, and Figure 8 illustrates the improvement for nitrogen dioxide. (Carbon monoxide air quality is virtually the same in the Basin as in L.A. County.) The results that can be achieved by EQL Strategy #1 are summarized in the following table:

TABLE 5
EQL Strategy No. 1—South Coast Air Basin

STANDARD/YEAR	1970	1975	1977
Nitrogen dioxide concentration 0.25 ppm for 1 hr.	115	10	5
Maximum daily 1 hr. average oxidant level			
0.10 ppm	241	50	30
0.20 ppm	150	15	10
Carbon monoxide 10 ppm for 12 hrs.	203	15	5

By 1977 EQL Strategy #1 virtually eliminates the nitrogen dioxide and carbon monoxide problems in this Basin. It accomplishes the objectives set forth for photochemical oxidants in Part I and reduces the number of "health warning" days to 10 or less.

In Figure 7 we observe a "flattening out" of the graph of air quality vs. time in the late 1970's at a level of about 80 days per year for the present strategy and about 25 days per year for EQL Strategy #1. This trend reflects the increasing difficulty of achieving additional reductions in emissions of reactive hydrocarbons and nitrogen oxides, as shown by Figures 3-6. In fact, if no *new* steps are taken, these emissions will begin to *increase* again in the early 1980's because of growth in population and in the rates of consumption of gasoline, natural gas and oil. Two highly simplified long-range projections are shown in Figure 14, based on the assumption that starting in 1982 emissions will increase either at an annual rate of 2% per year or at 4% per year.

Section II/6 contains a brief discussion of some new approaches to the long-term air pollution problem in the Basin.

II/2.5 Lower Limits on Emissions and on the Average Number of "Objectionable" Days Per Year

In Figures 27-29 we illustrate probable lower limits on motor vehicle emissions of reactive hydrocarbons, nitrogen oxides and carbon monoxide in L.A. County that can be achieved in the 1972-1982 time period. The curves labelled "conservative" are reproduced from Figures 3, 4 and 10, and represent either the present strategy or EQL Strategy #1, based on the conservative assumption that after 1974 new cars meet the 1974 California exhaust emissions standards. The curves labelled "optimistic" show the reductions in emissions that can be achieved if after 1974 new cars do, in fact, meet the tighter 1975/76 federal standards.[21] As expected, the differences are small by the initial target date of December 31, 1975, but are significant by 1980. Because of the high probability of operational difficulties with the complex control devices on new post-1974 cars during the first few years after their introduction, the calculations of improvements in air quality in Section II/2.4 are based on the "conservative" projections of emissions.

By assuming that emissions from stationary sources are unchanged from the projected values shown in Figures 5 and 6 for EQL Strategy #1, we calculate that the minimum total emissions of reactive hydrocarbons amount to about 150 tons per day by 1980, and the minimum total emissions of nitrogen oxides amount to about 250 tons per day (EQL Strategy #1—"optimistic").

Professor List[22] has done an independent inventory of emissions minima obtainable in the South Coast Air Basin, based on reasonably "optimistic" technology. He credits motor vehicles with performance equivalent to the 1975/76 federal emissions standards. Power plants are assumed to have emissions factors similar to domestic gas appliances as opposed to high temperature furnaces. Allowance is made for minimum hydrocarbon emissions from evaporation of solvents and gasoline.

Dr. List's minimum figure of about 200 tons per day of total reactive hydrocarbons and 240 tons per day of nitrogen oxides are fairly close to the "optimistic" estimates given here.

In Figure 30 we show the improvement in oxidant air quality at the State standard for both the "conservative" and the "optimistic" projections of emissions. The average number of "objectionable" days per year reaches a minimum of about 15, according to the optimistic EQL Strategy #1, and then rises again beyond 1982 because of the growth in emissions with a *fixed* technology.

[21]As explained earlier conversion to gaseous fuels would cease after 1975 if new cars met the tighter 1975/76 federal standards.

[22]List, E.J.: *Energy Use in California: Implications for the Environment,* EQL Report #3, December 1971.

II/2.6 The Air Quality Problem for Sulfur Dioxide and Particulate Matter

EQL Strategy #1 concentrates on reduction of reactive hydrocarbons, oxides of nitrogen and carbon monoxide emissions. However, there are two other pollutants in the Los Angeles atmosphere which currently exceed the State and federal ambient air quality standards—sulfur dioxide and particulate matter.

Sulfur Dioxide

Sulfur dioxide is a problem in the vicinity of the heavily industrialized southwest coastal and south coastal areas, extending from Torrance east to Long Beach. Sulfur dioxide emissions, summarized in Table 6, originate mainly from stationary sources. The ambient air quality standard for California (0.04 ppm average for 24 hours) is violated almost every day in the vicinity of these sources. The APCD recently adopted rules 53.2 and 53.3 to control the sulfur dioxide emissions from the sulfur industry from 115 tons per day to 10-15 tons per day. Additional controls will probably be needed to reduce the emissions of the petroleum industry.

The remaining major source of sulfur dioxide is the electric power generating plants. The plants are already required to burn natural gas when it is available (Rules 62 and 62.1) and low sulfur oil at all other times (Rule 62.2).

However, the supply of natural gas for power plants is declining rapidly, and these facilities will have to use more oil. In 1968 the two major electrical utilities in the Basin burned 86% natural gas and 14% oil. By 1971 the mix was 67% natural gas and 40% oil, and for 1972, 36% natural gas and 64% oil was predicted.[23]

Ideally, the power plants should be equipped to burn a wide variety of fuels so that they can choose the fuel with the lowest sulfur content, including distillate oils, naptha, and other low sulfur hydrocarbons. This procedure would require burners that could be adapted to different fuel properties, such as variation in viscosity.

Particulate Matter

California has separate standards for suspended particulate matter, lead particulates, and visibility reduction. The sources of direct particulate emissions are listed in Table 7. However, secondary particulate aerosols are known to form as a result of the photochemical smog reaction, and these aerosols may amount to as much as 25% of the total in the atmosphere, on the basis of a yearly average. On particularly "smoggy" days these chemically-produced aerosols may amount to 75% of the total in the atmosphere.[24] These processes

[23]SCE, 1970 Financial and Statistical Report and 1971 Annual Report; Board of Water and Power Commissioners, City of Los Angeles, Los Angeles Dept. of Water and Power Annual Reports, 1968-1971.

[24]Friedlander, S.K., *Chemical Element Balances and the Identification of Air Pollution Sources,* Conference on Science in the Control of Smog, Caltech, November 15-16, 1971.

are not well understood, and the problem requires more work in order to formulate a rational control strategy for particulate matter.

In general one can say that EQL Strategy #1 will contribute to a reduction in particulate levels. For example, conversion of vehicles to gaseous fuels eliminates direct emissions of lead and carbon, and the exhaust gases are virtually photochemically nonreactive. Overall reductions in emissions of reactive hydrocarbons and nitrogen oxides should also contribute to a reduced production of photochemical aerosols. However, little or nothing is known about the effects of these changes on the particle-size spectrum distribution of aerosols, which plays a key role in determining visibility reduction.

TABLE 6
Sulfur Dioxide Emissions in L.A. County[25]

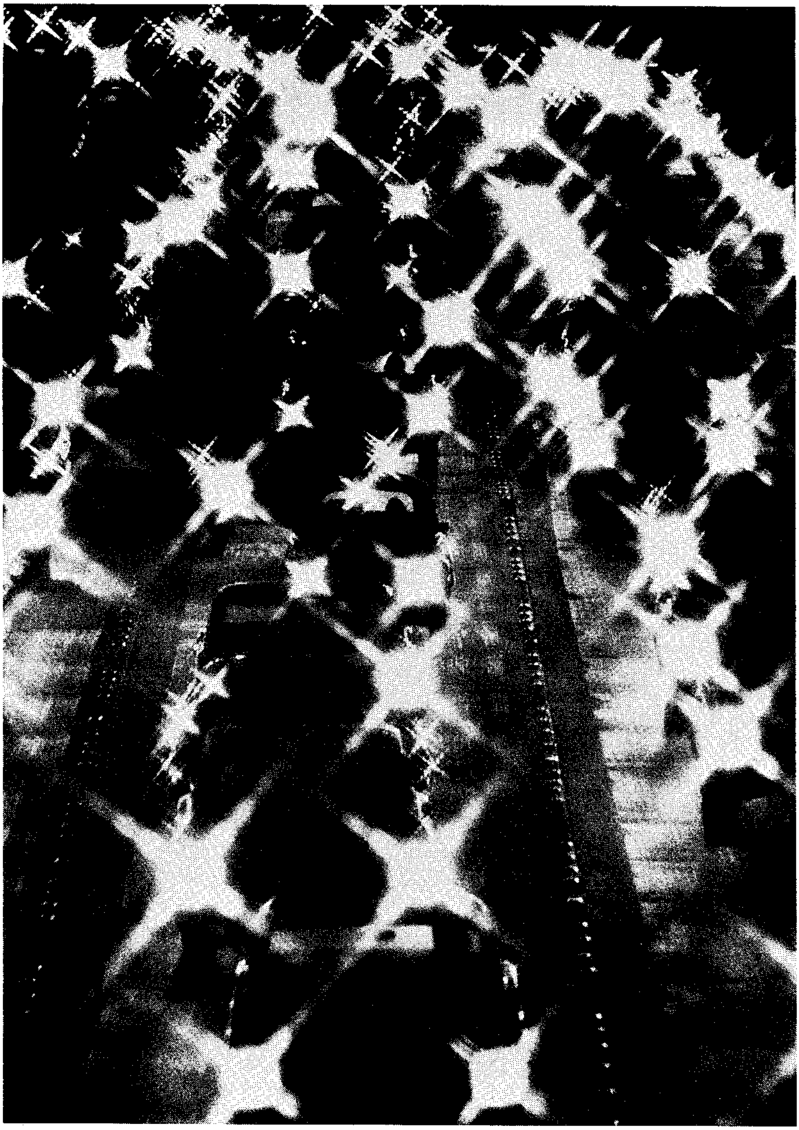
			(tons/day)
Industrial			
Chemical (Sulfur industry)			115
Metallurgical			5
Petroleum			55
Power Plants			
Summer	0		
Winter	70	Average	35
Vehicles			35
Aircraft			5
Total			
Summer	215		
Winter	285	Average	250

[25]Source: Los Angeles APCD data

TABLE 7
Particulate Emissions in L.A. County[25]

	(tons/day)		(tons/day)
Industrial		**Commercial**	10
Chemical	10	**Residential**	5
Metallurgical	10	**Vehicles**	
Mineral	5	Gasoline	45
Petroleum	10	Diesel	10
Other	5	Aircraft	15
Power Plants	5	Total	130

[25]Source: Los Angeles APCD data



PART II: SECTION II/3

Over the years there have been a number of ideas for reducing air pollution in Los Angeles ranging from banning the internal combustion engine to punching holes in the inversion layer. There has never been any widespread agreement as to which of these were practical and feasible.

In the technical measures discussed in this section, the EQL team considered only the technology that was "on the shelf," if not yet widely in use. In a strategy aimed at significantly reducing air pollution within three to five years, one is necessarily stuck with the internal combustion engine. One is not, however, limited to gasoline as its fuel. There was considerable data available to show that motor vehicle emissions could be cut up to 90% and at least 50% by using a rather simple system for converting them to burn natural gas, propane, or some other gaseous fuel.

There are problems. Is the supply of these fuels sufficient? The answer which the EQL team found—with the help of a petroleum industry consulting firm— is that as much as one-third of the gasoline used in the Los Angeles Basin could be converted to natural gas or propane within present supply constraints. Research by one member of the Lab showed that even when natural gas had to be taken away from power plants to supply converted motor vehicles, this would clearly be the thing to do, since the reduction in emissions from burning the gaseous fuel in motor vehicles is so much greater than burning it in the plants.

The study showed that conversion often paid for itself in fuel and maintenance savings and that safety and insurance really were not important problems.

The other devices and techniques—vacuum spark advance disconnect, capacitor discharge ignition optimization, and the evaporative retrofit device for controlling escape of gasoline vapors from auto tanks—were found to have been adequately tested or proved in actual use on new cars. Their adoption for widespread use on the existing stock of older cars was considered feasible both from the standpoint of cost and results.

II/3 FEASIBILITY OF CONTROL MEASURES FOR MOTOR VEHICLES

II/3.1 Supply and Distribution of Gaseous Fuels

EQL strategy #1 calls for the replacement of one-third of the gasoline burned by motor vehicles in the South Coast Air Basin with gaseous fuels, such as compressed natural gas (CNG) and liquid petroleum gas (LPG).[1] The most obvious question raised by this proposal is this: Why advocate the use of natural gas in motor vehicles in the face of an increasingly serious national shortage of this fuel?

In addition to studies of the supply question carried out by EQL staff members, the Lab commissioned the Pace Company of Houston, Texas, a well-known oil and gas consulting firm, to study the availability of gaseous fuels for vehicle use in this Basin. The Pace Company report[2] concluded that supplies of CNG and LPG are adequate to replace up to 33% of the gasoline burned in the Basin, provided that a "mix" of 25% CNG and 8% LPG is used to make up the figure of 33%. Details of the supply situation are as follows:

II/3.1.1 Natural Gas Supply

The Pace Company report indicates that the South Coast Air Basin is now entering a period during which total demand for natural gas will exceed supply, and that the shortage will grow during the next few years unless new supply sources are discovered or developed more rapidly than at present. However, it should be remembered that consumption of natural gas in this Basin is so large that only about 7.8% of the projected 1975 supply would be needed to replace 25% of the gasoline used in vehicles.

Figure 12 illustrates the proportion that this amount of natural gas bears to total anticipated supply and demand. In 1969 average daily supply in August was still ahead of total demand, but by 1975 both conservative and optimistic projections place demand beyond average supply by an imbalance of from 0.3 billion to 1 billion cubic feet per day.

In other words the relatively small amount of natural gas needed for conversion—an average of about 0.27 billion cubic feet a day by 1975—will have to be diverted from other uses. It cannot be taken from homes and other "firm" gas customers, but it can be taken from "interruptible" users—power plants and industries—whose supply of gas is presently subject to curtailment or shut-off when supply runs low. Such a diversion could be accomplished by means of a small price differential.

Since power plants and industrial furnaces are also sources of pollution, is it a good idea to take 10% of their natural gas away from them and substitute residual crude? Clearly, in terms of reduced emissions, the answer is "yes,"

[1]LPG is mainly propane.

[2]The Pace Company, *Evaluation of Gaseous Fuels Supply for Motor Vehicle Usage in the Los Angeles Basin,* prepared for the EQL, Houston, Texas, February 15, 1971.

according to an analysis by Dr. E. J. List of Caltech.[3] The use of natural gas in place of gasoline in vehicles results in emission reductions more than ten times greater per kilowatt hour of energy produced than the use of the gas in place of residual crude in industrial and power plant boilers.

Dr. List suggests that there are additional gains to be made by fuel substitution: "Since burning gasoline in power furnaces would not lead to any hydrocarbon or carbon monoxide emissions to speak of (because of the long flame residence times), there would be an enormous reduction in these two emissions if the automobiles burned the methane and the power plants the gasoline. Such a fuel substitution process is not without precedent. The British converted virtually all Londoners to burn a smokeless fuel after the disastrous 1952 killer smog."[4]

Figure 12 gives the natural gas supply picture for August, during which "firm" demand for gas is at a minimum, and Figure 32 illustrates the situation in February. During the coldest months firm demand for gas requires a large fraction of the entire supply, and there have been some predictions of shortages for residential and other "firm" users within the next few years (Figures 31 and 32). It seems quite probable that no gas can be diverted to vehicles during these months. Converted vehicles will have to be equipped with the dual-fuel system that allows a switch to gasoline during the winter months and outside the Basin where fuel supply may be difficult. (Almost all the current conversions do use the dual-fuel system.) Fortunately, the colder months are the meteorologically "best" time to burn gasoline in the Basin because of reduced sunlight intensity.

Gas suppliers have forecast that pressures on the natural gas supply will be somewhat relieved after 1975 because of coal gasification and importation of liquefied natural gas (LNG) so that vehicle owners who convert to natural gas and want to continue using it for reasons of emission reduction, easier engine maintenance and economy will be able to obtain the fuel throughout the useful life of any vehicles converted within the next few years.

II/3.1.2 Propane Supply

The existing market for liquid petroleum gas (LPG or propane) in Southern California is so small relative to that for natural gas that conversion of any significant number of vehicles to propane would mean an improbably rapid growth in production and marketing facilities. Even the 8% conversion of gasoline to propane found feasible in the Pace report involves a doubling of the California supply in about four years—from the 12.5 million barrels a year projected for 1971 to 26.1 million barrels in 1975 (Figure 13).

In recent years the market for propane has been rather static and seasonal—conditions not conducive to calling forth maximum production of propane

[3]List, E. J., "Energy and the Environment in Southern California," *Engineering and Science*, California Institute of Technology, Pasadena, November, 1971.

[4]List, E. J., *Energy Use in California: Implications for the Environment*, EQL Report #3, December, 1971.

from existing natural gas field processing and oil refining. Nevertheless, there has been a growing surplus of propane, and it is estimated that U.S. supply will increase by 27% by 1975.[5]

Up to now most propane has been a by-product of natural gas processing in producing fields. But propane is also produced as a by-product of petroleum refining, and this source will become the major one within this decade. Refineries will be producing more unleaded gasoline, which involves modifications of the refining process that will result in a greater yield of propane.

According to the estimates in the Pace report, propane demand in California will reach 13.7 million barrels a year by 1975 if present trends continue (Figure 13). When the equivalent of an 8% conversion of the gasoline in the South Coast Air Basin to propane is added to these estimates, projected demand increases to 22.6 million barrels a year in 1975. The 1975 propane supply—17.2 barrels—would fall considerably short of demand if the needs of the converted vehicles were added. The difference would be made up by attracting additional supplies from California refineries and field producers and from producers in heavy surplus areas like west Texas, the Rocky Mountain region and western Canada. This additional propane is indicated in Figure 13 by the curve marked "augmented supply." The Pace Report estimates that a refinery-gate price of ten cents per gallon and a stable market—which vehicle conversion would provide—would be needed to bring forth the maximum propane supply for California during the 1971-1975 period. (Currently, refinery-gate propane prices in the Los Angeles area are in the range of 6 to 6.5 cents per gallon.)[6]

II/3.1.3 Distribution

At the moment the distribution system for propane as an automotive fuel is somewhat better developed than that for natural gas. There are 64 service stations in the South Coast Air Basin selling propane as a vehicle fuel and 477 in California.[7] A number of others sell the fuel to campers and could easily get the necessary permit to sell to vehicles if a market developed. In fact, every service station is a potential propane outlet once the market has developed enough to justify the capital costs of the tank and dispensing equipment. Current availability of propane is often better outside urban areas, since propane now has its greatest market as a household fuel in rural areas beyond the reach of natural gas pipelines. Small fleet owners who want to convert to propane but do not want to invest in a central fueling facility should be able to get their supplies on the existing retail market with increasing ease.

[5]Pace Report, Table 10, p. 43.

[6]The Pace Report, page 84.

[7]*1972 LP-Gas Refueling Directory,* Woodall's National LP-Gas Association.

The situation for natural gas is somewhat different. Although natural gas is readily available throughout the Basin, it must be compressed and stored under pressure for use in vehicles. Generally, fleet owners who convert will have to install central fueling facilities (Section II/3.2). Two Union service stations in Riverside, California, have been selling CNG to motor vehicles since May, 1972. Dual Fuel Systems, Inc., one of the partners in the pilot program, indicated that if the venture is successful arrangements will be made for the sale of natural gas to motorists at a number of other service stations in the area.[8]

II/3.2 Economics of Conversion to Gaseous Fuels

A substantial investment is required to modify a vehicle to burn one of the gaseous fuels, but the investment yields savings on both fuel and maintenance. If the vehicle is driven a great deal, the savings are often great enough to justify conversion on economic grounds alone. The economics for the conversion of each vehicle and fleet are different, and the examples given in this section quote typical numbers for each of the factors which must be considered in order to determine whether the economics are favorable in a particular case. Additional detailed information is available in the *Gaseous Fuels Manual,* published in March, 1972, by the Caltech Clean Air Car Project.

II/3.2.1 Costs of Conversion

The range of costs is summarized in the following table:

	NATURAL GAS	PROPANE
Equipment	\$300	\$300
Fuel tankage	\$20-40 per gallon	\$3.50-\$10 per gallon[9]
Installation	\$100-\$300	\$100-\$300

The equipment kit needed for conversion costs about the same for any type of vehicle, but the costs of installation vary according to the kind of vehicle and the amount of tankage to be installed. Natural gas tankage is more expensive because it is heavy and bulky—a gallon equivalent occupying about two cubic feet and weighing 35 to 40 pounds. For the same reason the range of natural gas vehicles is usually limited to less than 100 miles. Since almost all natural gas conversions are of the dual-fuel type, which allows alternate use of gasoline, the problem of limited range can be overcome by switching fuels.

For natural gas conversions a central fueling facility must be included in the initial capital costs. Unlike propane, natural gas is not widely available at service stations at present. A central fueling facility consisting of a compressor, storage tanks and piping is necessary to transfer the gas from the pipeline to vehicles. The least expensive facility, which costs as little as

[8]News release, Dual Fuel Systems, Inc., Los Angeles, May 3, 1972.

[9]Per gallon equivalent capacity.

$200 per vehicle, requires connecting the vehicle to the compressor overnight for refueling. A compressor capable of fueling a vehicle *directly* from the gas line in a few minutes is available, but will increase the cost of the fueling installation to as much as $500 per vehicle.

II/3.2.2 Savings of Conversion

Fuel: Both natural gas and propane are exempted from the California fuel use tax when used in approved conversion systems.[10] With these exemptions a gallon equivalent of natural gas costs about one-third and propane about two-thirds the price of gasoline purchased at bulk rates.

Maintenance: Because natural gas and propane burn cleanly, savings are realized on engine maintenance. Oil and spark plugs need changing less often and tune-ups are required less frequently than in gasoline systems.

Two specific examples of costs and savings are given here for purposes of illustration. Example 1 involves the conversion of a 30-truck fleet (garbage trucks), where the economics is especially favorable for conversion to gaseous fuels. Example 2 discusses the conversion of a fleet of eight sedans and eighteen trucks; this case may be more representative. In the first case the figures indicate that the conversion investment for natural gas would be paid back within three years without any fuel tax exemption, while the conversion costs of propane would be made up in five years. However, with the State fuel tax exemption approved by the 1971 Legislature for vehicles over 6,000 pounds gross weight, the payback periods are one and three-quarters years with natural gas and one year with propane. In the second example the payback periods are five years for CNG and five and one-half years for LPG, because much less gasoline is used by this second fleet.

TABLE 8

Example 1. CONVERSION OF A TRUCK FLEET

General Assumptions:

1. Fleet consists of 30 trucks (over 6000 pounds gross weight)
2. Trucks drive 80 miles/day, 5 days/week, not more than 14 hours/day; 260 days/year
3. Mileage: 4 miles/gallon gasoline
   4 miles/100 standard cubic feet (unit) natural gas
   3.6 miles/gallon LPG
4. Fuel cost: 23¢/gallon gasoline
   16¢/unit compressed natural gas (including 7¢/unit State tax)
   22¢/gallon LPG (including 4¢/gallon Federal tax and 6¢/gallon State tax)
   including all Federal and State taxes (no exemption)

[10]Under the present law the exemption, about seven cents per gallon equivalent, expires at the end of 1975. A bill to extend this exemption to 1980 is pending in the State Legislature.

5. Oil changes: (cost of $6.50/change)
   gasoline: once every three weeks
   natural gas: once every eight weeks
   LPG: once every six weeks
6. Tune-ups: (cost of $25/tune-up)
   gasoline: once every six weeks
   natural gas: once every sixteen weeks
   LPG: once every twelve weeks

Conversion Costs:

Natural gas: $880/truck, installed, providing a range of 90 miles per truck, requiring 9 hours concurrent filling time

125 scfm[11] compressor, cost of $18,000

overnight fill station at $150/truck

30 × $880 =	$26,400	conversions
30 × $150 =	4,500	overnight fill
	18,000	compressor
	1,000	fueling station installation
	$49,900	Total

LPG: $425/truck, installed, providing a range of 200 miles per truck

1,000 gallon storage tank, leased at $200 per year

30 × $425 =	$12,750	conversions
	1,000	storage tank installation
	$13,750	+$200/year tank leasing

Other costs:

Fuel:

gasoline: 80 miles/day/truck = 20 gal/day/truck
= 5,200 gal/yr/truck at 23¢/gal
= $1,196/yr/truck

natural gas: 80 miles/day/truck = 20 units/day/truck
= 5,200 units/yr/truck at 16¢/unit
= $832/yr/truck

LPG: 80 miles/day/truck = 22 gal/day/truck
= 5,720 gal/yr/truck at 22¢/gal
= $1,258/yr/truck

Fuel savings: $364/yr/truck = $10,920/yr with natural gas for fleet
Fuel additional costs: $62/yr/truck = $1,860/yr with LPG for fleet

Oil:

gasoline: 30 × $6.50 = $195 every 3 weeks
= $3,380/yr

natural gas: 30 × $6.50 = $195 every 8 weeks
= $1,270/yr

LPG: 30 × $6.50 = $195 every 6 weeks
= $1,690/yr

Fleet oil savings: $2,110/yr with natural gas
$1,690/yr with LPG

[11] Standard cubic feet/minute.

Tune-ups:

gasoline: 30 × $25 = $750 every 6 weeks
= $6,500/yr
natural gas: 30 × $25 = $750 every 16 weeks
= $2,440/yr
LPG: 30 × $25 = $750 every 12 weeks
= $3,250/yr

Fleet tune-up savings: $4,060/yr with natural gas
$3,250/yr with LPG

Net savings with natural gas: $10,920/yr in fuel savings
2,110/yr in oil savings
4,060/yr in tune-up savings
$17,090/yr total net savings

Net savings with LPG: $1,860/yr in additional fuel costs
200/yr storage tank leasing
$2,060/YR TOTAL ADDITIONAL COSTS

$1,690/yr in oil savings
3,250/yr in tune-up savings
$4,940/YR TOTAL SAVINGS
$2,880/YR TOTAL NET SAVINGS

Payback time:

Natural gas: $49,900/$17,090 = approximately 3 years
LPG: $13,750/$2,880 = approximately 5 years

Additional savings possible in tax exemptions until 1976:

State tax: 6¢ gallon/LPG, 7¢ unit/CNG
Natural gas: 5,200 units/yr/truck at 7¢/unit
= $364/yr/truck
= $10,920/yr/fleet
LPG: 5,720 gal/yr/truck at 6¢/gallon
= $343/yr/truck
= $10,300/yr/fleet

Total savings: $28,000/yr with natural gas
$13,200/yr with LPG

These additional savings greatly reduce the payback time.
Payback time: Natural gas - 1-3/4 years
LPG - 1 year

The economics of each fleet vary greatly and must be investigated on an individual basis. This is an example in which the economics definitely favor conversion.

TABLE 9
Example 2. CONVERSION OF FLEET OF 8 SEDANS AND 18 TRUCKS

Cost of Fuels/Gallon

gasoline	26¢ regular	32¢	ethyl
propane	14½¢		
	+4¢ federal tax		

compressed natural gas

5.5¢/100 cu. ft.
1.0¢/100 cu. ft. compression and service cost
6.5¢/100 cu. ft.
(there is no federal fuel tax on compressed natural gas)

State tax exemptions for both propane and natural gas have been included

Cost of Fuel/Year

gasoline

$$\frac{21{,}280 \text{ gallons}}{\text{year}} \times \frac{28.8¢ \text{ (avg.)}}{\text{gallon}} = 6130/\text{year}$$

propane

$$\frac{25{,}500 \text{ gallons}}{\text{year}} \times \frac{18.5¢}{\text{gallon}} = \$4720/\text{year}$$

natural gas

$$\frac{2{,}128{,}000 \text{ cu. ft.}}{\text{year}} \times \frac{6.5¢}{100 \text{ cu. ft.}} = \$1382$$

please note that 100 cu. ft. natural gas = 1 gallon of gasoline and that 1.2 gallons of propane = 1 gallon of gasoline

Cost of Routine Maintenance/Year

(Oil changes and tune ups)

gasoline	$1688
propane	1/3 × 1688 = $563
natural gas	1/3 × 1688 = $563

Total Fuel and Maintenance Cost/Year

gasoline	6130	fuel
	+1688	routine maintenance
	$7818	total cost/year
propane	4720	fuel
	+ 563	routine maintenance
	$5283	total
natural gas	1382	fuel
	+ 563	routine maintenance
	$1945	total

Savings/Year

propane	cost on gasoline	7818
	cost on propane	5283
	saving	$2535

We estimate that if natural gas were used, approximately 80% of the driving would be done on natural gas and the remaining 20% would be done on gasoline.

cost on dual fuel (natural gas and gasoline)
$.2 \times 7818 + .8 \times 1945 = \$3120$

natural gas	cost on gasoline	7818
	cost on dual fuel	3120
	saving	$4698

Cost of Converting to Propane

8 sedans at $525/sedan	=	4,200
18 trucks at $450/truck	=	8,100
storage tank installation	=	1,000 estimate
		$13,300

Cost of Converting to Compressed Natural Gas

cost of conversion and refueling equipment	23,066
installation cost (est.)	1,000
	$24,066 total

Simple Equipment Payoff Times

propane $\dfrac{\$13{,}300 \text{ total cost}}{\$2535 \text{ net saving/year}} = 5.25 \text{ years}$

natural gas $\dfrac{\$24{,}066 \text{ total cost}}{4698 \text{ net saving/year}} = 5.12 \text{ years}$

(Note that if the use of gasoline rises to 30% the payoff time becomes 5.7 years.)

An additional economic benefit not taken into account is the extended engine lifetimes for gaseous fueled vehicles. Fleet operators currently using gaseous fuels report that the lifetime of engines (time between overhauls) is extended by 50% to 100% over the average engine lifetime burning gasoline.

II/3.3 Gaseous Fueled Vehicles: Safety and Insurance

II/3.3.1 Safety

Gaseous fuel systems have a number of qualities that make them inherently safe for use in motor vehicles. Gaseous fuel tanks are constructed of heavy boiler plate steel, since they are pressure tanks. They have more than twenty times the resistance of ordinary gasoline or diesel tanks in a collision. Gaseous fuel tanks are fitted with strong valves and fittings which are recessed for added safety and which contain shutoff valves that operate automatically in the event of a fuel line or valve break.[12] Nearly twenty years ago an Interstate Commerce Commission report stated:

> "It would appear from examination of accident records that . . . liquefied petroleum gas equipment is practically never involved in a fire accident because of failure or rupture of the fuel system. This increased safety may be attributed . . . to the necessarily sturdy construction of butane and propane tanks."[13]

Gaseous fuel systems must meet exacting standards. Conversion equipment must be of a type tested and approved by the California State Air Resources Board.[14] Gaseous fuel tanks must meet standards set by the Department of Transportation (D.O.T.)[15] or the American Society of Mechanical Engineers (A.S.M.E.).[16] The tanks must be reinspected and certified every five years or whenever they are repaired or installed.

A U.S. Department of Commerce report recently pinpointed the principal drawback of gaseous fuels:

> "From a fire and explosion safety standpoint, leakage is more of a problem with gaseous than liquid fuels. With proper equipment and handling, LPG presents no undue hazards, but if used by the general public, vehicle engineering and maintenance would have to be more severe than has been the practice with liquid fuels. Experience with LPG fueled vehicles indicates that this is possible."[17]

Gas leaks in enclosed spaces are the principal fire hazard associated with gaseous fuels. When natural gas is leaked into the open atmosphere, it will rise and dissipate harmlessly. Gasoline "puddles" on the ground and presents a potential fire hazard. LPG descends to the ground and dissipates as vapor unless it is confined. In closed buildings, LPG flows down to the lowest levels when spilled, creeping through ventilators and cracks to the lowest level of the building. Since many buildings have furnaces in the basement, an LPG spill presents the same fire and explosion hazard as a gasoline spill

[12]"Safety Factors in Operating LP-Gas Engines," *National LP-Gas Association Times,* Spring 1970, pp. 25-26.

[13]*Motor Carrier Fire Accidents, 1951,* ICC Bureau of Motor Carriers, Section of Safety (December 14, 1953) p. 38.

[14]Cal. Health and Safety Code, Sections 39110-14 (1970).

[15]49 CFR 173.34 (1971).

[16]ASME Boiler and Pressure Vessel Code (1968). *Proposed Regulations of the Department of the California Highway Patrol, Fuel containers and fuel system for compressed natural gas, liquefied natural gas and liquefied petroleum gas* (1971); National Fire Protection Association Standard No. 58; *Liquefied Petroleum Gas Safe Handling and Use,* American Insurance Association (1965).

[17]*The Automobile and Air Pollution: A Program for Progress,* U.S. Department of Commerce, December, 1967, Part II, p. 47.

in a building which is not adequately ventilated for the purpose of dissipating heavy vapors. Both LPG and CNG contain odorizers which reveal the presence of gas in the event of a leak. The odorizer condenses out of natural gas during liquefaction, however. An LNG leak would not be evident because the revaporized gas is almost pure methane and therefore odorless. New odorizers are being developed to remedy the problem.

Gaseous fuels have higher ignition temperatures than gasoline, so it requires a hotter spark to ignite them. Gasoline ignites at 600°-700° F, compared to 870° F for LPG and 1,300° F for natural gas. The burning range of LP gas is narrower than that of gasoline. Natural gas has a somewhat wider burning range, but it dissipates into the atmosphere very rapidly, while gasoline puddles and slowly vaporizes. On the whole, gaseous fuels pose no greater fire and explosion hazard than gasoline. R. H. Eshelman, Detroit Technical Editor for *Automotive Industries,* recently wrote, "Evidence from many fleet type operations to date suggest LPG fuel systems may prove as safe or safer than conventional ones."[18]

Experience with gaseous fueled vehicles indicates that they are at least as safe as vehicles burning gasoline. General Telephone Company of Florida has been using gaseous fuels in its 1,850-vehicle fleet since 1964. Mr. Gary Powell, General Plant Administrator for Transportation, wrote, "I feel as far as LP gas being safe, it is much safer than gasoline, if used in the correct way. With the extra thickness of the tank and the electric lock off, it makes LP gas much safer to use as motor fuel than gasoline." The Chicago Transit Authority (CTA) has run LP gas-fueled buses 716 million miles without ever suffering damage of significance to the LP gas-fuel systems as a result of traffic accidents. Some fueling accidents resulted in fire losses, but according to Mr. Stanley D. Forsyth, former CTA general superintendent of engineering, "There have been a few small fires in the engine compartments during this six-year period, but the loss per mile of operation due to all causes is lower with LP gas than with the other two standard fuels (diesel and gasoline)."[19]

The General Services Administration (GSA) recently tested a fleet of dual-fuel vehicles burning either gasoline or natural gas. The GSA report said:

> "The first year's experience with these dual-fuel vehicles has resulted in an enviable safety record. None of the data studies or the people consulted indicates any safety problem when these vehicles were used under normal conditions. . . .
>
> "The GSA test fleet record shows no fires, injuries or hazardous incidents. . .
>
> "Studies have indicated that methane systems should be appreciably safer than gasoline in accident situations. The tankage is considerably more rugged, the maximum leak or

[18]Eshelman, "LP Gas Conversion," *Automotive Industries,* May 15, 1970, p. 60.

[19]"Safety Factors in Operating LP Gas Engines," *op. cit.*, p. 26.

> fire is greatly reduced and spillage due to overturning is not possible."[20]

The cities of Los Angeles and San Francisco have promulgated stringent regulations for parking LP gas-powered vehicles inside of buildings. Under Los Angeles Fire Protection Bureau Requirement No. 35, inside storage of liquefied flammable gas (LFG)-powered vehicles "may be permitted in areas designated by the Fire Department. No vehicle shall be stored, parked or maintained in any building occupied or used as an Institutional or Assemblage Occupancy." Under the San Francisco Fire Code, an LP gas-powered vehicle cannot be parked or stored in any building except a building used exclusively for storing, parking or repairing. The vehicle is not permitted below the grade level, and buildings used to house them shall have no basement or open area below grade level. In San Francisco a vehicle powered by LPG cannot be parked on the premises outside of buildings except in approved locations. Although such stringent regulations appear to be unreasonable in view of the safety record of gaseous fuels, it is wise for the fleet owner contemplating conversion to be thoroughly familiar with fire regulations in his operating area and follow them to the letter until they are changed.

Mr. R. L. Davis, Assistant Manager for Regional Loss Control, Insurance Company of North America, stresses the fact that gaseous fuel system installations must meet all applicable codes and safety standards if they are to be safely used. Statistics gathered by the National Fire Protection Association over 30 years showed 18 accidents where LP gas as an engine fuel was involved. In every case the cause of the accident was traced to noncompliance with national standards.[21] Gaseous fuels, then, are safe to use as motor fuel when used in state certified systems which are installed and maintained by competent personnel in accordance with all applicable codes and safety standards.

II/3.3.2 Insurance

The insurance industry does not recognize any distinction between gaseous fueled vehicles and gasoline powered vehicles in its rate structure. Mr. William G. Meade, Director of the Environmental Sciences Unit for the Hartford Insurance Group, recently wrote:

> "There is no difference in premium between an LP gas-powered or gasoline-powered vehicle or, for that matter, a diesel-powered vehicle. The rates and premiums are based upon many

[20] *A Report on the General Services Administration's Dual-Fuel Vehicle Experiments: Pollution Reduction with Cost Savings,* General Services Administration. Washington, D.C.: U.S. Government Printing Office (1971), p. 17.

[21] "Safety Factors in Operating LP-Gas Engines," *op. cit.*, p. 25.

factors, including use, locations, etc., but the fuel is not one of the criteria."[22]

Insurance underwriters insist that conversions meet applicable state and local standards if they are to insure a vehicle. One standard often referred to is "National Fire Protection Association Standard No. 58, Storage and Handling of Liquefied Petroleum Gases, 1969."[23] The Uniform Fire Code, County of Los Angeles, and the Pacific Fire Rating Bureau, a commercial rating organization for the insurance industry, both require that vehicles converted to gaseous fuels comply with NFPA standard No. 58. The Los Angeles City Fire Department specifies strict standards that must be met by gaseous fuel conversions in the city.[24] The State of California requires that the conversion use a system approved by the California State Air Resources Board and use tanks which meet D.O.T. or A.S.M.E. standards.[25]

The insurance industry does distinguish between gaseous fuels and gasoline in refueling installations and structures in which vehicles are stored. Both underwriting and price distinctions may be made, depending on the nature and location of facilities. The *Underwriting Manual* of the National Bureau of Casualty Underwriters, 1971, establishes a higher basic bodily injury rate for LPG fueling stations than for gasoline stations. The basic property damage rate is the same. No rate has been established for natural gas fueling stations, but analogous rates for natural gas are higher than for either propane or gasoline. Rates vary, however, depending on facilities, safety record, and types of coverage sought. Anyone contemplating the installation of gaseous fueling facilities should contact his insurance company to determine whether or not his insurance cost will change.

Insurance companies may determine that gaseous fuels are safer than gasoline for many uses. When Disneyland converted some of its boats to burn natural gas, its insurance underwriters determined:

> "This fueling system should eliminate many of the exposures that exist with the present gasoline fueling system and should present no unusual operating problem or excessive exposure to employees or guests."[26]

[22]The conclusion that no rate differential exists between gaseous fueled and gasoline fueled vehicles was supported by: Mr. Hubbard of the Insurance Services Office, a licensed rating organization, telephone conversation of September 16, 1971; Mr. John J. Bailey, Fleet Safety Coordinator, American Insurance Association, letter dated June 9, 1971; Mr. Paul E. Lippold, Public Affairs Manager, Allstate Insurance Company, letter dated June 7, 1971; Mr. Gerold L. Maatman, Vice President, Lumbermens Mutual Casualty Company, letter dated June 18, 1971; and Mr. R. L. Davis, Assistant Manager for Loss Control, Insurance Company of North America, letter dated June 9, 1971.

[23]NFPA No. 58. Copies are available from the National Fire Protection Association, 60 Batterymarch Street, Boston, Massachusetts, 02110.

[24]Los Angeles Fire Department Requirements for Liquified Flammable Gas Powered-Internal Combustion Engines, Fire Prevention Bureau Requirement No. 35, 5-17-71(rev.). Los Angeles City Fire Code, sections 57.44.39, 57.44.40 (1971).

[25]California Administrative Code, Title 8, pp. 451-550, Unified Pressure Vessel Safety Orders.

[26]Mr. R. L. Davis, Assistant Manager Regional Loss Control, Insurance Company of North America, letter of March 12, 1970.

Gaseous fuels are safe and easy to insure if they are installed and used in strict compliance with all applicable standards and maintained by qualified repairmen. Failure to use certified pressure vessels or conversion systems on gaseous fueled vehicles will increase the potential for accidents and make it difficult to insure vehicle fleets and terminal facilities.

II/3.4 Feasibility and Costs of Exhaust and Evaporative Emissions Control Devices for Used Cars

II/3.4.1 Vacuum Spark Advance Disconnect (VSAD)

The vacuum spark advance disconnect interrupts the normal vacuum signals applied to the distributor from the carburetor. The principal effect is that ignition occurs later in the engine cycle so that peak temperatures and pressures are reduced, thus leading to a lower rate of formation of oxides of nitrogen. This improvement is especially significant for 1966-1970 vehicles because of their high NO_X emissions (Section II/2.3, Table 4).

Figure 33 illustrates a typical VSAD installation. Normally the vacuum line runs directly from the carburetor to the distributor. However, in the retrofit device a thermostatic (overtemperature) switch is placed in the vacuum line, interrupting the normal vacuum signal when the switch is open. The switch is connected into the coolant return line (upper radiator hose) so that it can sense if the engine is overheating and reconnect the advance.

Many vehicles will operate satisfactorily without the overtemperature switch if the advance line is merely disconnected and plugged. Undergraduates in the Clean Air Car Project of the EQL are investigating the operating characteristics of pre-1970 gasoline powered cars subjected to the "Clean Air Tune-up." This procedure consists of the following elements:

1. Test of the cooling system to insure that it is functioning properly;
2. Testing and tuning of fuel and electrical systems;
3. Disconnecting the vacuum spark advance;
4. Tuning for idle engine rpm of 600 in "drive" for vehicles with automatic shift and 700 for vehicles with manual shift at lean "best idle" (normally at 14:1 air-fuel ratio).

This procedure is the same as that proposed by General Motors, except that the thermal vacuum switch which reconnects the vacuum advance at engine temperatures above 205°F is not included. Preliminary results give the following percentage reductions in exhaust emissions for pre-1966 cars:

HC	41%	CO	32%	NO_X	32%

Estimated cost is $10-15, including the "tune-up," as compared with a minimum estimated cost of the VSAD illustrated in Figure 33 of $20 *without* the tune-up.

As noted in Part I, legislation passed in 1971 requires that beginning in 1973 all 1966-1970 cars must be equipped with a device that will "significantly" cut nitrogen oxide emissions. The certification that such a device is installed on the car is to be made on initial registration, or transfer of ownership, or on renewal of registration. A limit of $35 is set on the initial cost of such a device, including installation charges, and the device must not require maintenance more often than once every 12,000 miles at a maximum cost of $15. The State ARB recently set the standards for such a device or control measure. These standards require a 30% decrease in NO_X emissions for engines with a displacement greater than 140 cubic inches, and a 20% reduction in NO_X emissions for engines under 140 cubic inches displacement. Emissions are to be measured by the constant volume sampling (CVS) 7-mode cycle, with a 60 mph cruise mode included.

The motor vehicle population in the South Coast Air Basin is projected at 6.3 million in 1975, and 35% of these vehicles will be 1966-1970 models (Appendix), or about 2.2 million vehicles. If retrofit of these vehicles is completed by the end of 1975, the estimated cost of the VSAD itself is about 45 million dollars and the estimated maintenance cost is about 30 million dollars, or a total of 75 million dollars. If the procedure recommended by the Clean Air Car Project is adopted, the cost of the disconnect plus "tune-up" is about 33 million dollars. Additional yearly "tune-ups" at a cost of about 22 million dollars per year for the 1966-1970 cars would probably be required anyway as part of a mandatory annual vehicle emissions inspection system for all vehicles. In any case these costs will be borne by the motorists. (See Section II/5.3 on emissions taxes.)

II/3.4.2 Capacitor Discharge Ignition Optimization System

This system was developed by Air Quality Products, Inc., to meet the emissions standards for 1955-1965 model used car devices set forth in the Health and Safety Code, Sections 39107 and 39175 to 39184.[27] It was accredited by the ARB on September 15, 1971, in Resolution 71-72. At that time the board had some reservations about the device, but on December 17, 1971, the ARB adopted Resolution 71-72A, removing all reservations except that the applicant is required to submit manufacturing and marketing plans prior to action by the ARB making the device mandatory for 1955-1965 vehicles.

The system installation, shown in Figure 34, involves certain adjustments of the internal programming of the system to fit the characteristics of each particular vehicle. In addition, the carburetor is set for an idle speed of 50-75 rpm over normal manufacturer's specification and for lean idle mixture (1.5% CO in the exhaust).

[27] Also Title 13 of California Administrative Code, Chapter 3, Sub-chapter 2, Parts 2 and 3.

The ignition optimization system retards the spark under certain conditions by interrupting the vacuum advance signal via a solenoid-activated switch and/or electronically delaying the spark. This measure lowers peak pressures and temperatures in the combustion process and reduces NO_x emissions. However, some reduction in hydrocarbon emissions also occurs. The best explanation of this phenomenon is that combustion probably continues to take place right into part of the exhaust cycle of the engine, and some residual HC is burned as it is swept out of the cylinder.

Additional hydrocarbon emissions reduction results from the "leaning out" of the carburetor away from the normally "rich" setting found in the older vehicles. The slight increase in NO_x that usually accompanies this change is more than compensated for by the timing changes.

ARB data obtained during accreditation testing shows that an average reduction of 60-70% in hydrocarbons and 30-40% reduction in NO_x is possible in pre-1966 vehicles. Except for a slightly larger reduction in HC emissions, this performance is about the same as for the simpler VSAD.

This system would also be applicable to 1966-1970 vehicles. These cars have already been tuned "lean" to meet hydrocarbon and carbon monoxide emissions standards, but they tend to emit high levels of oxides of nitrogen. The manufacturer claims that a 50-60% reduction in NO_x and 10-15% reduction in HC are possible on these vehicles. This performance is also about the same as for the simpler VSAD.

At present the installed cost of this system is claimed to be $40, as compared to a maximum allowable price of $85.[28] By 1975, about 12% of the vehicles would be in the pre-1966 category, or about 760,000 vehicles in the South Coast Air Basin. At the estimated price of $40 the cost of the retrofit would be about 30 million dollars in the South Coast Air Basin.

II/3.4.3 Evaporative Control Retrofit

Evaporative losses of gasoline in pre-1970 vehicles without evaporative control systems are as follows:

1. Breathing losses from the fuel tank and other parts of the fuel system because of diurnal heating and cooling;
2. Running losses from the fuel tank and carburetor vents during operation;
3. Evaporation of the fuel from the heated carburetor and other parts of the fuel system during "hot soak" after the engine is turned off.

The evaporative control standard for 1970-1972 vehicles limits the total evaporative emissions to 6 gms of hydrocarbons under a test procedure simulating one diurnal cycle and a 21-minute trip with the associated "hot soak."

[28]Until 1971 the maximum allowable cost was $65, but legislation passed in 1971 raised this limit to $85.

After 1972 the limit is 2 gms per test.[29] Uncontrolled vehicles typically show 20-60 gms per test. Controlled vehicles seem to be able to meet the standard easily, and the test results are often reported as "zero."[30] A considerable number of techniques are used in evaporative control systems. Many are applicable to retrofit systems.

Carburetor losses in operation and during "hot soak" are controlled in several ways. External vents for the carburetor float bowl and other chambers are either eliminated, made internal (so the vapors are consumed by the engine), or manifolded to a vapor storage system such as a carbon canister or the engine crankcase.

Fuel tank losses are controlled by collecting the emitted vapors in either a carbon canister or the engine crankcase, after separation from the liquid gasoline via a suitable standpipe system. Losses occurring during engine operation are drawn into the engine via the air induction to the carburetor and/or the positive crankcase ventilation (PCV) system. The diurnal and "hot soak" losses are stored in the vapor collection system, which is purged with outside air when the vehicle is started. The contaminated purge air is drawn into the engine via the carburetor or the PCV system.

A typical system utilizing a carbon canister for storage is illustrated in Figure 35. The canister stores both fuel tank and carburetor losses when the engine is not operating. Purge is accomplished via the PCV system.

The cost of the evaporative control retrofit is currently estimated as high as $150. Probably the vehicle fuel tank would have to be removed and either modified or replaced. Installation of the other components under the hood would have to be made, along with the necessary connections to the engine and/or carburetor. The problem is complicated by the large variety of vehicle makes and models, so that specialized components are required. However, all the pertinent technology exists. What remains is the design and testing of the suitable systems. Studies of simpler, less expensive systems are in progress as part of the EQL Clean Air Car Project.

By 1975, 38% of the vehicle population will be pre-1970 vehicles with no evaporative controls. The 1966-1969 vehicles will represent 25% of the population. Assuming that evaporative control systems reduce losses by 90%, all 1966-69 vehicles would have to be retrofitted to achieve the 50% reduction in evaporative losses projected in the EQL strategy. The cost of this retrofit would be 230 million dollars for the South Coast Air Basin.

Such an expensive retrofit will almost certainly require some cost-sharing between the motorist and the general public. In general these devices will be installed on older vehicles having lower registration fees, so registration fee deductions would be a poor method of compensation. State income tax write-offs are a possible method, but most likely a straight cash subsidy of part of the retrofit cost will be required. The State will have to find an appro-

[29]California Fuel Evaporative Emission Standard and Test Procedure for 1970 Model Gasoline Powered Vehicles Under 6,001 Pounds Gross Weight—ARB—as Amended March 19, 1969.

[30]Sarto, J. O., et al, *Chrysler Evaporation Control System, The Vapor Saver,* 1970 SAE Paper 700150.

priate revenue source, such as emissions taxes, to finance this control measure (Section II/5.3).

If a partial or total subsidy were to be paid to vehicle owners for installation of an evaporative control device on 1966-1969 vehicles, an equal subsidy ought to be made available to vehicle owners who take any other step that would reduce hydrocarbon emissions by a comparable amount. Two examples are:

1. "Junking" of the vehicle and purchase of a post-1969 vehicle;
2. Sale of vehicle to a new owner who lives and works outside the Basin and purchase of a post-1969 vehicle. (See also Section II/5.4 for discussion of "export" subsidy.)

PART II: SECTION II/4

Emissions from stationary sources are not the major reason for the poor quality of air in the South Coast Air Basin today but neither are they negligible. With 35% of nitrogen oxides and 80% of sulfur dioxide coming from power plants, industry, and other non-mobile sources, it is clear that some reductions should be made in this area. Moreover, even the 10% of reactive hydrocarbons attributable to stationary sources will become about 50% by 1975 if the accelerated program of dealing with automotive pollution proposed in this report is carried out.

The EQL team found that a number of conventional techniques for reducing emissions are not being required of a number of power plants and industrial pollution sources which, when taken together, make a significant contribution to the problem. Thirty-seven small power plants in Los Angeles County are not required to control their oxides of nitrogen emissions, as large plants are. One hundred and twenty large industrial boilers and 60 large heaters at oil refineries are not controlled for NO_X emissions, nor are 140 large stationary internal combustion engines, whose emissions could be reduced by much the same techniques as are used for automobile engines. Altogether, about 80 of the 230 tons of NO_X being emitted daily by power plants and industry in Los Angeles County would be eliminated easily.

There are 11,300 gasoline stations in Los Angeles County. Every time a vehicle fuel tank or the station's main storage tank is filled, vapors containing reactive hydrocarbons are released into the air. Though these sources are dwarfed by hydrocarbon emissions from cars now, in a few years—assuming success in reducing automotive emissions—service stations will be a major source. Similarly, very soon it will be necessary to control more strictly hydrocarbon emissions from paint and from solvents used in drycleaning plants.

II/4 EQL STRATEGY NO. 1 FOR REDUCTIONS IN EMISSIONS FROM STATIONARY SOURCES

II/4.1 Introduction

In 1971 motor vehicle emissions in the South Coast Air Basin were so large compared to emissions from stationary sources that additional efforts to reduce stationary source emissions might not have seemed warranted. For example, reactive hydrocarbon emissions from stationary sources were about 15% of the total (Figure 5), while nitrogen oxide emissions were about 28% of the total (Figure 6). But this situation would not hold for very long if EQL Strategy #1 for motor vehicles were adopted. By 1975 reactive hydrocarbon emissions from stationary sources would be 50% of the total (Figure 5) if no reductions were made in these emissions, and nitrogen oxide emissions would be 65% of the total (Figure 6). Thus it is not surprising that the 50% reduction in stationary source emissions by 1975 called for by EQL Strategy #1 leads to a substantial improvement in air quality (Figure 22).

The responsibility for stationary sources in Los Angeles County rests with the Air Pollution Control District. The District has broad powers to control and abate air pollution from stationary sources. These powers come from the California Health and Safety Code, sections 24260 to 24263.

In the past the District has chosen to utilize its power by constructing a series of rules on abatement of emissions of various pollutants. A series of inspection procedures is administered to insure that sources are in compliance with the rules.

Los Angeles County contributes about 75% of the stationary source emissions to South Coast Air Basin totals, so it is the dominating factor, as with vehicular emissions. The air pollution control boards of the other counties in the Basin tend to adopt the Los Angeles APCD rules, so that the situation in these areas is similar to Los Angeles County.

II/4.2 Reductions in Reactive Hydrocarbon Emissions

The APCD has utilized two methods for reducing the amount of reactive hydrocarbons emitted into the atmosphere. One method is to limit the emission of total hydrocarbons by recondensing, reabsorbing or burning the hydrocarbon vapors before they can be emitted into the atmosphere. Alternatively, especially in cases where vapor collection and control seemed highly impractical, limitations on the reactivity of hydrocarbons were imposed to encourage substitution of lower reactivity materials.

Table 10 gives the principal sources of high reactivity hydrocarbons in Los Angeles County at present. The two principal sources are evaporative losses of gasoline and of solvents. The gasoline is lost in transfer to tankage at filling stations and to automobile fuel tanks. The solvents are emitted in the drying of paints and other surface coatings, as well as from solvent baths used in various industrial processes.

Certain new controls are needed in order to achieve additional reductions in emissions from stationary sources. The most likely candidates are the losses of gasoline vapors displaced in the filling of underground tanks at service stations and the losses incurred in filling of vehicle fuel tanks. Complete control of the former was considered by the APCD in 1962,[1] but ruled out as "too costly." A simpler, less expensive, but also less effective submerged fill system was instituted instead. This system greatly reduced fuel splashing, but did nothing to control displaced vapors.

A complete vapor recovery system for station filling is illustrated in Figure 36. The vapor from the underground tank is returned to the tank truck. Upon return to the refinery the tank truck delivers this vapor to a vapor recovery system (which is already installed and in use) as it is filled for the next load.

There are approximately 32,000 underground storage tanks in L.A. County contributing approximately 17 tons per day of reactive hydrocarbons during refilling operations. The estimated cost of such a system is about $350 per tank, including the modification of the truck.[2] (Note: The cost of modifying the truck is several times as much, but is distributed over many tanks, so it is a small fraction of the total.) Thus the total cost would be approximately 10 million dollars for L.A. County.

A second system could be used to recover the 37 tons per day of vapor displaced in the filling of fuel tanks on motor vehicles. Such a system is shown in Figure 37. A vapor recovery manifold surrounds the fill spigot to collect the displaced vapors. The station attendant will have to hold the filler tightly against the vehicle filler pipe opening to maintain the seal. More care in avoiding careless spillage would also be advisable.

An alternative method is to fit vehicles with standard vapor-tight fuel connections and an associated vapor return passage. This method would allow unattended filling at a higher cost. The vapors are returned to the underground storage and then to the tank truck when the storage tank is refilled.

The cost of this system is estimated as follows: additional piping for each tank—$300. Each tank is considered to supply three pumps, which require a $200 new hose and delivery nozzle with the vapor return. Thus each tank costs $900 to modify. The L.A. County cost is 30 million dollars.

Considering that the gasoline retail sales in L.A. County are one billion dollars per year, these costs seem rather small. The estimated recovery of over a million dollars per year in gasoline not evaporated pays a small part of the system cost.

[1]Burlin, R. M. and Fudurich, A. P., *Air Pollution from Filling Underground Storage Tanks* APCD Report, December 1962.

[2]Cost figures are based on *A Study of Vapor Emission Control in Gasoline Marketing* report to Gilbarco, Inc., Dec. 1967, (C-69599) of Arthur D. Little, Inc.

On January 17, 1972, the San Diego APCD adopted Rule 63 requiring the control of hydrocarbon vapors resulting from the transfer of gasoline to underground storage tanks at service stations, and from vehicles when they are refueled. The Los Angeles APCD is presently considering this problem.

Solvent losses are another likely area for further emissions reductions. Rule 66 places an upper limit of 20% on the total high reactivity material in a solvent and specific lower percentage limits on certain classes of reactive compounds.

Present APCD data indicate that the reactive hydrocarbons are 20-25% of the total solvents being emitted. This figure suggests that most solvents contain nearly the legally allowed fraction of reactive material. Recently, modifications were made to Rule 66 to encourage further reduction in the use of reactive organic solvents. This issue is a very complex one which we will not attempt to cover in depth. However, some typical specific measures that could be considered are:

1. Use of trichloroethylene (TCE) degreaser should be discontinued and nonreactivie 1,1,1-trichloroethane substituted. No substantial cost seems to be associated with this change. This step accounts for 20 tons per day of reactive hydrocarbons.
2. Better solvent recovery systems could be used in certain dry-cleaning establishments utilizing reactive solvents. The cost is estimated at a million dollars to eliminate five tons per day of reactive hydrocarbons.

A summary of the proposed program for reducing reactive hydrocarbon emissions in L.A. County is given in Table 11. EQL Strategy #1 calls for reductions in these emissions by about 74 tons per day by the end of 1975.

II/4.2 Reduction in Oxides of Nitrogen Emissions

The principal stationary sources of NO_X are listed in Table 12. The largest contributors are the boilers at electric power generating plants. The petroleum industry contributes NO_X emissions from boilers and heaters as well as from fixed internal combustion engines used to power process equipment. Commercial and residential use of fuel also contribute to NO_X production from a very large number of small sources.

Most of the NO_X reduction effort has been concentrated on the large power plants. Attempts to reduce sulfur dioxide by requiring a shift from oil to natural gas in power plants effected some decrease in the NO_X levels, because the combustion of the gas can be better controlled to achieve lower NO_X emissions.

However, recently the APCD has taken a more active role in limiting and reducing the NO_X emissions. Rule 67 sets a strict upper limit on the total emissions of any one *new* source (140 pounds/hour NO_X) so as to prohibit any new large sources unless the technology improves significantly. Rule 68 imposes stricter emissions limits on NO_X emissions from *existing* large sources by requiring reductions in the stack concentrations, as shown in Table 13.

Several techniques have been used to achieve these reductions without affecting the boiler efficiency. One is multiple-stage combustion, which achieves some reduction in the peak temperatures of the combustion flame. This reduction can be further augmented by flue-gas recirculation, but recirculation is more difficult to retrofit to existing boilers. Another technique involves reducing the excess air, so that combustion is closer to stoichiometric, while carefully avoiding any increase in hydrocarbon or carbon monoxide emissions.

Similar techniques could be applied to many other industrial boilers and heaters in use. The petroleum industry is the largest contributor. Most likely additional rules will be required so that Rule 68-type constraints are applied to these NO_X producers.

Industrial plants also use large internal combustion engines (operating with process-produced fuel gas) to supply mechanical power for pumping, etc. These engines would respond to the same NO_X control techniques used for automobiles, such as exhaust gas recirculation, manifold or catalytic exhaust reactors, etc., to reduce their NO_X emissions. However, additional rules would be needed, since these sources are not controlled by any of the present regulations.

A feasible control program is outlined in quantitative terms in Table 14. The strategy involves achieving some reductions from each of several source types by one of the possible control techniques. Additional reductions of about 14 tons per day are possible in large boilers and small power plants by utilizing flue-gas recirculation, as well as low excess air, at an additional cost of about 14 million dollars.

One problem facing the NO_X reduction program is the difficulty in obtaining sufficient natural gas to meet the fuel requirements over the next few years. This shortage will necessitate burning oil, with resultant higher NO_X levels because of poorer combustion control.

TABLE 10
Sources of Reactive Hydrocarbons (tons/day)

Industrial				
Chemical		15		
Petroleum		60	Station Filling	17
			Auto Filling	31
			Other	12
Other	(Solvents)	55		
Commercial	(Solvents)	10	Total Solvents	80
Residential	(Solvents)	15		
	TOTAL	155		

Source: Los Angeles County Air Pollution Control District, *Profile,* 1971.

TABLE 11
Reactive HC Reduction (L.A. County)

	SOURCE	CONTROL MEASURE	NUMBER OF SOURCES	CURRENT EMISSIONS TONS/DAY	% REDUCTION	EMISSIONS REDUCTION TONS/DAY	COST: MILLIONS OF DOLLARS
I	Gasoline Station Tank Filling	Vapor recovery system	34,000	20	100	20	10
II	Gasoline Station Auto Filling	Vapor recovery system	11,300	40	100	40	30
III	Solvent Degreasing	Switch to zero reactivity solvent		26	100	26	zero cost
IV	Dry Cleaning	More complete vapor recovery system	25	5	100	5	1
	TOTAL			91		91	41

Source: Trijonis, John, "An Economic Air Pollution Model. Application: Photochemical Smog in Los Angeles County in 1975," Summer, 1972.

Another problem that requires careful attention is the increasing use of gas turbines by electric utilities in this Basin for peaking power. Because of their relatively small size, these units meet the standards set by Rule 67, even though they produce much higher NO_X emissions *per unit of electrical energy generated* than well-designed steam plants of much larger capacity. A consistent program for reducing NO_X emissions in this Basin may require that no new gas turbine installations be permitted after a certain date.

TABLE 12
Sources of Oxides of Nitrogen (1971)

	NO_X (TONS/DAY)	
Industrial		
Chemical	10	130
Metallurgical	15	
Mineral	10	
Petroleum	95	
Power Plants	100	
Commercial	25	
Residential	25	
TOTAL	280	

Source: Los Angeles County Air Pollution Control District, *Profile,* 1971.

TABLE 13
Rule 68—Limitations on NO_X Concentrations from Power Plants

	GAS	OIL
By December 31, 1971	225 ppm	325 ppm
By December 31, 1974	125 ppm	225 ppm

Source: Los Angeles Air Pollution Control District, *Rules and Regulations,* June 7, 1971.

TABLE 14
Stationary Source NO_X Reduction Program for L.A. County

	SOURCE	CONTROL MEASURE	NUMBER OF SOURCES	CURRENT EMISSIONS TONS/DAY	% REDUCTION	EMISSION REDUCTION TONS/DAY	COST: MILLIONS F DOLLARS
1	Large industrial boilers (>30 MBTU/hr)	Low excess air	120	24	40	10	2.4
II	Large refinery heaters (>90 MBTU/hr)	Low excess air	60	14	40	6	1.8
III	Small Refinery heaters	Low excess air	160	10	40	4	3.2
IV	Large power plants (>175MW) not meeting Rule 68	Combustion control & flue gas recirculation	8	76	40	30	12.0
V	Small power plants	Low excess air	37	23	30	6	3.7
VI	Large stationary ICE's	Exhaust recirculation	140	25	75	18	0.28
VII	Small compressor ICE's1	Exhaust recirculation	360	7	75	5	0.22
	TOTAL		885	179	48	81	23.6

ICE = *Internal Combustion Engine*

Source: Trijonis, John, "An Economic Air Pollution Model. Application: Photochemical Smog in Los Angeles County in 1975," Summer, 1972.


CALTECH
CLEAN AIR CAR


MINI-BUS LOOP

PART II: SECTION II/5

In the long discussion of possible solutions to air pollution there has been a "black box syndrome." There is a tendency to assume that the answer must be some add-on device for cars and factories that would work as magically as the television enzymes chewing up wash-day dirt. The EQL team looked for but found no magic boxes. They assumed none existed, at least for the next few years when we will be striving to meet the new federal air quality standards.

The technical measures proposed by the EQL team represented technology they felt was actually available and practical between now and 1977. Clearly it is not enough, particularly for the control of automotive emissions.

This is the reason why socio-economic measures designed to cut emissions by reducing the use of motor vehicles were added to the proposals. Their feasibility is much more difficult to argue than that for the technical measures. But if one assumes that an all-out effort should be made to meet the air quality goals and deadlines of the Clean Air Amendments, then it is clear that various steps must be taken to control vehicle use. The EQL team settled for a modest 20% reduction in the number of vehicle miles driven within the Basin, realizing that public acceptance of such a different approach will be problematical.

The central proposal in this area is a system of taxing emission from motor vehicles. The taxes, if high enough, would promote a whole range of alternatives that would reduce automotive emissions. One alternative would be to drive less and use other forms of transportation more. Others would involve shifting to less-polluting vehicles, for example, newer ones or others using gaseous fuels.

Necessarily, emissions taxes depend on mandatory inspection and testing of motor vehicles, a system that would also insure that all technical measures for reducing emissions from both new and used cars were working at maximum efficiency—or at all.

Other socio-economic measures are proposed to reinforce the results of taxing emissions. A scheme for subsidizing the export of older, high-emission cars from the Basin is put forward. A system of incentives and penalties to more directly promote the kinds of transportation alternatives people would need in order to reduce their emissions taxes is outlined. Essentially, it proposes the freeways as immediately available "tracks" for a mass, rapid transit system. Buses and car pools would be given the advantage over driver-only cars with reserved freeway lanes or priority access to freeways, and the effect of these measures would be reinforced by cheap parking for car pools, expensive parking for driver-only cars, and expanded and cheaper bus service. A scheme for rationing gasoline is proposed "as a last resort."

II/5 SOCIAL AND ECONOMIC INCENTIVES AND DISINCENTIVES DESIGNED TO REDUCE EMISSIONS

II/5.1 Introduction

Part I of this report and Sections 3 and 4 of Part II propose a series of new "technical" controls on stationary sources of emissions and on *used* motor vehicles. But even in the short run (1972-1977) these technical measures alone are not sufficient to achieve the management air quality standards set down in Part I, page 9, and Part III, Section 1.3. We found it necessary to down in Sections I/2.1 and II/1.3. We found it necessary to combine the technical measures with a set of social and economic incentives and disincentives designed to encourage a shift to low-pollution motor vehicles, to encourage the use of multiple-occupancy vehicles (buses, carpools, etc.), and to reduce the annual rate of increase in gasoline consumption in the Basin.

There are three main reasons for turning to these social and economic measures: (1) the rapidly increasing incremental cost of cutting emissions by means of technical controls alone once the total emissions in the Basin are reduced to about 50% of their 1970 levels;[1] (2) the annual rate of increase in total emissions in the Basin attributable to growth that would eventually overwhelm even the best control technology likely to be available in this decade (Figure 14); (3) the advantages, in terms of efficiency, of economic incentive systems in comparison to purely technical-regulatory approaches.

The measures we propose in this section will work in the short run to speed up the process of achieving improved air quality and to introduce some flexibility into our proposed strategy. In the longer run these socioeconomic measures will continue to provide incentives to reduce emissions even after all automobiles on the road meet the 1975/76 Federal standards. It will be argued in Section II/6 that fundamental changes in life-styles and technologies are needed to provide a long-term solution to the problem of controlling air pollution in this Basin. Although the measures discussed in this section have more immediate impact, they would help prepare the way for larger social change.

In Section II/5.2 we discuss the basic concept of "internalization of risk" and the need to stimulate the development of a widely varied and flexible menu of alternatives to clean up the environment. One way to put a policy of risk-internalization into operation is by means of an emissions tax based on the total amount of "harmful" emissions emitted by an automobile (Section II/5.3). This control measure, designed to induce motorists to pollute less, could be made more efficient by a system of incentives to promote the export of old high-emission cars out of the Basin (Section II/5.4).

The provision of economically and socially viable alternatives to the payment of the emissions tax is clearly an important part of the strategy.

[1]Trijonis, John, *An Economic Air Pollution Model Application: Photochemical Smog in Los Angeles County in 1975,* Summer, 1972. Copies available from the EQL on request.

In Section II/5.5 we propose a system of mutually reinforcing incentives and disincentives that promote the use of multiple-occupancy vehicles such as buses, carpools and jitney cabs, and that penalize driver-only cars.

Finally, in Section II/5.6 we discuss two possible gasoline rationing schemes that would reduce the annual rate of increase in gasoline consumption.

The measures discussed in this section represent relatively new approaches to the problem of controlling motor vehicle emissions. Each measure needs further study and discussion. Ways in which these measures might best be combined among themselves and with subsidies and regulatory programs need to be investigated. These measures, then, are not exclusive responses, nor are they "final." Research on this aspect of air pollution control is continuing at the EQL. The main purpose here is to introduce some ideas, analyze their advantages and disadvantages, and stimulate badly needed discussion among the public and the policy-makers.

II/5.2 The Public Policy Issues

What is the appropriate concept to use in order to design an effective strategy to deal with the problems of the environment? According to conventional wisdom, the appropriate rationale is internalization of the costs of environmental degradation. Firms and individuals would be required to spend such amounts to improve environmental quality as will make the marginal benefits equal to the marginal costs. However, it will be argued here that despite its intrinsic logic, internalization of costs doesn't provide an operational concept adequate to deal with the problems of the environment. What, then, is the appropriate concept? While there isn't any ideal concept, a better approximation to reality is "internalization of risk."

The concept of cost internalization relies on cost-benefit analysis, but there are two serious problems with cost-benefit analysis. One of them is that even if the costs and benefits could be precisely measured, there isn't any obvious way to take into account the fact that each person will be affected differently, both as he perceives the benefits and is affected by cost internalization. Hence, there is no unarbitrary way to relate individual costs to social costs and individual benefits to social benefits. How, in fact, these calculations get made depends in large part on the nature of the political process.

A second and even more serious limitation of cost-benefit analysis is the absence of theories that would enable us to predict the potential benefits in economic terms. There is no way to provide a damage function for human receptors, because the consequences to present and future generations of people can be foreseen only as incalculable risks (e.g., the risk that smog will result in a substantial increase in the incidence of respiratory diseases). And whether policy makers act now or wait to impose air quality management standards until more is known about the risk, they are, in either event, engaged in very arbitrary judgments.

Thus, the problems facing the country in dealing with degradation of the environment aren't those of "static efficiency," that is, of choosing among existing alternatives and balancing predictable costs against predictable benefits. They are, rather, "dynamic efficiency" problems, which means they are problems of making decisions in the face of strong uncertainties (uncertainties which cannot be reduced to a known probabilistic basis) and of resolving a host of conflicts between theory and practice. The aim is to produce a better menu of alternatives, thus reducing the risks to society as a whole.

There is no correct method of deciding beforehand how much society should spend on the prevention of environmental degradation. That will become clearer only when more is known about the risks, for example, when as much is known as, say, is now known about the effects of smoking on lung cancer. It should be apparent, however, that just as there are risks of doing too much, so are there risks of doing too little.

Risks for society as a whole are not necessarily risks for the individual business firm or person. The immediate policy question is how risks for society as a whole can be translated into risks for the business firm and the individual, that is, how such risks can be internalized.

A. The Appropriate Concept: Internalization of Risks

The argument for risk internalization doesn't rest simply on its theoretical appeal. The fact of the matter is, it isn't only an interesting theory: it works. For one thing, it has played a major role in the economic development of this country. Econometric analysis has revealed that during the period 1919-1957 only about one-eighth of the increase of the gross national product per worker can be explained by the increase in capital per worker—leaving seven-eighths to be explained as a mysterious new form of energy called "technological change." There is good reason for believing that technological competition played a very important role in producing this "new" form of energy. Furthermore, it can be stated that technological competition played a major role in making this country the undisputed technological leader of the world from, roughly, the beginning until the middle of this century. Starting in agriculture, shortly after the Civil War, the concept of technological competition soon spread to industry. There are substantial reasons for believing that, in part, the U.S. enjoyed a comparative advantage in trading with the rest of the world because of the role technological competition played and, in part, because of broader sociological factors which favored a highly pragmatic society adept at dealing with conflicts between theory and practice.

Of course, no one could have predicted in, say, 1900 just what would be the outcome of all the competition, flexibility and pragmatism which characterized this country.

However, the test of good economic theory doesn't consist of being able to predict the unpredictable, but rather of trying to understand the conditions which produce certain kinds of beneficial mutations, and how to translate risks for society as a whole into market risks for the individual firm or person.

B. Implementing A Policy of Risk-Internalization: Some of the Key Issues

How might a policy of risk-internalization be put into operation? One way, to be discussed in detail in the next section, is through an emissions tax. Here the idea is only briefly described to show how it is related to the concept of risk-internalization and what general kinds of policy issues arise from implementing such a concept.

Assume that an automobile emissions tax is levied in conjunction with an inspection scheme. Assume, further,that the difference between owning a low emitting car and a high emitting car is a difference of, say, $300 a year. The immediate impact of such a tax would be on the consumer: Presumably, he would drive less or discover in some cases that a second car was unnecessary (i.e., several studies have indicated that carpooling becomes a very attractive option at about $300 per year), and/or shift to a lower polluting type of car. How might such a tax bring about an internalization of risk-taking? For one thing automobile dealers would be more conscious of the risks to society as a whole of pollution devices which weren't easy to maintain. People would scream if they had to pay high taxes because a "clean-on-delivery" car turned out to be very difficult to maintain. And their screaming might force automobile dealers to offer a 20,000 mile warranty on the air pollution devices.

In addition, an emissions tax would provide a way to introduce into the automobile industry a concept of dynamic workable competition in which automobile emissions became a major factor in determining a manufacturer's share of the market. Thus, the effect of adding an emissions tax up to, say, $300 a year would be like adding an excise tax of $300 a year; and the effect of producing a car which didn't have to pay any emissions tax would be like being exempt from such a tax. Whether dealers were forced to absorb such a tax or whether it resulted in a direct loss of sales, it certainly would provide manufacturers with strong incentives to push as hard as they could for continued improvements in emissions control technology. The risks associated with being technologically backward in the anti-pollution field wouldn't be small and they would be measurable in dollars.

The more general policy issues which this example raises are the following: (1) the respective roles to be played by incentive schemes and direct regulation; (2) how to take care of "hardship" cases in getting users to adopt the best set of available technologies; and (3) how to insure that industry will, in fact, compete.

1. The Relationship Between Incentive Schemes and Direct Regulation

One of the principal virtues of the present method of regulation is that the requirements placed upon industry are in terms of performance specifications rather than technical specifications. The government tells industry what reductions in emissions must be achieved by particular dates, but it doesn't say how industry ought to go about achieving these reductions. Regulation in terms of performance rather than technical specifications is the appropriate method, because technical specifications impose additional constraints on the developer—and thereby make development much more expensive.

On the other hand the central defect of present regulatory procedures is the assumption that regulators can, in fact, produce high-confidence estimates of achievable goals—when, in fact, they can't. The inability of the regulatory agencies to unearth that which can be discovered only in the process of research and development puts them in double jeopardy. Either they are criticized for being too easy on industry or they promulgate rigid standards which simply cannot be met—and thereby risk defeat of their own purpose.

In order to avoid this kind of dilemma the role of regulation should be to provide *minimum* targets, which if unmet by, say, auto manufacturers would mean that they simply wouldn't be permitted to sell automobiles in high pollution areas. And those manufacturers who do better should be correspondingly rewarded. In other words, the incentives should be continuous. Moreover, as better alternatives are discovered, the minimum target should be progressively tightened.

2. Hardship Cases

A main concern which frequently is voiced has to do with promoting the adoption of already developed technology: gaseous-fueled vehicles for fleet use and evaporative control devices for older cars are cases in point. The simplest way to handle "hardship cases" would be not to recognize any; for example, as in the case of Britain to make propane (or its equivalent) mandatory for all taxi cabs in London. Just as with the income tax the general argument against providing loopholes is that there is no natural stopping place. On the other hand, it also must be recognized that politicians sometimes aren't willing to be as harsh as they might, because they regard the political risks as too great. Hence, all that really can be said is, to the extent subsidies or exemptions are used, the legislation should contain a self-terminating feature which would make the subsidy or exemption expire when it had achieved its intended purpose.

There is, however, one point which is much less controversial: That subsidies (if permitted) ought to be created on the basis of meeting certain performance specifications rather than in terms of adopting particular technical devices. Thus, fleet owners should be given the same treatment whether they use gaseous-fueled vehicles or find some other equally satisfactory way to reduce emissions. Similarly, a private owner should receive the same subsidy whether he installs a new $150 evaporative control device on his automobile, manages to find an equally effective device for $50, or decides to scrap his second car and join a carpool. The purpose of providing equal treatment for equally effective remedies is simply to increase the odds that if people don't like one way of becoming a friend of the environment, they can find another. Moreover, equal treatment clauses also provide a way of increasing the menu of alternatives. For example, given the proper inducements, manufacturers of electric golf carts might be persuaded to penetrate the highway transportation market.

3. Making Dynamic Competition Work

The concept of dynamic competition supplies a highly relevant means for internalization of risk. But will it work? The honest answer is that no one knows. As in sports the teams sometimes compete vigorously. But again they don't. And should dynamic competition prove to be unworkable, it will become necessary for the government to face up to some basic issues in the antitrust field. Moreover, especially insofar as projects involving a high degree of risk are concerned, it may in any event become necessary for the government to initiate a much larger publicly supported R&D effort. It is true, of course, that policy makers are often disinclined to face up to such basic issues: The almost inevitable response to a crisis is a series of "patch-ups" accompanied by the proclamation that prosperity is just around the corner.

On the other hand what are the alternatives to increasing the performance of business concerns via a policy of risk internalization? The only real one is an increasing degree of government regulation and control. But there is good reason to suspect this is not a viable alternative: In the first place, to date at least, not one of the government's regulatory efforts can be said to have been highly successful. In the second place, given the highly dynamic character of environmental problems, there is good reason to doubt that regulation *alone* will be even as successful in the pollution control field as it has been with other problems in the past. If it has not been possible for the government to keep up with the problems of the railroads, how about the environment?

II/5.3 The Motor Vehicle Emissions Tax as an Air Pollution Control Measure

II/5.3.1 General Considerations

An emissions tax based on "harmful" automotive emissions can be thought of as a payment by a motorist for the privilege of driving an automobile which contributes to the pollution problem. There are many ways of defining and collecting such a tax, and they vary in their impact on the many decisions made by the motorist. We will consider explicitly five types of decisions: (1) the choice of the age and model of car owned; (2) the decision on how much the car will be used; (3) the amount of maintenance to be performed on the car; (4) the type of fuel used in the car; (5) the number of occupants in the car.

The emissions tax is not the only method available for influencing these decisions, and we will discuss several very different methods in Section II/5.5. All share a common characteristic: they impose a penalty on those motorists who insist on owning a type of car, or using it in a manner which makes an excessive contribution to air pollution. The emissions tax imposes a financial penalty. Other measures, such as the introduction of restricted access to freeways (Section II/5.5) impose a penalty in terms of time spent in commuting. We will not be able to choose the proper "mix" of these methods until we have determined which penalty gives more leverage on important decisions.

The use of a tax to affect automobile purchase and use decisions is based on the assumption that motorists do give some consideration to the cost of automobile travel. The extent to which this assumption is justified is a matter of considerable debate; therefore, we must be careful to institute a tax scheme in a manner which makes its cost visible and easy for the motorist to determine. A concealed tax is worse than useless: It imposes a financial burden, which may be substantial, without inducing the environmentally appropriate behavior which we desire.

II/5.3.2 The Types of Emissions Tax

There are three basic rationales which have been used to recommend the institution of an emissions tax. Depending on the rationale chosen, the tax will be set at varying levels, and the type and amount of information needed to determine the charge will differ. We label the types of scheme which result from these rationales the emissions charge, the emissions tax and the emissions fee.

A. The Emissions Charge

Some economists propose that an emissions charge be used as the fundamental device both for choosing and for achieving desirable levels of air pollution. The charge is set at a level which reflects the value of the incremental damage done to society by an additional unit of emissions. Then, it is argued, each motorist will choose to reduce his contribution to pollution until the cost of an additional unit of emissions reduction equals the charge which he must pay for the privilege of putting out that unit.

When the charge equals the damage done by an additional unit of emissions, it follows that the cost of further reduction in emissions exceeds the damage which would be avoided by reduction in emissions. Therefore, it is argued, the level of air quality achieved by the emissions charge is the "desirable" level, in the sense that it minimizes the sum of the damage done by pollution and the costs incurred in reducing pollution.

The major difficulty with this concept of emissions charges is that the damage done by air pollution has proved itself nearly impossible to measure.[2] Moreover, in talking about "damage to society" we inevitably make some value judgment about how to compare the damage suffered by one person with the damage suffered by another person. The criticisms levelled at cost-benefit analysis apply equally to the effluent charge proposal. There is no ethically neutral way to define the "social damages" of air pollution, and it is not the role of social scientists to make these ethical choices. Although we recommend the use of financial penalties to bring about improved air quality, we recognize that the emissions charge approach is not the correct way to determine what the penalties should be.

B. Emissions Tax

The political system decides who shall pay for and who shall benefit from its measures as part of its day-to-day business. In designing an emissions tax we take as *given* some political decision as to the desired level of air quality, together with the benefits to society which such a choice implies.

The emissions tax is designed to achieve the predetermined standard and to do so in a manner which minimizes the undesirable economic impact of pollution control. By raising the cost of using an automobile which emits excessive quantities of harmful emissions, the emissions tax leads to changes in the amount of driving and in the characteristics of automobiles being driven, and thus brings about an improvement in air quality. By leaving each motorist a free choice among many options for reducing his contribution to air pollution so that he can respond in the manner most advantageous to himself, the emissions tax removes the danger that motorists will be forced to pay for unnecessary or ineffective pollution control measures. In this manner a properly designed emissions tax can minimize the economic burden of pollution control, and can be determined without reference to the concept of "damage to society."

C. Emissions Fee

The emissions charge and the emissions tax, as we have defined them, serve two functions: to give an incentive to reduce emissions and to allocate the necessary reduction in emissions among motorists in an "efficient" manner. The emissions fee serves only as an incentive. To set the fee we must determine in advance a set of desirable steps to be taken to reduce automotive pollution. The emissions fee enters the picture because we do not enforce the law absolutely. Rather, we impose on any motorist who does not observe the obligations of the law a fee for the privilege of continuing to use his car. By setting the fee higher than the average cost of compliance, we give an incentive to motorists to satisfy the previously determined standard.

[2]See, for example, the pessimistic conclusions reached in Ronald G. Ridker, *Economic Costs of Air Pollution,* New York, 1967.

The emissions fee approach is attractive because it is relatively simple to decide on an appropriate charge level. It also allows the individual motorist some flexibility in his choice of actions, and unlike, for example, the absolute prohibition of cars failing an emissions test, it insures that no motorist will face a catastrophic penalty. No one can be forced to incur a cost greater than the fee.

Unfortunately, the emissions fee approach shares a fundamental defect of all schemes based on standards applying to individual automobiles. It is infeasible to state the standards in sufficient detail and with sufficient precision to cover all the ingenious ways by which a motorist could reduce his contribution to pollution.

Writing standards in sufficient detail to include all eventualities compares in magnitude to the task of central economic planning. In this case it is administratively impossible and unjustified in terms of the relation between effort and result. We should not abandon the coordinating role of emissions taxes by falling back on rigid standards and fees.

Moreover, a system of fees designed to bring about specific, predetermined actions can reduce the probability that responses will go in the predicted direction. Note that although we cannot yet predict that a tax of X dollars will produce a decrease of Y percent in emissions, we all believe that with some tax, emissions will not increase. The tax to achieve a specific action is capable, because of the very real unpredictability of individual choice, of violating this law. The individual is much more familiar with his particular circumstance than the planner: there is a significant probability that he will find a way out of the dilemma posed by the specific incentive which involves increased emissions. If, on the other hand, we tax emissions directly, then the only way a person can reduce his tax bill is by reducing his emissions.

In summary, we find that the emissions tax is administratively workable, more efficient than uniform standards and regulations, and potentially effective in achieving desirable levels of air quality. In the remainder of this section we will develop and defend specific proposals for emissions tax programs.

II/5.3.3 Decisions and Instruments

The motorist makes a number of decisions which affect his contribution to air pollution. There are also a number of ways in which we could construct and impose an emissions tax. Roughly, our approach is to choose those decision areas which are most effective in reducing pollution, and choose the tax scheme which concentrates incentives on those decision areas. Moreover, the decision areas must be not only effective in reducing pollution but responsive to economic incentives.

Let us assume for the moment that we can measure precisely the number of grams of pollution put out by an automobile during the course of a year. Then we can impose a yearly tax equal to αP, where α is the tax rate in dollars per gram of emissions, and P is total emissions during the year.

How will the motorist respond? One person may find that he can get a tune-up and reduce his emissions by 50%. Then during the period during which benefits of the tune-up last the motorist will save a sum equal to one-half of this emissions tax. If the tune-up costs less than half the emissions tax, the motorist will save money by getting a tune-up. Another motorist may find that a tune-up is not worthwhile, but that he would prefer driving 25% less (perhaps by joining a carpool) in order to pay 25% less tax to continuing to drive the same amount and paying a larger tax.

A third motorist with a car he would trade in in a year anyway may find that by buying a new car with much lower emissions he will save enough to justify trading in his old car immediately.

The point of the emissions tax is to leave each motorist a free choice among many options, so that he can respond in the manner most advantageous to himself.

It has already been stated that a uniform emissions tax tends to keep total expenditure on pollution control at the lowest level consistent with the achievement of desired air quality. To establish this point we must distinguish between expenditures made to pay the tax and expenditures made on reducing emissions (in which we include the monetary valuation which the motorist puts on things he gives up). If each motorist chooses that combination of emission reduction (through tune-ups, trade-ins, reduced driving, etc.) and tax payment which is most advantageous to him privately, then by setting a high enough tax we can make polluting sufficiently expensive that aggregate emissions are reduced to some desired level. This tax will also result in each motorist choosing such abatement techniques that total expenditures made on emissions reduction are as small as possible while still achieving desired results.

The revenues generated by the emissions tax represent an additional cost to the motorist, but not to society, since they are pure transfers. If these taxes simply go into the general fund and replace, for example, property taxes, the net financial burden of the emissions tax strategy will be just the expenditures made directly on reducing emissions. Since the property tax causes a loss by distorting the allocation of goods (and the emissions tax does not), the real economic cost of the strategy will be less than the cost of reducing emissions. If the taxes are used to finance the introduction of other measures recommended in this report, they again disappear, since they simply represent a source of money for programs which must be funded in some way. Because of its beneficial (rather than detrimental) allocation effects, the emissions tax is a good source of such funds.

A theoretically perfect emissions tax would be one in which each automobile had a device on its tailpipe (and fuel system and crankcase) which continuously analyzed the composition of waste gases and recorded the mass of emissions. With 7.2 million cars in the Basin this degree of precision is too expensive to be warranted. Some surrogates closely, and hopefully invariantly, related to total mass emissions must be chosen and used to levy taxes.

The first step in constructing a surrogate is to factor total emissions into two components—the average emission rate measured in grams per mile and the number of miles driven. The most appropriate way to measure average emissions is the mandatory annual or semi-annual inspection of each automobile, to discover the grams per mile which it emits under average driving conditions. Of course, emission rates as measured at an annual test are only a surrogate for actual emission rates in real driving conditions. But as long as the driver is unable to make decisions which change the relation between estimated emissions and actual emissions—as for example by spending more time sitting in traffic jams—the surrogate will be a good one.

Some emissions tax proposals use an estimate of average emissions in conjunction with an estimate of average mileage to compute the total mass emissions which are to be taxed. There are two ways of collecting such a tax: one is to impose the tax as an excise or sales tax, and the other is to bill the motorist periodically. In either case the tax is unrelated to the mileage driven by any particular motorist, since it is computed on the basis of Basin-wide average annual mileage.

One such proposal has the tax based on estimated emissions and estimated miles driven throughout the life of the car.[3] The tax is collected at the time of original sale of a new car. Since one important reason why new car emissions standards provide only a slow reduction in air pollution in the South Coast Air Basin is the slow rate at which old cars die off and new cars are purchased, this proposal by itself is unworkable. It would raise the price of new cars relative to old cars, and thus be detrimental to air quality by reducing the demand for new cars.

We could, however, construct a tax based on estimated emissions and average mileage until next resale, and impose the tax every time a car is sold. Such a tax would not vary with the actual miles driven, and thus gives no incentive to reduce driving. Its virtue is that it would not discriminate against new cars.

Taxes collected as a sales tax would give no incentive to maintain a well-tuned automobile, and they would tend to make it desirable to keep a car as long as possible. If each motorist received an annual tax bill based on his performance on the emission inspection, there would be an incentive to operate a well-tuned car even if the tax did not vary with actual miles driven.

If the motorist is to pay the tax, however, there is a simple way to make the tax vary with actual mileage. The odometer of each automobile can be checked at the annual emissions test, and the motorist sent a bill based on measured emissions and *actual* miles driven. This annual payment of a tax might still have little effect on the number of miles driven, even though it in fact varies with miles driven. If, however, each motorist is required to report his odometer reading monthly, and pay an emission tax monthly, the impact on miles driven will be greater. The incentive to report inaccurately under such

[3]Suggested by Donald N. Dewees, *Automobile Air Pollution: An Economic Analysis,* unpublished doctoral dissertation, Harvard University, September 1971.

a system would be minimal if the odometer reading were checked at each emissions inspection. Then the motorist would know that he must pay, each year, a tax based on his true mileage and that any under-reporting will simply result in a larger final bill. Both these odometer reading schemes suffer from the problem that it would be difficult to exempt miles which are driven outside the South Coast Air Basin. Some method of abating the tax in proportion to miles driven outside the South Coast Air Basin must be provided.

We can reach some general conclusions as to the kind of decisions each type of emission tax will affect. Any tax which is collected at the time a car is sold will have no effect on the decision to drive less, to join a carpool, or to maintain the car once purchased. It will only affect total driving if it makes it impossible for some people to own a car at all. It will affect the type of car chosen and, if so constructed, the decision to convert a new car to a gaseous fuel. The decision as to how much to drive a car and the maintenance decision will be affected by taxes based on actual mileage collected throughout the life of the car. Indeed, an annual tax would provide an incentive to operate a well-tuned car even if it did not vary with miles driven. It appears that the more often a tax is collected the greater will be its impact on the number of miles a car is driven.

Finally, it should be pointed out that in theory a tax scheme which imposes increased costs per mile of driving a car with high emissions will divert demand away from such cars. Eventually as motorists become aware of the fact that because of the emissions tax car X costs 2¢ per mile more to run than car Y, identical to X in all respects but emissions, they will become unwilling to buy car X unless the seller reduces the price. The effect on the decision to purchase a car of a per mile tax will be similar to the effect of a tax at time of purchase. Because of the difficulty in knowing in advance what emissions tax a particular car will incur, the effect will, however, be weaker. If organizations like the Consumers' Union provide such information, the impact on purchase decisions would be increased. Manufacturers would be given an additional incentive to produce new cars with lower lifetime emissions (Section II/5.2).

We do not believe, however, that a tax collected from the motorist periodically throughout the life of an automobile will have a strong effect on the purchase decision, because of the difficulties of estimating lifetime emissions and the long time interval between the making of the purchase decision and the payment of the emission tax. The effect of the sales tax on the purchase decision must be balanced against the effect of the periodic tax, proportional to mileage, on driving, maintenance, etc.

II/5.3.4 The Specific Proposal

We propose that an emissions tax based on average emissions, as measured at the emissions inspection, and actual miles driven be instituted as a pilot project in the South Coast Air Basin, and that the tax be collected at monthly intervals. Vouchers similar to those used for payment of Federal estimated tax should be provided so that the motorist can compute and pay his monthly tax due. Such a scheme will have the greatest impact (of all feasible alternatives) on the decisions on how much to drive, how well to maintain the vehicle, what type of fuel to use (i.e., gasoline or a gaseous fuel) and whether to join a carpool. Since the effect of the decision about what type of automobile to buy will be weaker than in a time of purchase tax scheme, we propose that the emissions tax be supplemented by measures to facilitate the exporting of old high emission vehicles from the Basin and the importing of low emission used vehicles (Section II/5.4). The periodic emissions tax based on actual mileage, when combined with this plan for reducing the number of older cars in the Basin, forms a system which is clearly superior to the time of purchase tax.

Under this proposal the motorist will pay a tax computed in the following manner: If the tax is imposed at a rate α, and if E = average grams per mile of emissions and M = miles driven in the South Coast Air Basin, the motorist will face a total tax equal to $\alpha \cdot E\ M$ or a tax of $\alpha \cdot E$ for every mile he drives. Clearly the more a car emits, the greater the incentive to reduce driving mileage.

If the declared mileage were measured by periodic odometer checks, there would be no way to determine how much driving took place outside the Air Basin. This problem can be resolved by abating the tax for any motorist who presents receipts for gasoline purchased at locations more than a specified distance outside the boundaries of the South Coast Air Basin. The actual mileage driven outside the Basin can be estimated from gasoline consumption by applying a factor equal to the average miles per gallon obtained by the type of car driven. Such mileage would be subtracted from the total in order to determine the number of miles driven for which an emissions tax must be paid.

II/5.3.5 How High a Tax?

There are two methods by which we can determine an appropriate level of taxation to achieve the standard. The first is to develop a large-scale model of the demand for automotive travel, in order to predict how auto use will change if the cost of driving certain vehicles in certain ways is increased. We can then choose a tax structure which will produce a predicted response that achieves air quality goals. The advantage of this demand-projection approach is that in estimating the model we will discover the interactions between various ways of reducing motor vehicle emissions. We may find nonlinearities which can be exploited to bring about desired behavior in the most efficient manner, and we can also expect to discover any unexpected perversities of behavior which would defeat the purpose of the tax. We can certainly expect to find which decisions are most responsive to economic incentives and concentrate our leverage on them. The drawback of this approach is the time which it would take to develop such a model and the quality of the data required.

Because of the immediacy of our air pollution problem, we cannot depend on such a large-scale study alone. By delegating the authority to set the level of emissions tax to an air quality management agency, we would make it possible to determine the appropriate level experimentally. A pilot project to make such a determination in the South Coast Air Basin is what we recommend.

The project would work in the following way: On the basis of rough predictions of response an initial level of taxation could be chosen. Air quality levels prior to the institution of the tax would be measured and recorded. After the tax had been in effect for, say, six months or a year, new measurements would be made. The influence of fleet conversion to gaseous fuels, mandatory retrofit, natural dying off of old high-emission cars and all other mandatory improvements during the trial period would then be estimated and removed from the measured improvement in air quality. If the remaining improvement were less than desired, the level of the emissions tax would be raised. If the improvement was measured to be more rapid than desired, the tax would be reduced.

Because of meteorological and other factors which cause unpredictable changes in air quality, it may be necessary to measure the effect of the tax indirectly during the first year or so. Such parameters as changes in declared mileage, changes in average performance on emissions tests, or changes in trade-in patterns could substitute for direct estimation of changes in air quality during this initial period.

Additional complexities are introduced by the fact that there is a natural lag in certain responses to the tax. Not everyone will immediately trade in an old car which is charged a high emissions tax for a newer, cheaper one, but over longer periods we can expect such changes in behavior. Therefore, even with the iterative, experimental approach to the determination of the emissions tax, we will need some estimate of the underlying structure of auto use decisions. In particular, in order to determine whether or not the tax is producing adequate progress toward the air quality goals, we will need an estimate of the average length of time by which changes in behavior lag behind the introduction of new incentives.

Even before studies are made we can reach two conclusions about the nature of the emissions tax: (1) It must be positive for all automobiles. The use of subsidies is administratively cumbersome and difficult to finance in an equitable manner. (2) If we wish to minimize the total expenditure incurred by all motorists in changing the emissions for which they are responsible, we must set one tax rate which is applied to all automobiles on the basis of their total emissions.

An important objection to a system which minimizes total expenditure is that it ignores the burden which the tax places on particular people (e.g., the poor). If the emissions tax goes to replace other sources of revenue, it is not a net cost for motorists in the aggregate, but it may still be a net cost for certain individuals if their other tax payments are reduced by an amount less than the emissions tax. If the emissions tax replaces part of the income tax, for example, the poor may find that their income tax falls by less than the amount of the emissions tax. This is a crucial problem, but it can be dealt with by providing exemptions from the tax for any person who has an income below a certain level. For example, we could exempt any family with an income of less than $5,000 from the first $75 of emissions tax, and any family with an income of less than $3,000 from the first $150, when the tax rate is 0.15¢ per gram on all emissions. Although this exemption seems to make the tax nonuniform, it has the advantage that whether or not the exemption can be claimed does not affect or depend on any auto use decision. If these families in fact own automobiles which pollute so much that they still owe some tax, the tax rate is high enough that they have an incentive to reduce their emissions or driving.

In order to achieve desired air quality with this exemption, we may have to raise the uniform tax rate above what it would be if the poor paid the tax without exemptions. This procedure is acceptable because the poor are sheltered from the increased rate by their exemption, and the outcome is that the rich pay proportionately more than the poor for cleaning the environment.

Detailed consideration of the tax structure must await the experimental results of the pilot project. We can, however, find a reasonable initial level for a uniform base tax rate by considering some political constraints.

If we are concerned about the eventual use to which tax revenues are put, we should be careful to see that all the revenues collected from the tax are spent to benefit roughly the same population which pays the tax. This requirement imposes an additional constraint on the level at which the tax can be set, which may or may not be consistent with the long-run constraint that desired air quality be achieved. In choosing an initial level for the tax, however, we should be sensitive to political realities, *viz* the expectation that motorists in the South Coast Air Basin will find the tax more palatable if they see the revenue going to pay for improved air quality in the Basin. This consideration suggests that it would be reasonable to set the tax initially at a level at which it will just provide sufficient revenue to finance the other measures recommended in this report.

The tax revenue to the State which is lost by removing the tax from gaseous fuels when used in an approved system must be replaced. The installation of retrofit devices on used cars to control evaporative emissions, which we have recommended, is to be mandatory, but revenues from the emissions tax could well be used to subsidize the installation of such devices. Mandatory emissions inspection also requires financing. It has been estimated that these measures would account for almost one billion dollars over four years.[4] How high must the tax be to raise this revenue?

Total emissions from vehicles in Los Angeles County of reactive hydrocarbons and nitrogen oxides in 1972 are approximately 1,500 tons per day.

[4]See Part I.

By 1975, if EQL Strategy #1 is adopted, the total will fall to 500 tons per day.[5] If the totals decline linearly over that time, they will average 1,000 tons per day during the four-year period, or 3.65×10^5 tons per year. Converting to grams gives 3.65×10^{11} grams per year.

A tax rate of one-tenth of a cent (0.1¢) per gram on combined hydrocarbon and nitrogen oxide emissions would provide an average annual revenue over four years of 365 million dollars, and a tax rate of 1½ tenths of a cent (0.15¢) per gram would provide 547 million dollars per year. In Table 15 the actual taxes which would be paid in 1972 by automobiles of various ages with average emissions and mileage for their year are computed.

In 1960 there were in the Los Angeles area 256,418 families with incomes between $3,000 and $5,000 per year, and 216, 554 families with incomes below $3,000. If tax exemptions of respectively $75 and $150 are given these families, the loss in revenue would be between 50 million and 140 million dollars annually (depending on specific car ownership patterns among low income families).

On the grounds of being used to benefit air quality in the Basin, a tax in the neighborhood of 0.15¢ per gram of combined HC and NO_X emissions should provide a politically acceptable starting point for the experimental determination of an appropriate tax rate.

To see the incentive which is given to any particular motorist to purchase a newer car, consider the second line of Table 16. A motorist whose need for transportation is fixed will find that by switching from a 1969 to a 1972 automobile he could reduce his emission tax by 55%. If he drives 10,000 miles per year, this trade-in would save him $83.50 per year with a 0.15¢ per gram tax rate (for example).

Line 3 of Table 16 shows the annual saving to the *average* motorist if he resorts to measures such as tune-ups and repairs that reduce his emissions by one gram per mile.

If a motorist converts to CNG or LPG, he saves about 80% of the tax for a 1972 model vehicle and about 90% of the tax for a 1969 model vehicle, *in addition* to his savings on state fuel taxes and maintenance (Section II/3.2).

The first line of Table 16 lists the emissions tax expressed as an increased cost of motoring in cents per mile. A very rough estimate of the effect of this increased cost on driving mileage is obtained if we regard it as being equivalent to an increase in the cost of gasoline.

In Los Angeles the average motorist gets about 12 miles per gallon and pays about 36¢ per gallon, for a cost of 3¢ per mile. A motorist driving a 1972 model vehicle would experience an effective increase of about 23% in the cost of gasoline, while a motorist with a 1969 car would experience an increase of about 50% in this cost. Houthakker and Taylor[6] give estimates of elasticities

[5]See Figures 3 and 4 of this report.

[6]H. S. Houthakker and L. Taylor: *Consumer Demand in the United States, 1929-1970,* Cambridge, Massachusetts, Harvard University Press, 1966.

TABLE 15
Emissions Taxes for Various Model Year Vehicles

MODEL YEAR	1972	1971	1970	1969	1968	1967	1966	1965 & OLDER
Average Mileage Per Year ($\times 10^3$)	15	13	11	9.6	8.4	7.6	5.3	5.0 - 3.5
Average Emissions of NO_x and HC (gm/mi)	4.5	6.2	8.2	10.1	10.1	10.1	10.1	
Average Emissions Per Year (gm $\times 10^3$)	67.5	80.6	90.2	96.9	84.8	76.7	53.5	75 - 52.5
Tax at 0.15¢/gm	$101.25	$121	$135	$145	$127.20	$115	$80.30	$112.50 - $78.75
Tax at 0.1¢/gm	$67.50	$80.60	$90.20	$96.90	$84.80	$76.70	$53.50	$75 - $52.50

TABLE 16
Tax Savings for Emissions Reduction

MODEL YEAR	1972	1971	1970	1969	1968	1967	1966	1965 & OLDER
Tax per mile at 0.15¢/gram	.675¢	.93¢	1.23¢	1.51¢	1.51¢	1.51¢	1.51¢	2.25¢
Total tax at 0.15¢/gram paid by motorist who drives 10,000 mi./yr.	$67.50	$93	$123	$151	$151	$151	$151	$225
Tax savings for average motorist per 1 gram/mi. reduction in emissions (at 0.15¢/gram)	$22.50	$19.60	$16.20	$14.00	$12.90	$11.20	$8.00	$7.50 - $5.00

which imply that a 10% increase in the price of gasoline will cause a reduction in demand that lies between 0.5% and 0.75% in the short run, and between 1.5% and 2.25% in the long run. National rather than Southern California data were used in obtaining these estimates, and the estimating technique used by Houthakker and Taylor has been criticized. Therefore, these figures should be taken only as rough indications of the influence of price on demand for gasoline in the Los Angeles area.

If we assume that no change in the pattern of automobile ownership takes place after the price of gasoline is increased, so that there is no change in the average gasoline mileage of cars on the road, we can translate decreased gasoline consumption into decreased driving. We find that a motorist owning a 1972 car would decrease his driving by 1.2—1.7% in the short run and 3.5—5.2% in the long run. The owner of a 1969 vehicle would reduce his driving by 2.5—3.8% in the short run and 7.5—11.3% in the long run. This last figure amounts to about one-half the magnitude of reduced automobile use called for in Figures 3, 4, and 10.

II/5.4 Export of Old High Emissions Cars Out of the Basin[7]

The emissions tax scheme proposed in Section II/5.3 will undoubtedly provide some inducement to motorists to buy automobiles which cause less pollution. It should be supplemented by measures which directly increase the cost of older automobiles with characteristically high emissions. We propose a system of direct incentives to promote the export of old high-emissions cars out of the Basin and to facilitate the importation of newer, cleaner cars at reasonable prices.

Any individual owning a 1970 or earlier model year automobile would be paid a sum of money for removing his automobile from the Basin. The amount paid would depend on the age, condition, and estimated emissions of the particular automobile. Owners of such older automobiles would benefit from the scheme to the extent that the "export bounty" exceeded the cost of finding a buyer outside the Basin. We can indeed hope that one result of the bounty would be the appearance of "middlemen" who will offer a price, somewhat above the going market price, for older cars. Having obtained a stock of older cars the middlemen would export them in bulk to reduce transportation and marketing costs and as a result gain a clear profit from the bounty.

At the same time, we will tax old cars brought into the Basin (the parameters determining the various differences in cars being neglected at this point). The revenue will be used to defray the exportation costs.

The effects would be as follows. To outsiders the Basin would be a relatively cheap source of supply of old cars. Their efforts to purchase (for resale elsewhere) Basin cars would exert upward pressure on old car prices. As old cars became more expensive, the demand would begin to shift to the newer models. Presumably there would be little effect on new car prices since these

[7]Based on suggestions by Dr. Charles Plott, professor of economics, Caltech.

can be freely imported. The magnitude of the resulting equilibrium stock of old cars would depend on the amount of export subsidy and import tax.

This scheme fits in neatly with an emissions tax computed on a per mile basis. The weak effect of such a tax on the purchase decision becomes irrelevant, because direct incentives to export an old car and purchase a newer one are given. It is equally important to note that the stock of used cars will change at a faster rate because of this import-export system, so that an incentive at a certain level will produce greater response.

II/5.5 Moving More People in Fewer Vehicles

II/5.5.1 General Considerations

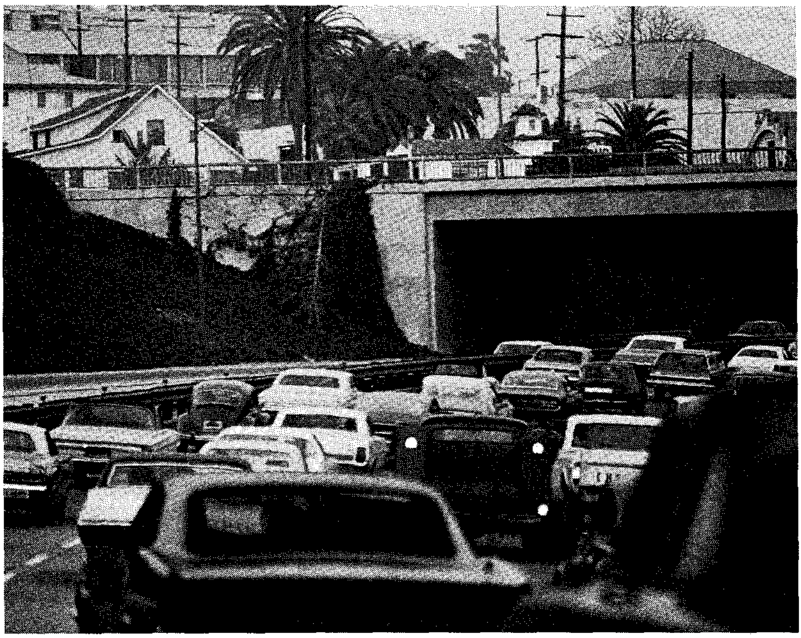
Aside from taxing automotive emissions there are other public policies which could cause motorists to behave as if they shared the risk of damage from air pollution. Everyone does, of course, share the risk, but it is not always in the immediate best interests of an individual to behave as if the risk were real. The reason is that whatever he does as an individual will probably have no effect on the problem. If he goes to the trouble of carpooling for the sake of cleaner air, he won't get the cleaner air unless a very large number of people make similar sacrifices. The public policies which should interest us, therefore, are those which cause *enough* people to behave in ways that yield cleaner air.

When we tax automotive emissions, we expect people to search among their options for those which minimize their penalty for polluting the air. Since we are especially interested in promoting choices that reduce driving, we want a system of mutually reinforcing incentives and disincentives that promote the use of multiple-occupancy vehicles like buses, carpools and jitney cabs, and that penalize driver-only cars.

The complementary relationship between emissions taxes and, say, good bus service is clear if you consider the dilemma of an individual deciding whether he would be better off paying the tax or riding the bus. He will pay a high tax to avoid a very slow, inconvenient and uncomfortable bus ride. But this is not the choice we want him to make if cleaner air is the objective. The policy-maker's choices are: raise the tax, improve the bus ride, or both. The encouragement of more and better transportation alternatives is an important adjunct of effective public policy in this area. Moreover, it is only fair to the penalized motorists—especially those of low income.

Following are brief discussions of some of the measures which might be part of an effective system of incentives and disincentives. Implicit in all the suggestions is the assumption that there is a necessity and an opportunity to use Los Angeles' extensive freeway system as the basis for more efficient mass transportation[8] without years of delay and massive expenditures. Such

[8]"Efficient mass transportation" is here defined as moving more people with fewer vehicles, or with fewer emissions per person, not as moving more vehicles over the existing freeway system.



an assumption is not, of course, meant to suggest that some very much more elaborate transportation system will not be a part of the long-term solution to air pollution and other urban environmental problems.

II/5.5.2 On the Freeways, Give Priority to Buses, Carpools and Other High-Occupancy Vehicles; Discriminate Against One-Person Vehicles

A. Control Access to the Freeway on the Basis of Vehicle Occupancy

The instrument for carrying out such a policy exists. The California Division of Highways already controls access to Los Angeles area freeways during the morning rush hours at a number of onramps. Freeway access is controlled by a traffic signal which admits one car per green light and is timed to slow entering traffic to some rate that will relieve congestion. Cars might wait as long as 15 minutes to enter the freeway. The master plan is to install such controls on most freeway onramps in the Los Angeles Basin within ten years.[9]

The controlled freeway access program has the potential merit of encouraging multiple-occupancy vehicles while it discourages driver-only cars. Buses, carpools, and other vehicles with, say, two or more persons would go ahead, while one-person cars would wait for long periods. However, we will not get the reduction in emissions we want if the penalized cars sit, morning after morning, in long lines with engines idling and traffic backing up on surface streets. But buses and carpools would enjoy an advantage which previously they never knew: top freeway speeds during the peak rush hours. The long waiting lines of private cars might then disappear as motorists joined carpools, took a new look at the faster bus service, or parked their cars at rendezvous points along freeways and flagged jitney cabs.

If the master plan for controlling freeway access could be moved ahead to full implementation within a year or two, and if we could begin to add up the capacity of our freeways in terms of *people*, not vehicles moved, then the controlled-access program might be used as a powerful sanction against driver-only vehicles.

Probably a very sizable pilot demonstration project would be required to determine whether the idea would work. The San Fernando Valley, with a limited number of freeway onramps, a very large population of commuters, and relative isolation from the central section of Los Angeles is a likely location for a test of this sort of social policy.

[9]California Division of Highways, District 7, Freeway Operation Dept., *A Program to Upgrade and Control the Los Angeles Freeway Network,* July 1970.

B. Reserve a Special Lane on Freeways for Carpools and Buses

Another approach would be one that uses present morning and evening rush hour congestion on freeways as an effective incentive for carpooling and bus riding. If a lane were reserved exclusively for carpools and buses, persons choosing these "more efficient" forms of transportation would immediately realize a benefit in the form of faster commuting time. At present carpool and bus riders suffer the same impeded movement as people in private cars. This being the case, the commuter reasons, why not endure the congestion in comfort and privacy?

The enabling legislation for reserved freeway lanes already exists in California. Assembly Bill No. 1, which became law in November, 1970, authorized the Department of Public Works to designate reserved freeway lanes for high-occupancy vehicles. Accordingly, on December 8 last year, the department launched an experiment that involved reserving an exclusive lane for buses and carpools on approaches to the Oakland Bay Bridge during the 6 to 9 a.m. rush hours on the Oakland side. As an added incentive for carpooling, cars with three or more persons were exempted from the 40-cent toll. Within less than two weeks the number of carpools had almost doubled from 1000 to nearly 2000. Nearly half the morning commuters into San Francisco across the Bay Bridge were already on buses, but bus company receipts indicated no passengers had been lost to carpools. Early traffic counts, however, did not confirm a significant decline in the number of vehicles crossing the bridge. Plans were to continue the experiment.[10]

The first exclusive lane for buses, designated in 1969 on a stretch of the Shirley Highway linking northern Virginia suburbs and Washington, D.C., increased bus ridership 15-20% within two months and significantly reduced commuting time on buses.[11] A recent detailed study supported by the Department of Transportation found the concept of freeway lane reservation potentially effective in reducing traffic and feasible in implementation. Analyzing the Memorial Shoreway in Cleveland, the study found that if only 5% of the commuters shifted from private cars to carpools and buses, a reserved lane would carry 50% more people 20 miles per hour faster than the unreserved lands. Traffic would move faster on the unreserved lanes as well.[12]

A slower and more expensive approach is to construct a special lane for buses. An 11-mile busway is presently under construction along the San Bernardino Freeway between El Monte and the outskirts of downtown Los Angeles. Sponsored by the Division of Highways and the Southern California Rapid Transit District, the busway will cost an estimated 52 million dollars

[10]Information from telephone conversations with supervising traffic engineers at the Department of Public Works in Sacramento and at the Oakland Bay Bridge.

[11]Turner, Francis C. "Moving People on Urban Highway," *Traffic Quarterly*, July, 1970, p. 325.

[12]U. S. Department of Transportation AMY-R061-1114, *Feasibility and Evaluation Study of Reserved Freeway Lanes for Buses and Car Pools*, prepared by Alan M. Voorhees & Associates, Inc., Jan 31, 1971.

and is expected to be in operation in 1972.[13] Given the entrenchment of the automobile in the life style of Los Angeles, perhaps the construction of special busways is a realistic first step toward mass rapid transit. But such large capital construction projects could play only a minor role in a strategy aimed at major reductions in automotive emissions with the next few years.[14]

II/5.5.3 Improve the Alternatives

A. Expand Bus Service

As a by-product of either of the traffic control policies discussed above, commuter bus service would automatically improve in terms of faster transit time. The recent sales tax subsidy for urban transit voted by the state legislature might be used to expand and revise rush hour service to accommodate new bus riders as conveniently and comfortably as possible. Revenues from the proposed emissions tax could also be so used. Information on bus schedules and routes could be disseminated much more broadly.

B. Facilitate Other Types of High Occupancy Vehicles

1. *Carpool matching:* A few civic organizations, government agencies, and businesses have provided their employees and members of the public with information services to help them find or organize suitable carpools. Operation Oxygen is an organization of concerned citizens which has developed and promoted the idea of using computers for carpool-matching in large organizations.[15] The service is provided for a fee by several firms.
2. *Parking incentives and disincentives:* In congested areas such as downtown Los Angeles, parking has become increasingly difficult and expensive. The response of many businesses and organizations has been to increase parking facilities for employees. Instead, management could adopt policies of free parking *only* for carpools, while those who drive to work alone would pay the full unsubsidized cost of parking. Employees who could not carpool could be given free or subsidized bus passes.
3. *License jitney cabs:* City councils could license jitney taxis similar to those common in many countries in the world. Passengers and taxis would rendezvous at established taxi stands; routes and schedules would be, within limits, flexible, allowing for short detours to drop off passengers near their destinations. Departures would depend on filling up the cabs. Jitneys would provide a middle ground between ordinary taxis, which are, of course, prohibitively expensive for commuting, and buses with their

[13]The Los Angeles Times, December 21, 1970 and October 22, 1971.

[14]The two freeway traffic control policies discussed here are probably not complementary. Obviously, if access control were applied to an extent which drastically reduced traffic on freeways during rush hours, an exclusive lane would offer buses and carpools no advantages.

[15]Operation Oxygen is headed by Mr. Jack Novack and is headquartered at Burroughs Corporation in Pasadena.

obvious disadvantages. The jitney operators could be full time or part time. The part-time operators might be low-income car owners whose jitney license would provide them with a small additional income for perhaps two trips a day—to and from work—in effect, a paid carpool.

4. *Provide rendezvous points and parking along freeways:* In the pattern of suburban commuting on the East Coast, motorists might prefer to leave their cars or to be dropped off at freeway "stations" near their homes. There they could take buses, flag jitney cabs, meet their carpools, or even pick up a stray commuter who might be the extra person needed to gain entrance to the freeway.
5. *Incorporate smog alerts into traffic control:* As suggested elsewhere, smog alerts could be used to discriminate against low-occupancy cars as well as high-emitting cars. When alerts are called, single-person cars could be banned from freeways not only during rush hours but throughout the duration of the alert.
6. *Provide the public with information:* While it seems unlikely that public information/education programs can by themselves quickly and radically change widespread behavior, such programs are an indispensable part of the system of incentives and disincentives proposed here. It is important that the public understand why it is being burdened; that it be persuaded that its sacrifices are fair and will be productive of clean air. Such a program will be an important part of enforcement, which can never be 100% perfect and must rely on widespread voluntary compliance. A Department of Public Works official recently reported that the great majority of complaints received when the exclusive bus and carpool lane was put into effect in Oakland came from persons who resented not their sacrifices but the lack of cooperation by cheaters they had observed.

II/5.6 Reducing the Annual Rate of Increase in Gasoline Consumption

Clearly the total tonnage of undesirable emissions from motor vehicles in the Basin is related in some complex manner to the amount of gasoline burned in the Basin. It is only natural to assume at first that, if the annual rate of increase in gasoline consumption of about 4% is reduced, the rate of growth in motor vehicle emissions will also be reduced. However, measures to limit gasoline consumption, *if taken by themselves,* might not have the desired effect at all. For example, motorists might purchase automobiles that deliver more miles per gallon than their present cars, so that the intensity of driving and the amount of emissions would change but little. In fact some makes of cars with low fuel consumption produce more grams per mile of undesirable emissions than some "gas hogs." In the short run it is by no means impossible that in the absence of other complementary measures limitations on gasoline consumption could result in more emissions rather than less.

A *combination* of the emissions tax (Section II/5.3) and restrictions on gasoline consumption might be effective, since each measure has advantages lacking in the other. The shift to cars with low fuel consumption but high emissions in grams per mile that might otherwise be encouraged by restrictions on gasoline consumption would be discouraged by the emissions tax. On the other hand the tendency of motorists owning newer cars with lower emissions in grams per mile to drive more miles per year than the average[16] would be restrained to some extent by limitations on gasoline consumption.

After considering a number of means designed to hold gasoline consumption close to its present level,[17] we have concluded that there are two measures worth detailed study: (1) limitation of aggregate sales of gasoline in the Basin to four billion gallons annually,[18] less conversions to gaseous fuels; (2) coupon-auction system for motorists.[19]

The limitation on aggregate sales of gasoline could be accomplished, for example, by periodically auctioning to the refineries the rights to sell gasoline in the Basin, at the rate of one right per gallon, with a certain fixed ceiling on total rights.[20] We call this scheme a gasoline market approach. Such an approach appears to make any additional coupon or rationing system unnecessary, because the existing gasoline market would take care of the problem of allocation. This approach also has the advantage that it does not require information about the elasticity of demand for gasoline and for automobile travel. Such information is not needed if the total supply is limited; the market would automatically establish the new price of gasoline (equivalent of the tax).

One obvious objection to the gasoline market approach is that the inevitable increases in the price of gasoline would generate additional revenue for the refineries and marketeers at the expense of the motoring public. An alternative gasoline rationing method involves the issuance of a certain number of coupons in 1-gallon and 5-gallon denominations to each motorist in the Basin, with the total equivalent gallonage held at the present level, less conversions to gaseous fuels. These coupons would have to be presented at the gasoline station for cancellation (e.g., punching) to match gasoline purchases. There are advantages in permitting and even encouraging "free trading" in gasoline coupons by licensed brokers. Those who have more coupons than they need could sell them through these brokers to motorists

[16]Section II/5.3, Table 15, line 1 and Table 16, line 1.

[17]After allowance for conversion of gasoline-powered vehicles to gaseous fuels, corresponding to one-third of the present gasoline consumption in the Basin.

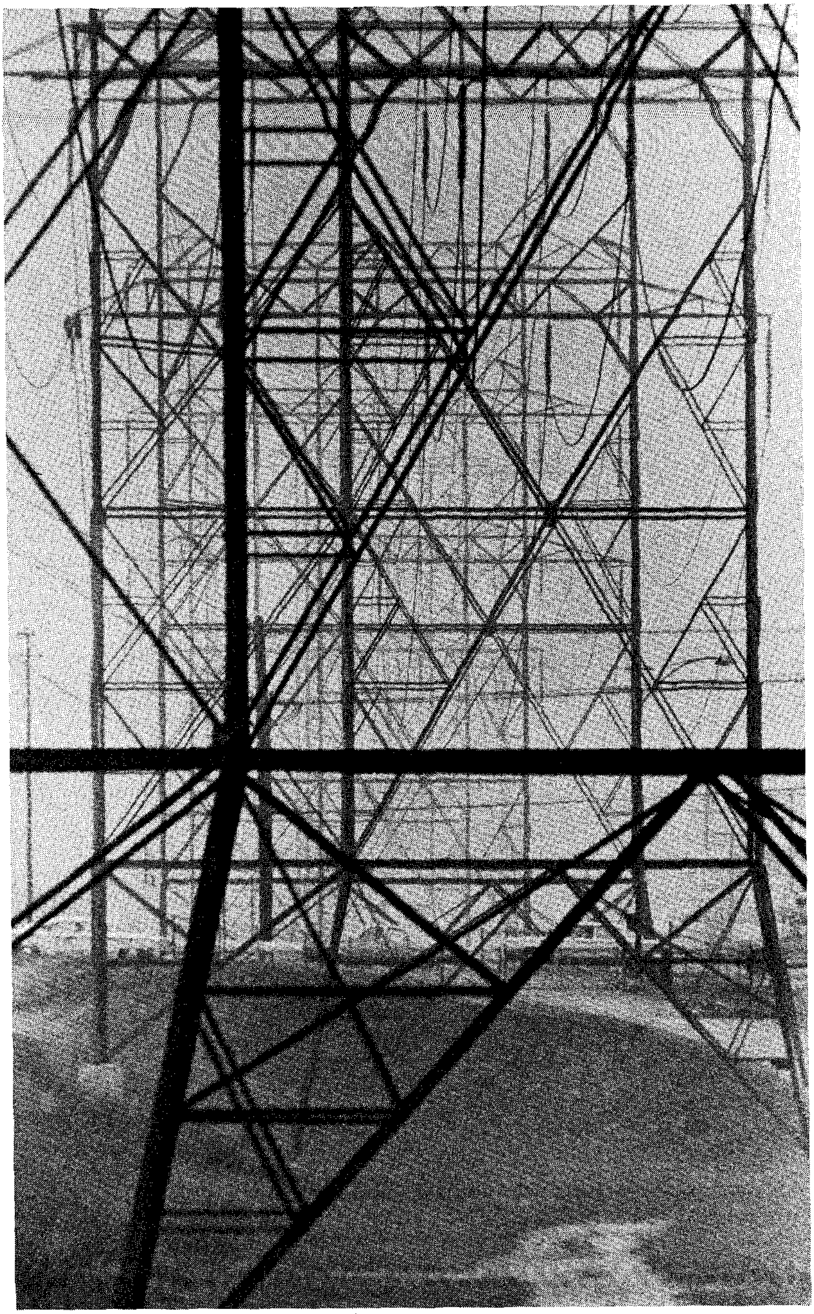
[18]1969 figure.

[19]A third possible measure is an environmental surcharge (or tax) on gasoline. However, this measure resembles the emissions tax (Section II/5.3) in its main effects on driving, so that we concluded that the desired changes in behavior could be stimulated just as well by increases in the emissions tax rate.

[20]Revenues received by the State from the sale of these rights could be recycled into other emissions control activities.

demanding more coupons than they receive from the State. The floating price of the coupons would establish an effective new price for gasoline.

Of course, all the usual objections to rationing schemes hold with equal (or greater) force here. Strict precautions would be necessary to guard against "bootlegging" into the Basin of additional gasoline. Several contiguous basins might have to be included in the scheme to reduce the incentives for "bootlegging." Americans do not take easily to rationing schemes except in times of war, local disasters, or temporary emergency, and public acceptance is an essential ingredient of any successful rationing program. For these reasons we have suggested a limitation on the total consumption of gasoline in the Basin only as a "last resort" measure to be introduced only if the socioeconomic measures proposed in this section fail to produce the 20% reduction in automobile use required to help meet the management air quality standards.



PART II: SECTION II/6

State and local air pollution officials have predicted that the present control program will lead to clean air—that is, air that meets California air quality standards—by 1990. Calculations by the EQL team indicate this could not be the case. The reason is growth in sources of emissions; additional vehicles, additional plants, and additional pollution-making affluence.

The present strategy will not lead to clean air; nor will the EQL program. By about 1982 air quality will begin to deteriorate again. The real rationale for EQL Strategy #1, which is to say the rationale for doubling what we are presently doing about air pollution, is to get much closer to the clean air goal before we are overtaken by growth. This will also give us much more time to make the really radical changes in life-styles, transportation modes, and technology that are needed for a long-term solution to the air quality and other environmental problems.

With so many people and so many pollution sources in the Basin, it is not low emissions but zero emissions that are required. Small battery-operated commuter cars would be an example of zero-emissions transportation mode that may be no further away than the next decade. But they would have to be coupled with zero-emissions energy sources such as nuclear power plants located outside the Basin. Solar energy conversion is another zero-emissions energy source which could play an increasingly important role in the long-term.

Nuclear energy has proved controversial but only mildly so compared to some of the socio-economic measures that must be considered for the ultimate cure to air pollution. Growth itself will have to be directly dealt with. The finite carrying capacity of the Los Angeles Basin became apparent in the 1970's. Incentives for resettlement elsewhere accompanied by zoning rollbacks and embargos on utility hook-ups for new customers are examples of interrelated, growth-control policies which may have to be considered.

The final implication of this detailed look at exactly what is involved in making exactly what improvements in air quality is this: our present way of life is not consistent with clean air.

We should be arguing about the really fundamental changes needed in the way we use energy. Instead the discussion has centered on whether we should take ineffectual steps that ultimately will prove no solution. We have been looking for a technological fix that won't cost much. We have been distracted from the real issues by an unrealistic promise of clean air in the distant future at bargain prices.

II/6 A GLIMPSE AT THE POST-1982 SITUATION AND LONG-RANGE NEEDS

Some time in the early 1980's emissions of reactive hydrocarbons, nitrogen oxides and carbon monoxide into the atmosphere of the Basin will begin to increase again, and so will the average number of "objectionable" days per year. The projected growth in population and in the rate of consumption of oil, gasoline and natural or synthetic gas in the Basin makes this outcome inevitable, if no *new* measures are taken. Figure 14 shows the projected deterioration in oxidant air quality beyond 1982, based on growth rates in reactive hydrocarbons and nitrogen oxides emissions of 2% per year and 4% per year, respectively.

If EQL Strategy #1 is fully implemented, ambient air quality will deteriorate rather slowly beyond 1982, because the "minimum" emissions levels reached in the early 1980's are much lower than the 1969 base levels. For example, total reactive hydrocarbon emissions in L.A. County in 1982 are estimated at about 20% of the 1969 level (Figure 5). Thus, a growth rate of 4% per year in these emissions in the post-1982 period amounts to a growth rate of less than 1% per year in terms of the 1969 base level. Starting at the new 1982 "base level," the "characteristic time" for deterioration in oxidant air quality from 25 "objectionable" days per year to 50 such days is about 10 years (Figure 14). This characteristic time is still uncomfortably short, but at least it is beginning to approach the "system time lag" or "lead time" for the introduction of new technology and new social and economic measures and for institutional changes that are designed not only to arrest the deterioration in ambient air quality, but to improve air quality, if possible.[1]

Members of the EQL staff have begun to identify and examine the main features that any long-range (1982-2000) strategy for air pollution control in this Basin must contain. The purpose of this section is to outline some of these features; a considerable amount of work is required to fill out the details. The main components of a long-range strategy are as follows: (1) introduction of new prime-movers and energy sources with low emissions, or even "zero emissions"; (2) provision of a balanced transportation system; (3) limitations on population, industry and commerce in this Basin; (4) community development and redevelopment, land use planning, and changes in communication and "life-style" designed to reduce air pollution.

As an example of new technology in prime movers one can visualize the introduction of small, battery-operated commuter cars beginning in the early 1980's. If these cars were to replace internal combustion engine-powered vehicles at a (conservative) rate of 2% of the total car population in the Basin per year, the rate of increase in reactive hydrocarbon and nitrogen oxides emissions from automobiles would be reduced by about the same amount.[2]

[1]This "lead time" is estimated to be on the order of 15-20 years.

[2]Two percent of the car population per year will amount to about 170,000 cars per year in the early 1980's, or about 20% of the new cars to be purchased in the Basin each year. At first these cars might be manufactured mainly for use in critical air basins, such as this one.

Emissions of these substances from automobiles constitute one-half to two-thirds of the total (Figures 5 and 6), so the rate of increase in total emissions would be reduced by at least 1% per year. In other words, a projected growth rate of 4% per year in total emissions would be reduced to 3% per year by means of this new technology alone. By interpolating between the curves for 2% and 4% annual growth rate shown in Figure 14, we can see that the time scale for significant deterioration in oxidant air quality is "stretched out" to perhaps 15 years.[3]

Of course, new electrical generating capacity would have to be provided to supply the electrical energy required to recharge the batteries of these electric cars. Based on an overall efficiency of 50% for the electric car, and a recharging time of eight hours, about 20,000 MW(e) would be needed if *all* the cars in the Basin were replaced by electric cars. If the birth rate of electric cars is 2% of the total car population per year, about 400 MW(e) per year is required, or about 500 MW(e) of new generating capacity per year, allowing for the usual 20% margin over demand. This figure amounts to an increment of about 2% per year in the electrical generating capacity projected for this Basin for the early 1980's. Because of the "tight" electrical energy supply situation in this Basin, this increment is significant.[4] These considerations show that an integrated master energy-transportation-air pollution control plan must be developed for the post-1982 period if this path is followed.

For example, the additional electrical energy required by electric cars and by many other activities in the Basin could be generated by nuclear power plants located at remote sites outside the Basin (possibly with all or part of the plant underground) or on off-shore floating barges. As coal gasification begins to produce significant quantities of synthetic gas, combined-cycle gas-and-steam turbine generating plants could also be located outside the Basin, possibly near the sources of coal. Along these same lines, existing fossil-fuel generating plants in the Basin could be phased out gradually and replaced by plants outside the Basin in order to reduce nitrogen oxides and particulate emissions. One could go a step further and replace large industrial furnaces and boilers using fossil fuels by electrically-operated units, or substitute pure oxygen for air in the combustion process (at increased cost).

About 8% of total energy consumption in this Basin is devoted to space conditioning, and an additional 6% of total energy is used for heating water, most of it involving fossil-fuel combustion at present. These sources of air pollution could be reduced by utilizing solar energy in thermal conversion and storage systems for new homes and buildings. Since new living units are added at the rate of about 3% per year, and new commercial floor space at about 5% per year, the effect of introducing solar energy systems is felt only gradually. Nevertheless, this option is an essential part of a long-range strategy of energy conservation and reduction in air pollution. It may also be

[3]Other examples of probable new automotive technologies could also be examined, such as "stratified-charge" internal combustion engines, or steam turbines.

[4]Lees, L., *Implications of the Growth in Demand for Commercial and Industrial Electrical Energy in the South Coast Air Basin,* EQL Report #2, November, 1971.

possible to retrofit existing homes with solar energy conversion units for heating water, thus greatly increasing the rate of impact of this new technology.

Even the supposedly "technical" measures just described raise a wide variety of environmental, economic, land-use and "life-style" issues that are presently unresolved. But the second component of a post-1982 air pollution control strategy, namely a balanced transportation system, obviously involves a complex "mix" of social, economic, legal and technical factors at every stage of its development. So far as energy conservation, air pollution and congestion are concerned, the situation is straightforward. The present ground-based vehicular transportation system in this Basin absorbs more than 30% of the total energy budget and produces a major share of the air pollution. The "average motorist" in the South Coast Air Basin travels 25 miles per day on two gallons of gasoline with an equivalent energy of about 60 KWH(t) per capita. A typical Los Angeles bus on the other hand uses eight gallons of gasoline to cover 25 miles, but it carries an average of 40 passengers, so the energy expenditure is about 6 KWH(t) per capita, or a factor of ten less than the single motorist.[5] The bus could be powered by a gaseous fuel or by a steam turbine, so the reduction in air pollution per capita could be even larger, depending on the distribution of emissions in grams per mile in the motor vehicle population.

Of course the problem is to get the people out of their cars and into the buses (Section II/5.5). The usual dirty subways or uncomfortable buses running infrequently would hardly entice people away from their own comfortable cars that provide door-to-door service. Some incentives to stimulate this process are already suggested as part of EQL Strategy #1 (Section II/5.5). In the EQL we have begun a study that will (1) assess possible and future urban transportation systems; (2) analyze transport demands (both passenger and freight) for large urban centers; (3) analyze the social, economic and institutional problems, including financing and authority over capital expenditures; (4) attempt to synthesize (1)-(3).

Almost everyone agrees that population, industry and commerce cannot continue to grow indefinitely at a constant annual rate in this Basin. But the surprising thing to most people is that the finite "carrying capacity" of the Basin should make itself felt so abruptly in the 1970's. This abrupt impingement is quite typical of exponential growth processes. The question now is not whether the growth rate will be reduced, but by how much and with what implications? Any program to limit the Basin's population to a certain level would be considered fairly radical. But incentives to settle or resettle elsewhere are not out of the question. And permanent regional zoning and zoning "roll-backs" to preserve the single-family home over wide areas of the Basin are now under consideration. In addition to these measures one large electric utility recently gave public notice that it may have to embargo connections to

[5]Similar remarks apply to fixed-rail rapid transit. Of course the energy expenditures for the single motorist could be reduced by designing motor vehicles with much higher mileage per gallon of gasoline.

new customers in certain areas.[6] About one-third of the growth rate in demand is attributed to new customers and two-thirds to increased use of electricity by existing customers. Although such an embargo was discussed publicly for the first time because of the tight electrical energy supply situation, the concept may have wide applicability. Finally, we should not overlook the effect of rapidly rising unit energy costs on energy demand. Studies have been made in the past of price elasticity in particular power-intensive industries, such as non-ferrous metals, but not much is known about the effect of substantial increases in unit energy costs in less power-intensive industries, and in the commercial, residential and public sectors.

Another approach to controlling growth is to guide the growth in such a way that a reduction in harmful emissions occurs naturally. For example, if industrial-commercial and residential areas were interspersed, it would be possible for people to live closer to their work and thus not have to drive so much. In principle, such integrated community development and land-use planning could reduce emissions even if the automobile population increased. Future two-way electronic communication over common carriers and cable TV-FM might also cut down on the need for travel from home to market or office.

A quite different approach to achieving cleaner air is based on the recognition that the atmosphere in this Basin can absorb more pollutants at some seasons than at other seasons, both because there is more air moving through the Basin and because there is less sunlight and a higher inversion layer. Even within a given season the air movement through the Basin varies considerably from day to day. This observation suggests that it might be desirable to vary our activities in accordance with the ability of the atmosphere to absorb pollutants. We already do that in a crude way by permitting power plants to burn oil in the winter time but requiring them to burn natural gas in the summer. The suggestion in EQL Strategy #1 described in Section I/2 that we begin to call meaningful smog alerts in July, August and September when the number of smoggy days has been significantly reduced is also a step in that same direction. More extensive measures could be taken to restrict personal, industrial and commercial activities on days that have a high potential for undesirable levels of pollutants.

This approach would require first of all an extensive and effective monitoring system plus a good predictive model to determine when activities should be curtailed. Secondly, there would have to be adequate social machinery to implement the curtailment. In a sense the situation would be similar to that which exists in some cities when it snows, and which has always existed in almost all agricultural areas where people adapt their activities to the weather. The significant difference is that people would be adapting to a *potential* for an undesirable situation. If effective, the program would assure that the person who was adapting his behavior would never see smog. This plan would

[6]Supplemental testimony by Robert M. Coe, Vice-President, Southern California Edison Company, in California Public Utilities Commission Case No. 9007, December 7, 1971.

require a great deal more understanding and sophistication than merely staying home from work when faced with four feet of newly-fallen snow. It would also require means for the community to impose restraints on the individual for the common good to a much greater extent than it now does.

The kinds of approaches that have been discussed to limit or control growth and to modify individual or collective behavior patterns are illustrative of the kinds of measures that may be required in the post-1982 era to reduce emissions levels. Most of these kinds of measures are different from those taken in the past to achieve social purposes. Thus, there is an imperfect understanding of how to assess the probable effects of such measures, particularly the side effects. Extensive studies should be undertaken to improve our understanding of these effects, and, since the lead-time for social changes is usually fairly long, the studies should be undertaken sooner rather than later. Because the situation is very complex and the methods for predicting the outcomes of social actions are not well developed, some experimentation will be required. As a society we must be prepared to accept some mistakes and to change direction when needed if we are to cope with these situations.

APPENDIX

Projection of Automotive Emissions

The automotive emissions for L.A. County that are projected in this report have been made on the following data base:

1. The birth and death of new vehicles as per Table 17.
2. The annual mileages driven by vehicles of different ages as per Table 18.
3. Projected increase in vehicle use for L.A. County as per page 45 of "Profile of Air Pollution Control," L.A. APCD, 1971.
4. Exhaust emissions levels for present and future vehicles as per Table 19.
5. Emission reduction ratios for VSAD as per Table 4.
6. Emissions levels for gaseous fuels as per Table 3. Propane exhaust is considered half as reactive as gasoline; natural gas exhaust one-fifth as reactive.[1]
7. Non-exhaust emissions as per page 47 of "Profile of Air Pollution Control," L.A. APCD, 1971.

As an example, this data is used to predict the emissions levels for reactive hydrocarbons in 1975 (Table 20). The average emissions level of a vehicle in 1975 is calculated as the sum of the contribution of each class of vehicle, based on the fraction of the mileage driven by that class (from Tables 17 and 18) and the characteristic hydrocarbon emissions of that class (Table 19). The total reactive exhaust hydrocarbons are then calculated from the APCD projection of the growth in vehicle use (gasoline consumption).

Evaporative and crankcase losses must be added to get the total automotive hydrocarbons. Two-thirds (.67) of the total weight emitted from these sources is considered reactive.

The effect of typical control measures can be assessed by considering the effect on the vehicle emissions. Using the reduction factors for hydrocarbon emissions resulting from VSAD of 1970 and older vehicles, the total reduction in reactive hydrocarbons can be calculated.

The effect of converting portions of each year's vehicles to gaseous fuels can be similarly calculated. Conversion of vehicles to gaseous fuels is considered to begin in 1970, with one-third of the fuel use by 1970 and later models being a mix of 75% natural gas and 25% propane. The emissions attributed to such vehicles are given by Table 3. (This is a compromise in estimation. Conversion of earlier vehicles produces a more substantial impact than does conversion of newer vehicles with their already controlled emissions.) For the "optimistic" projection, 1975-1976 and later, vehicles are not

[1]Based on unpublished literature survey by John Batchelder of the Clean Air Car Project, using data on photochemical smog, especially that of A. P. Altshuller.

considered to be converted because they are cleaner than the gaseous fueled vehicles.

The actual reduction in auto use that can be achieved by various measures discussed in the report is not known. However, to illustrate the potential effect of such measures a projection is made for a 20% reduction in the use of gasoline automobiles. This is considered to occur in addition to the conversion to gaseous fuels, and hence represents a 13% reduction in total use, or about 3-4 years normal growth.

Reductions in the evaporative emissions are based on the population by year, but not use, with the control system assumed to be 90% effective. Retrofit of 1966 through 1969 vehicles is found to reduce emissions by 50% by 1975.

TABLE 17
Birth-Death Schedule for Vehicles in L.A. County

AGE (years)	PERCENT OF POPULATION
0	11
1	11
2	11
3	10
4	10
5	9
6	8
7	7
8	6
9	5
10	4
11	3
12	2
13	2
14	1
15	1

Source: Los Angeles Air Pollution Control District

TABLE 18
Average Mileage vs. Vehicle Age

AGE (years)	ANNUAL MILEAGE (in thousands of miles)
0	15.0
1	13.0
2	11.0
3	9.6
4	8.4
5	7.6
6	5.3
7	5.0
8	4.4
9	4.2
10 and older	3.5

Source: California ARB

TABLE 19
Exhaust Emissions Levels for Present and Future Vehicles

YEAR	HYDROCARBONS gm/mi	REACTIVE HYDROCARBONS gm/mi	CARBON MONOXIDE gm/mi	OXIDES OF NITROGEN gm/mi
Pre-1966	11	8.25*	80	4.0
1966-1969**	4.1	3.08	37	6.0
1970	2.2	1.65	23	6.0
1971	2.2	1.65	23	4.0
1972-3	1.5	1.2	23	3.0
1974	1.5	1.2	23	1.3
For optimistic projections				
1975	0.23	0.0	2.3	1.0
1976	0.23	0.0	2.3	0.27

* Exhaust hydrocarbons are considered to be 80% reactive. However, for 1975 and later vehicles in the optimistic projection, reactive hydrocarbons are considered to be zero, based on the assumption that the cars are fitted with catalyst systems which eliminate reactive hydrocarbons.

** The observed deterioration of the hydrocarbon and carbon dioxide emissions levels with increasing automobile mileage has been included in these numbers, based on ARB data. Oxides of nitrogen have increased as compared to pre-1966 vehicles.

TABLE 20
Sample Calculation — Exhaust Emissions of Reactive Hydrocarbons for 1975

Basic Calculation

MODEL YEAR	FRACTION OF MILEAGE		CHARACTERISTIC EMISSIONS (gm/mi)		TOTAL EMISSIONS (gm/mi)
65 & older	0.054	×	11	=	.594
66-69	0.142	×	4.1	=	.582
70-71	0.181	×	2.2	=	.398
72-75	0.623	×	1.5	=	.935
					2.509

Vehicle use in 1975 $= 9.8 \times 10^{6} \dfrac{\text{gallons}}{\text{day}} \times 15.5 \dfrac{\text{miles}}{\text{gallon}} = 1.52 \times 10^{8} \dfrac{\text{miles}}{\text{day}}$

Exhaust emissions of reactive HC $= 1.52 \times 10^{8} \dfrac{\text{miles}}{\text{day}}$

$\times\ 2.509 \dfrac{\text{gm.}}{\text{mile}}$ (1975 average) $\times\ .75$ (Reactivity factor)

$\times\ 1.1 \times 10^{-6} \dfrac{\text{tons}}{\text{gm.}} = 315 \dfrac{\text{tons}}{\text{day}}$

TABLE 21
Effect of VSAD

MODEL YEAR	FRACTION OF MILEAGE		CHARACTERISTIC EMISSIONS (gm/mi)		VSAD FACTOR		TOTAL EMISSIONS (gm/mi)
65 & older	0.054	×	11	×	.90	=	.535
66-69	0.142	×	4.1	×	.77	=	.448
70	0.081	×	2.2	×	.77	=	.137
71	0.100	×	2.2			=	.220
72-75	0.623	×	1.5			=	.935
							2.275

Exhaust RHC $= 1.52 \times 10^{8} \dfrac{\text{miles}}{\text{day}} \times 2.275 \dfrac{\text{gm.}}{\text{mile}}$ (1975 average after VSAD)

$\times\ .75$ (Reactivity factor) $\times\ 1.1 \times 10^{-6} \dfrac{\text{tons}}{\text{gm.}} = 285 \dfrac{\text{tons}}{\text{day}}$

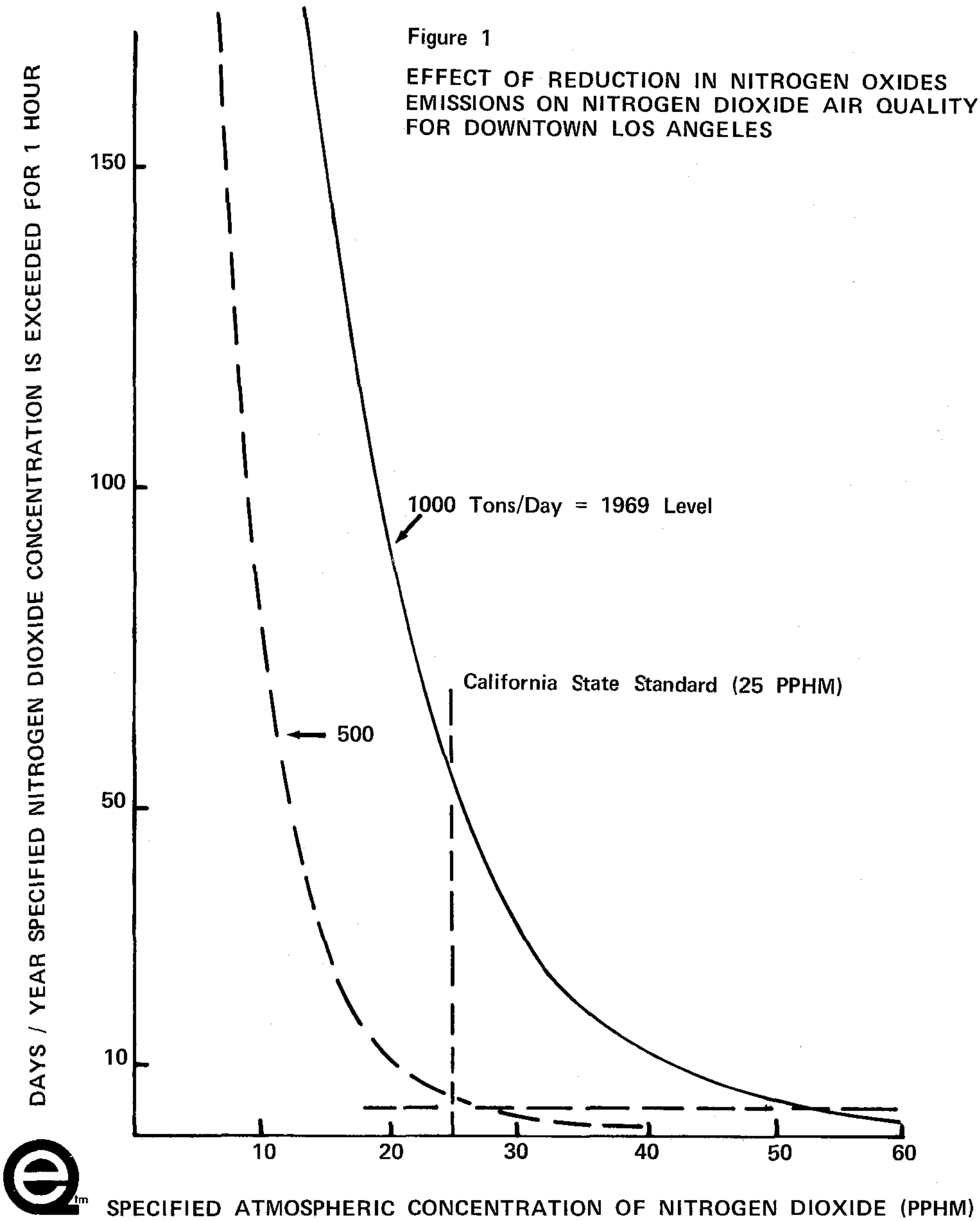


Figure 1
EFFECT OF REDUCTION IN NITROGEN OXIDES EMISSIONS ON NITROGEN DIOXIDE AIR QUALITY FOR DOWNTOWN LOS ANGELES
DAYS / YEAR SPECIFIED NITROGEN DIOXIDE CONCENTRATION IS EXCEEDED FOR 1 HOUR
150
100
50
10
1000 Tons/Day = 1969 Level
California State Standard (25 PPHM)
500
10
20
30
40
50
60
SPECIFIED ATMOSPHERIC CONCENTRATION OF NITROGEN DIOXIDE (PPHM)

Figure 2

NITROGEN DIOXIDE AIR QUALITY VS. EMISSIONS FOR VARIOUS STATIONS

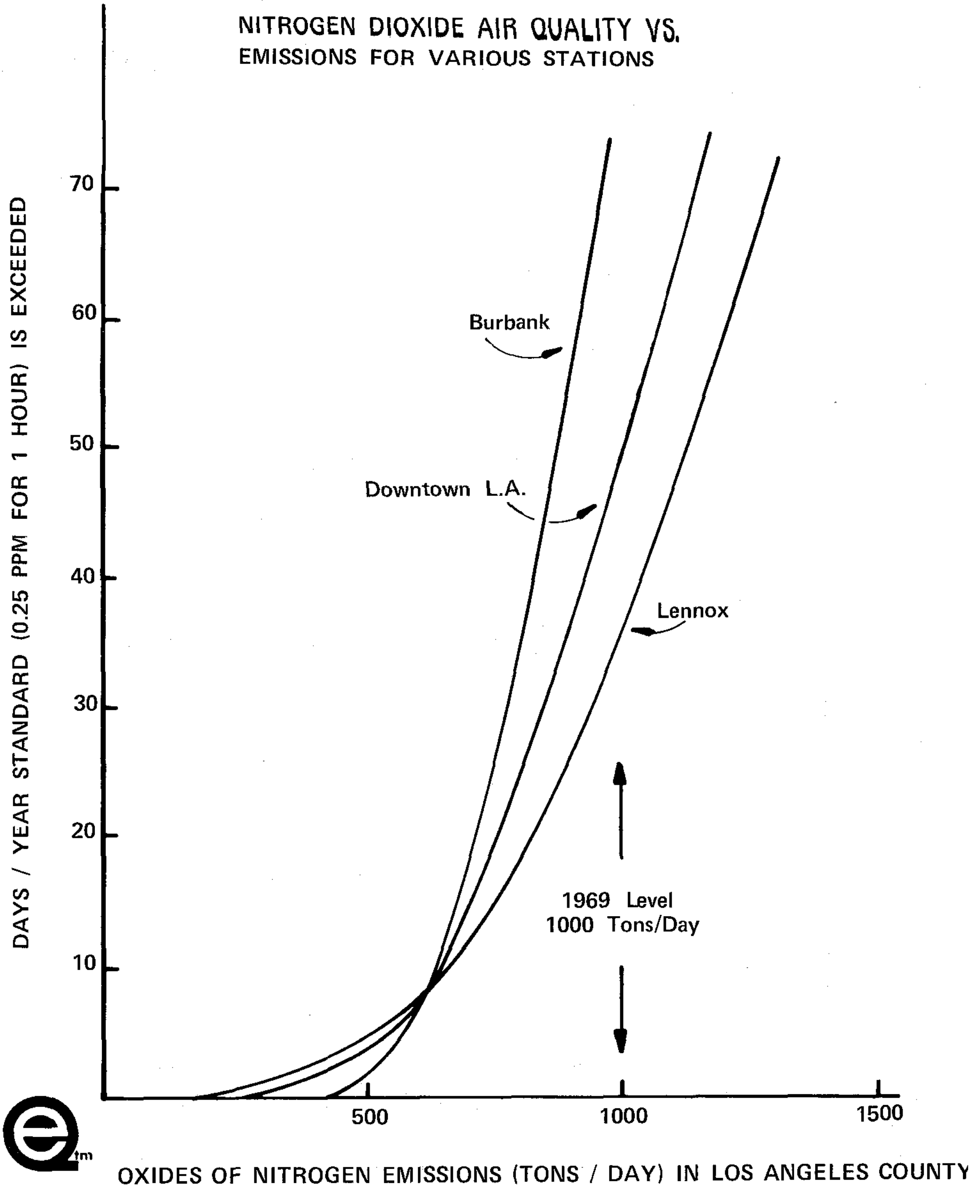


Figure 3

BREAKDOWN OF REDUCTIONS IN
REACTIVE AUTOMOTIVE HYDROCARBON
EMISSIONS FOR LOS ANGELES COUNTY

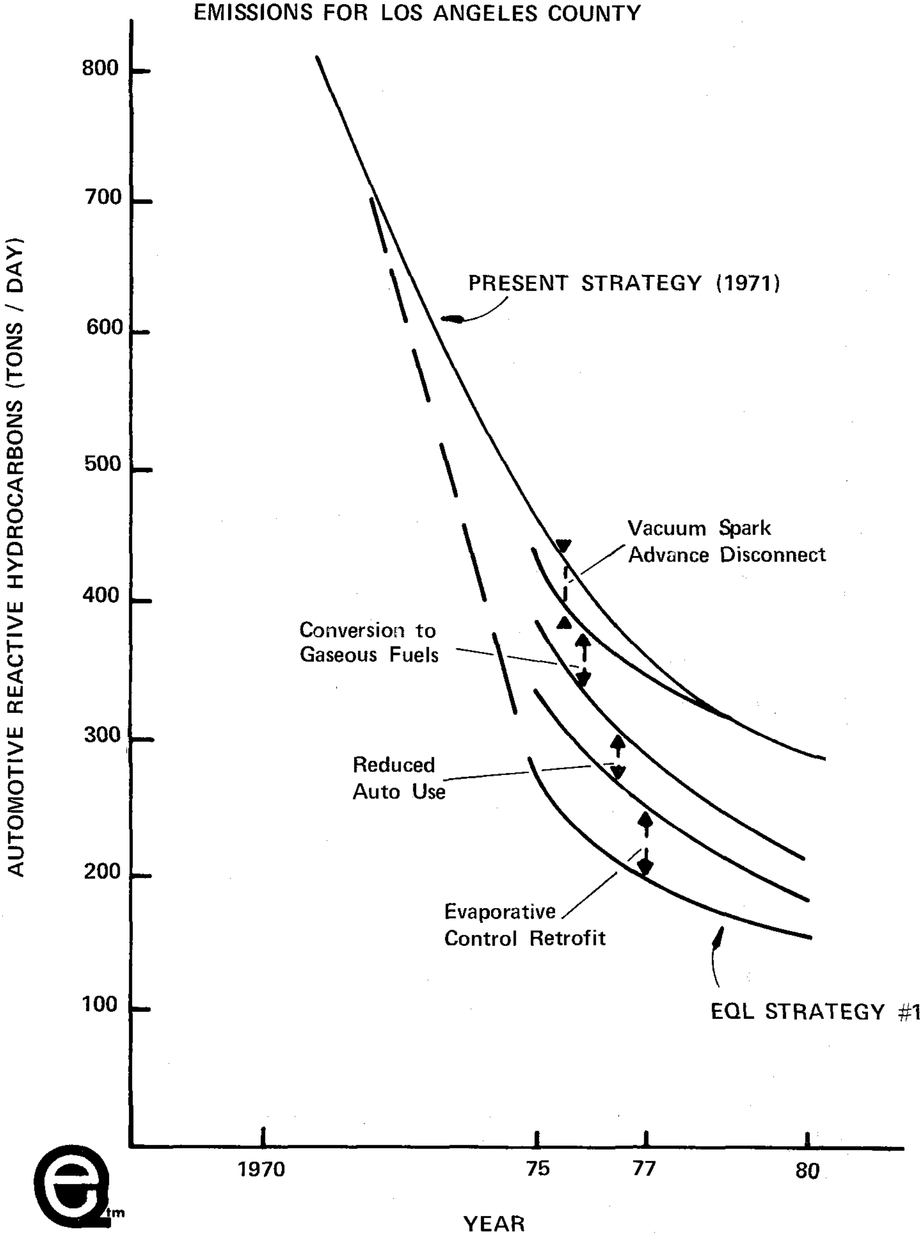


Figure 4

BREAKDOWN OF REDUCTIONS IN AUTOMOTIVE
OXIDES OF NITROGEN EMISSIONS FOR
LOS ANGELES COUNTY

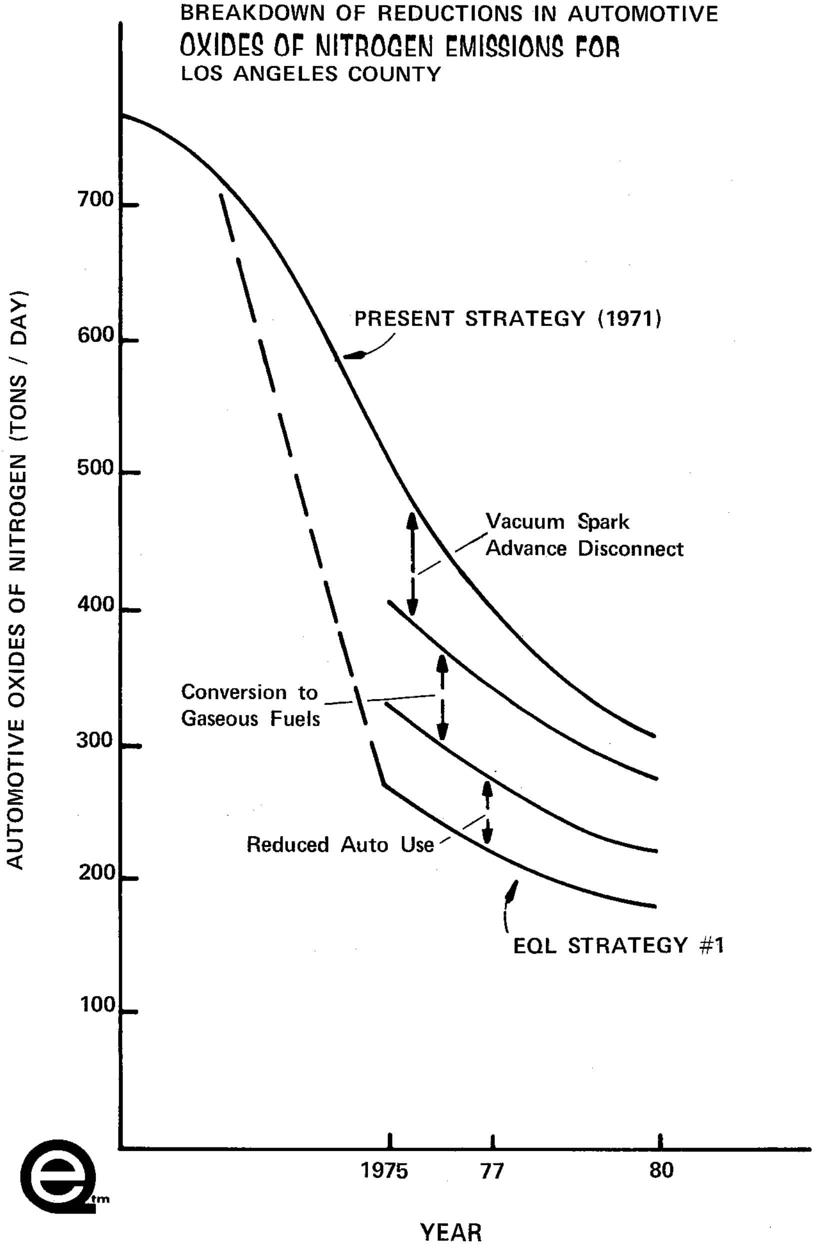


Figure 5

REDUCTION IN TOTAL REACTIVE HYDROCARBON EMISSIONS FOR LOS ANGELES COUNTY

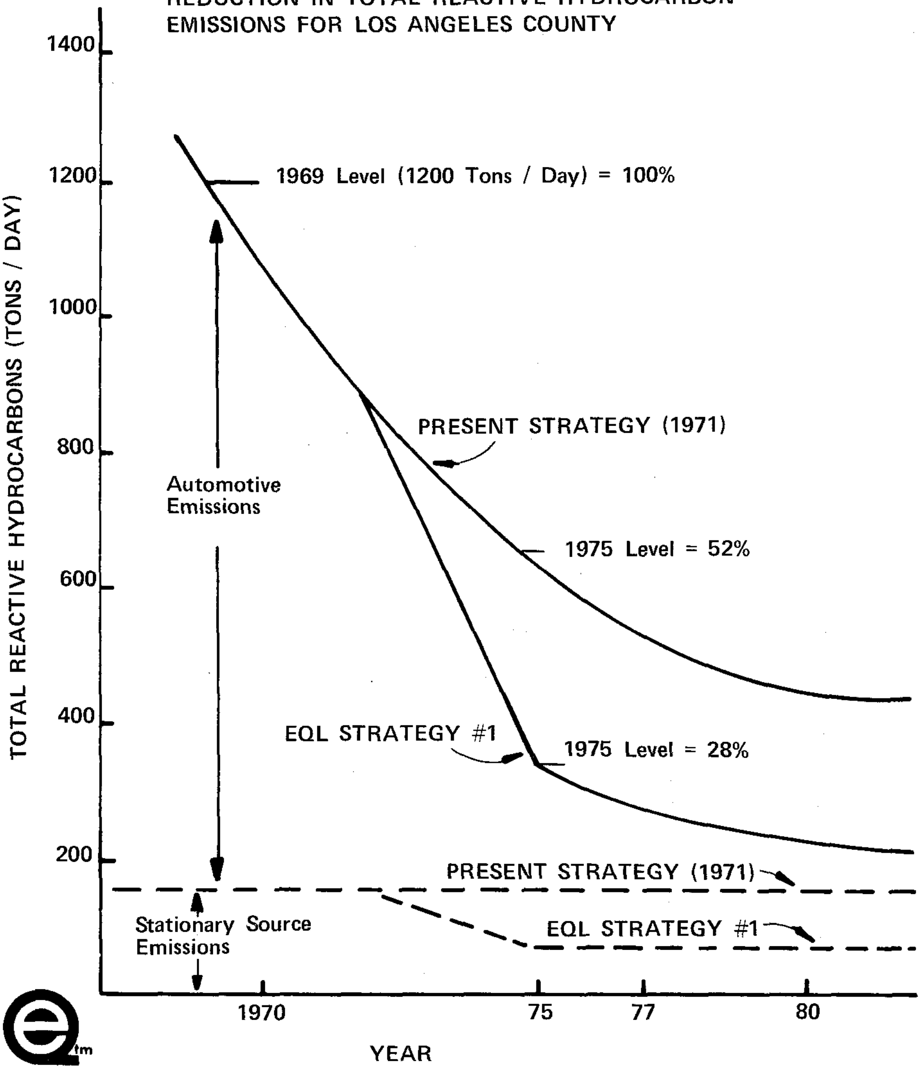


Figure 6

REDUCTION IN TOTAL OXIDES OF NITROGEN EMISSIONS FOR LOS ANGELES COUNTY

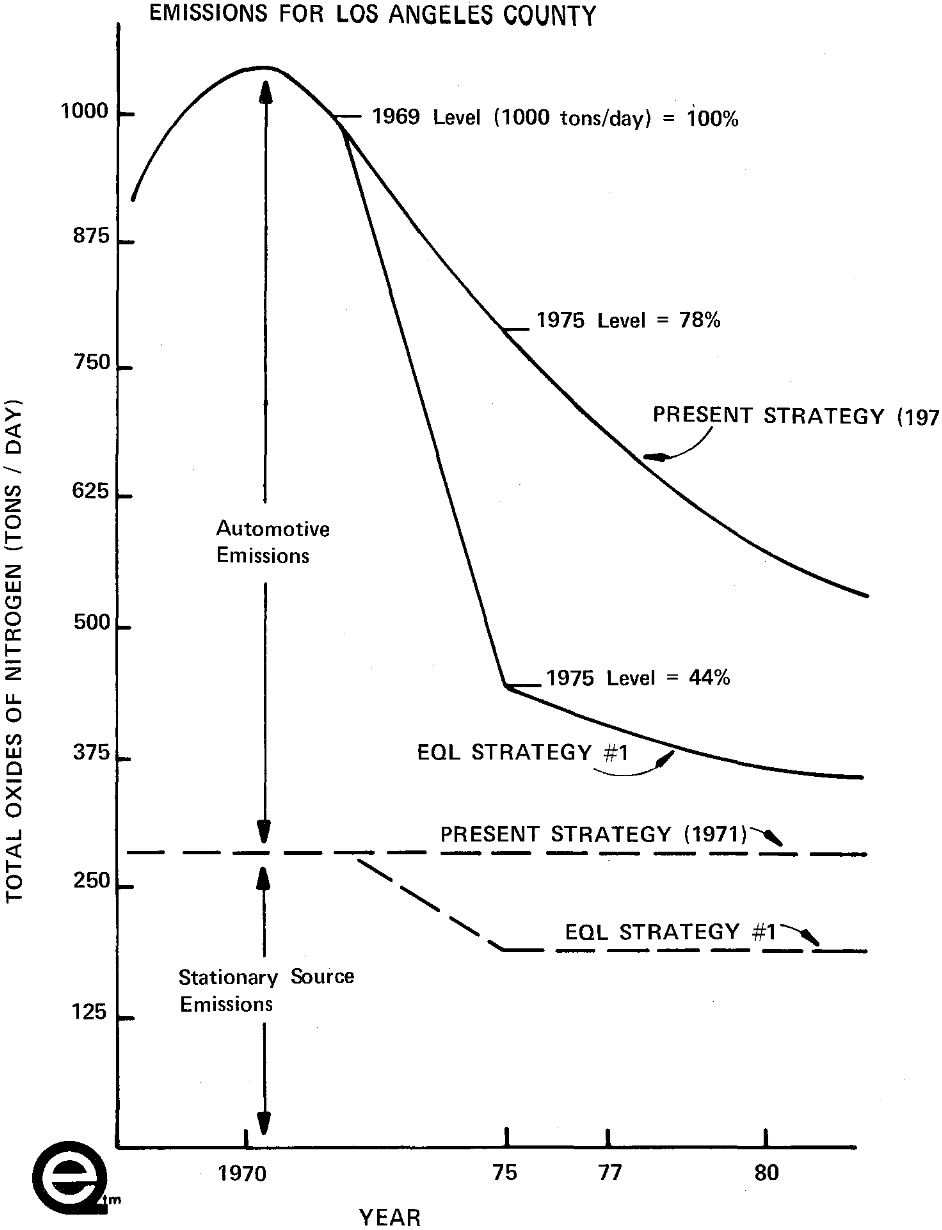


Figure 7

IMPROVEMENT IN OXIDANT AIR QUALITY
FOR THE SOUTH COAST AIR BASIN (0.10 PPM)

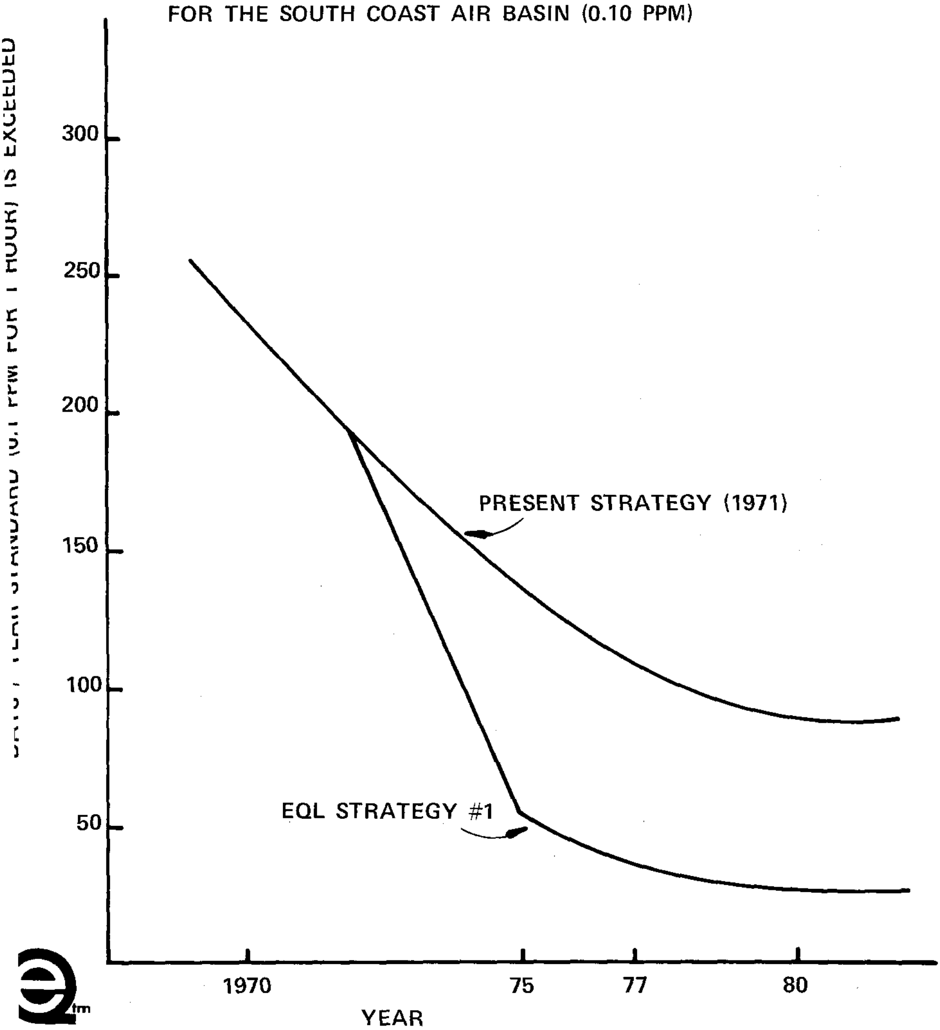


Figure 8

IMPROVEMENT IN NITROGEN DIOXIDE AIR QUALITY
FOR THE SOUTH COAST AIR BASIN

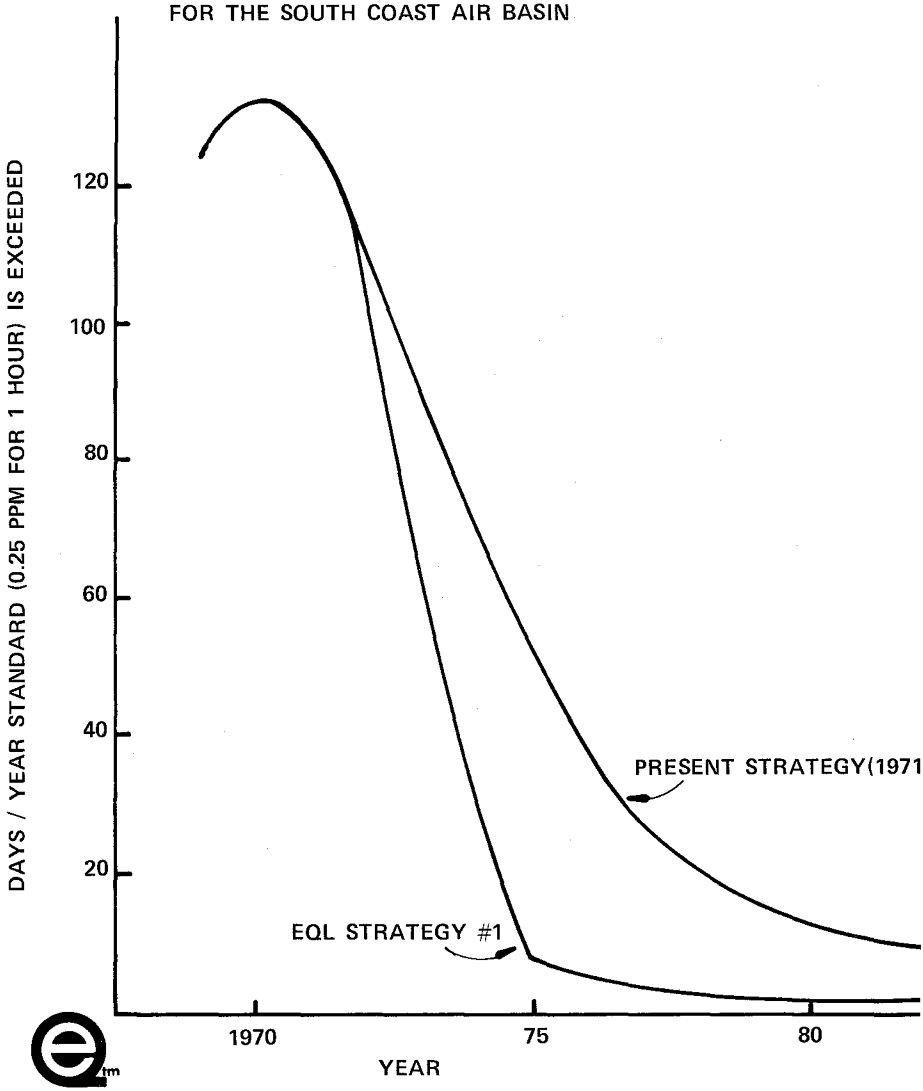


Figure 9

IMPROVEMENT IN OXIDANT AIR QUALITY FOR THE SOUTH COAST AIR BASIN (0.20 ppm)

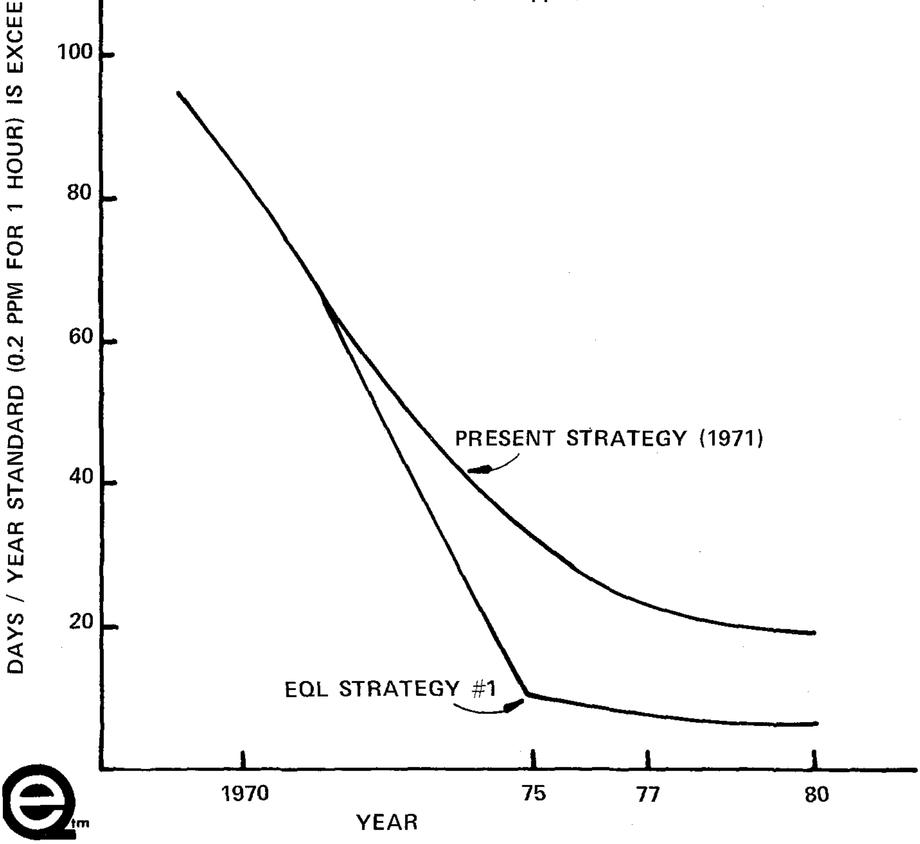


Figure 10

BREAKDOWN OF REDUCTIONS IN AUTOMOTIVE CARBON MONOXIDE EMISSIONS FOR LOS ANGELES COUNTY

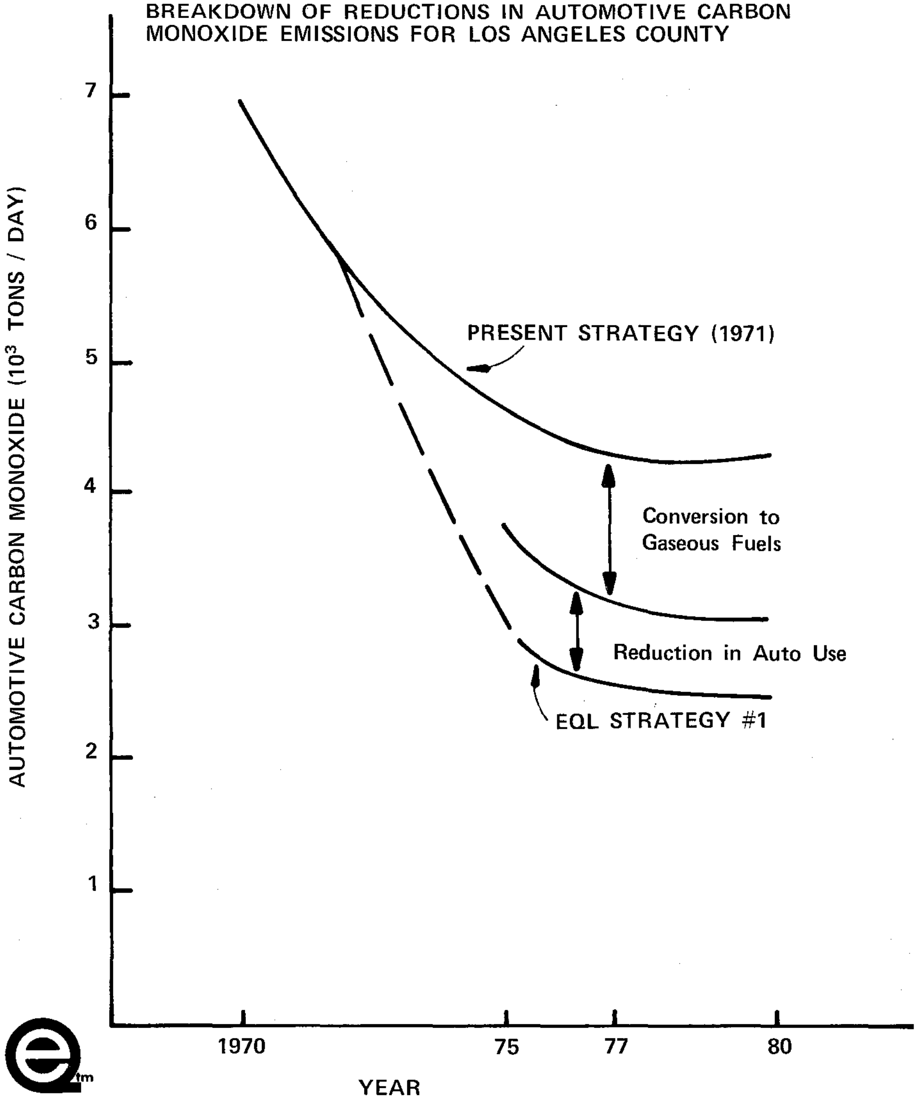


Figure 11

IMPROVEMENT IN CARBON MONOXIDE AIR QUALITY FOR LOS ANGELES COUNTY

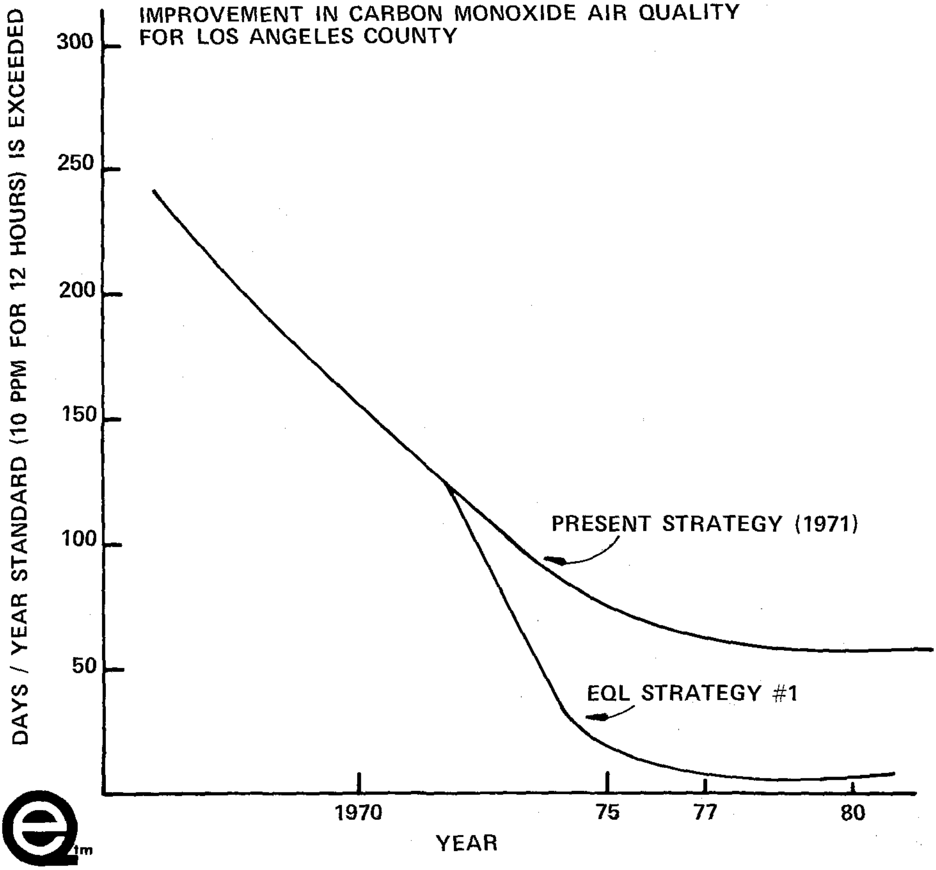


Figure 12

SUPPLY AND DEMAND OF NATURAL GAS IN AUGUST 1975 FOR SOUTHERN CALIFORNIA

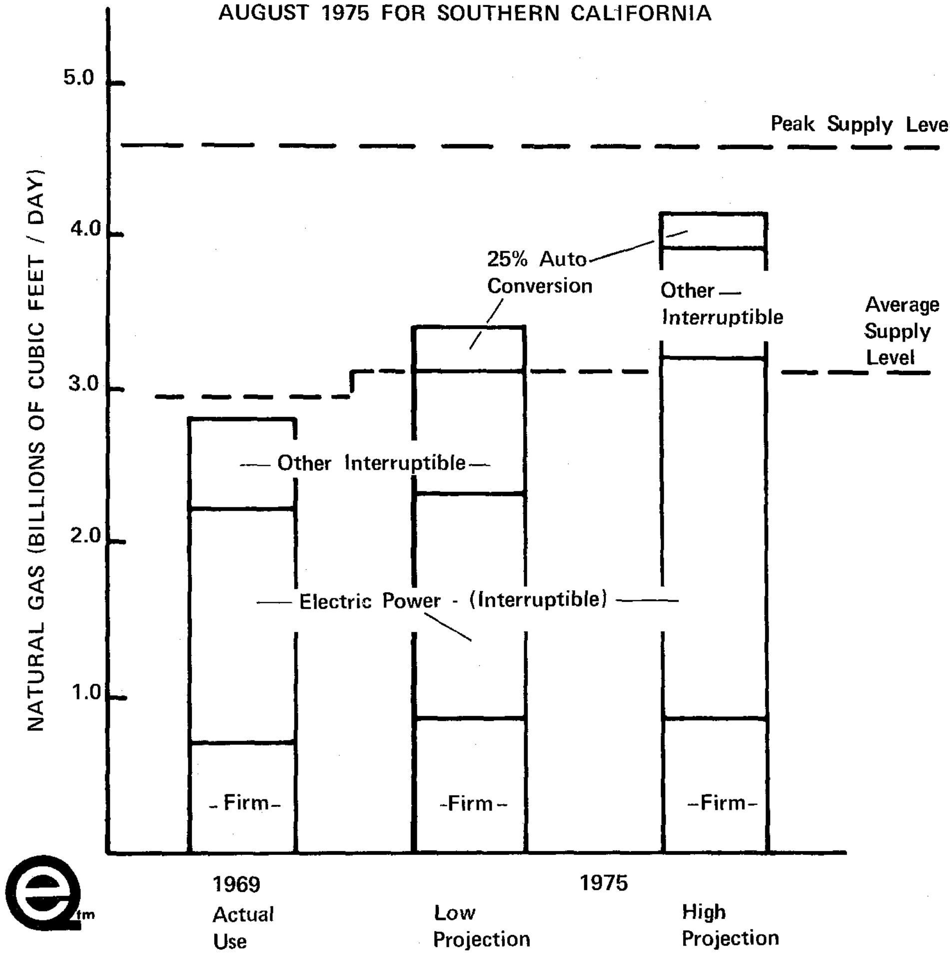


Figure 13

SUMMARY OF PROPANE SUPPLY AND DEMAND
ANNUAL AVERAGES FOR CALIFORNIA

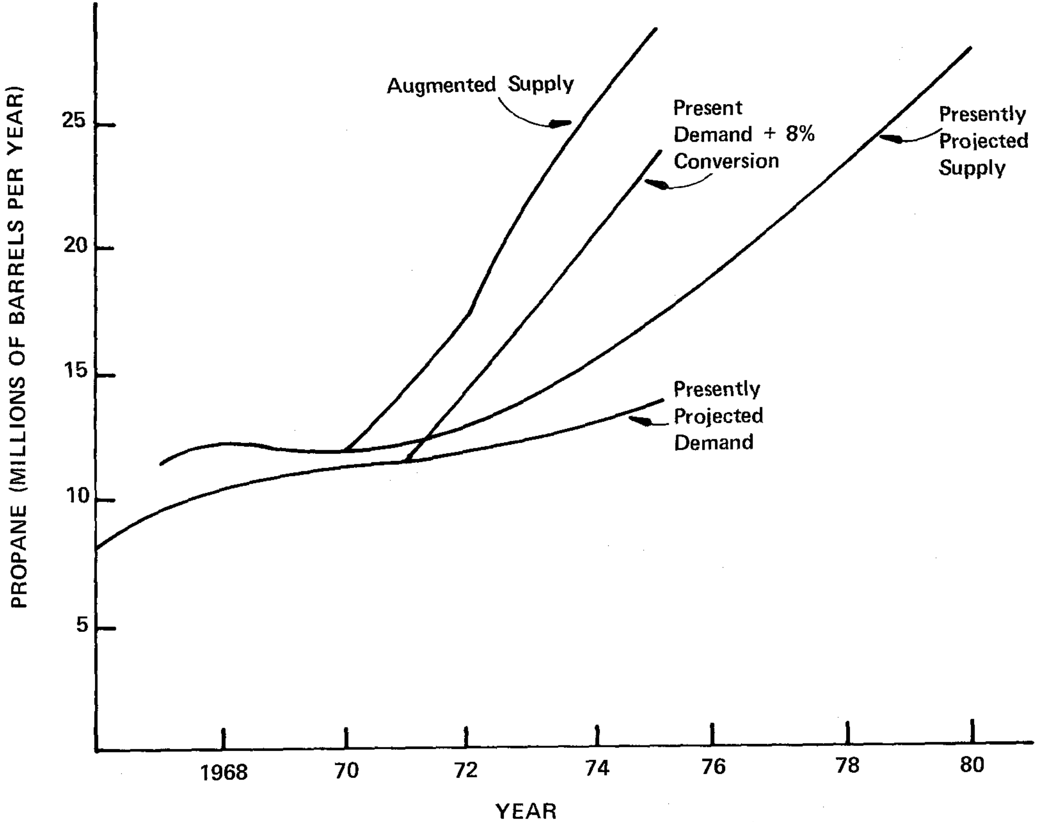


Figure 14

LONG RANGE PROJECTION OF OXIDANT
AIR QUALITY FOR THE SOUTH COAST AIR BASIN

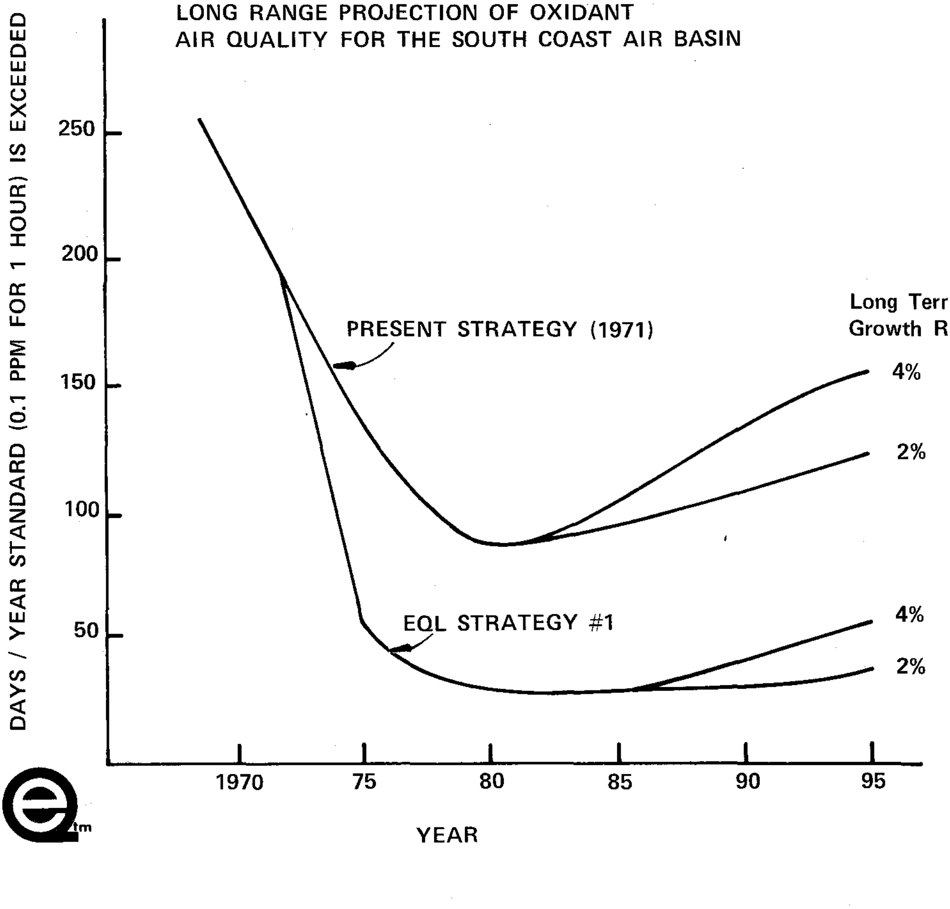


Figure 15

CARBON MONOXIDE AIR QUALITY VS. EMISSIONS
FOR DOWNTOWN LOS ANGELES

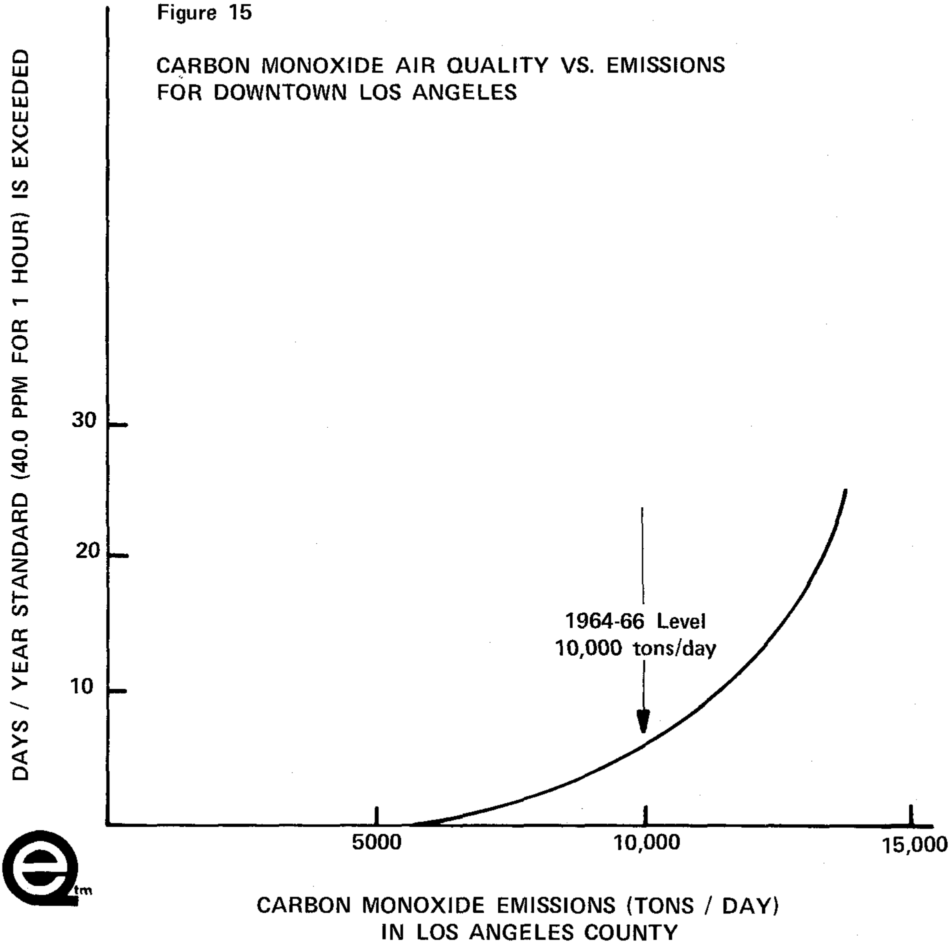
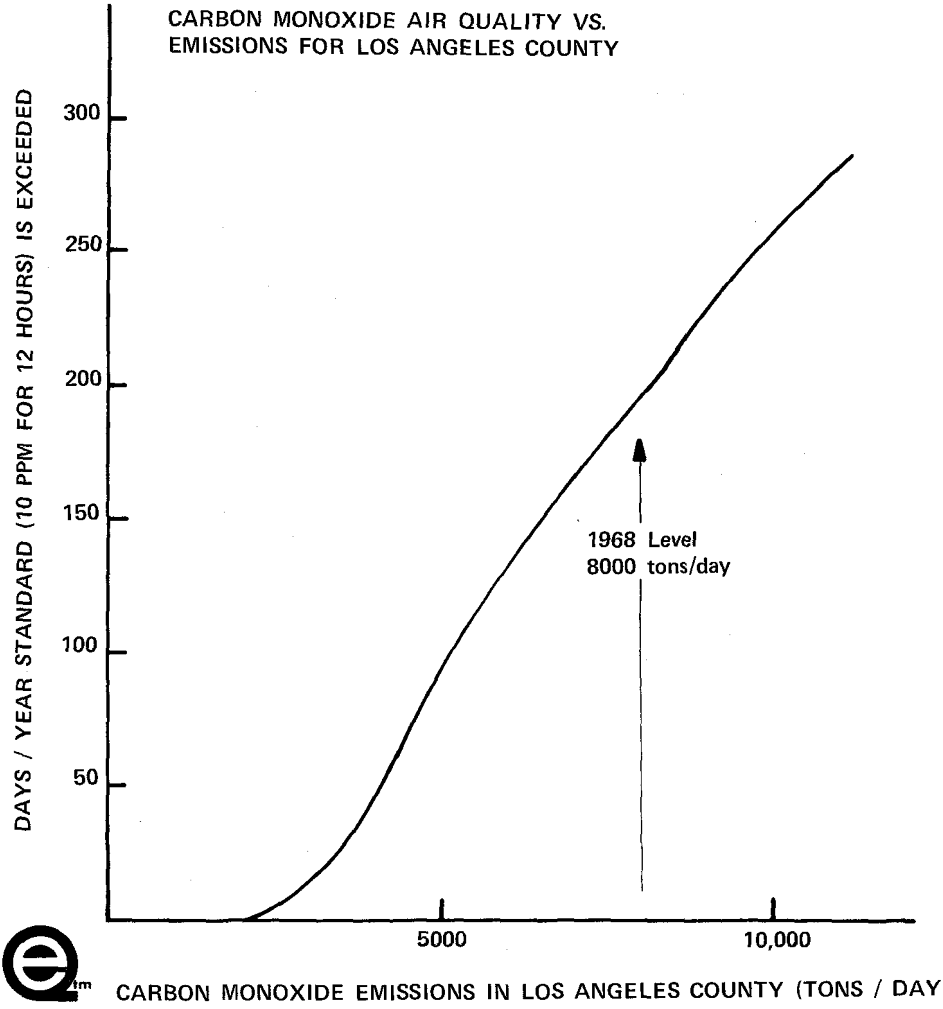


Figure 16


CARBON MONOXIDE AIR QUALITY VS.
EMISSIONS FOR LOS ANGELES COUNTY
DAYS / YEAR STANDARD (10 PPM FOR 12 HOURS) IS EXCEEDED
300
250
200
150
100
50
1968 Level
8000 tons/day
5000
10,000
CARBON MONOXIDE EMISSIONS IN LOS ANGELES COUNTY (TONS / DAY

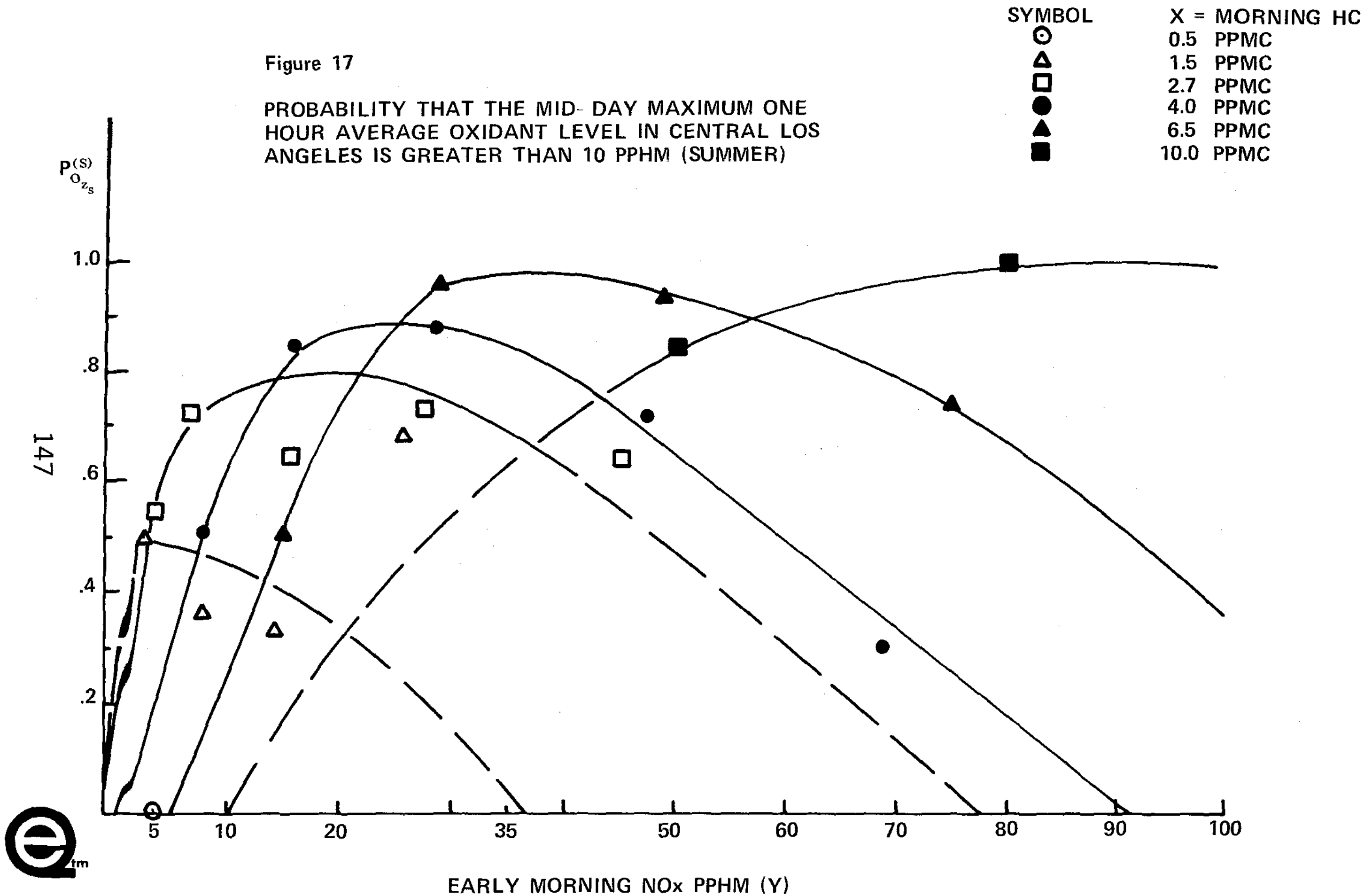
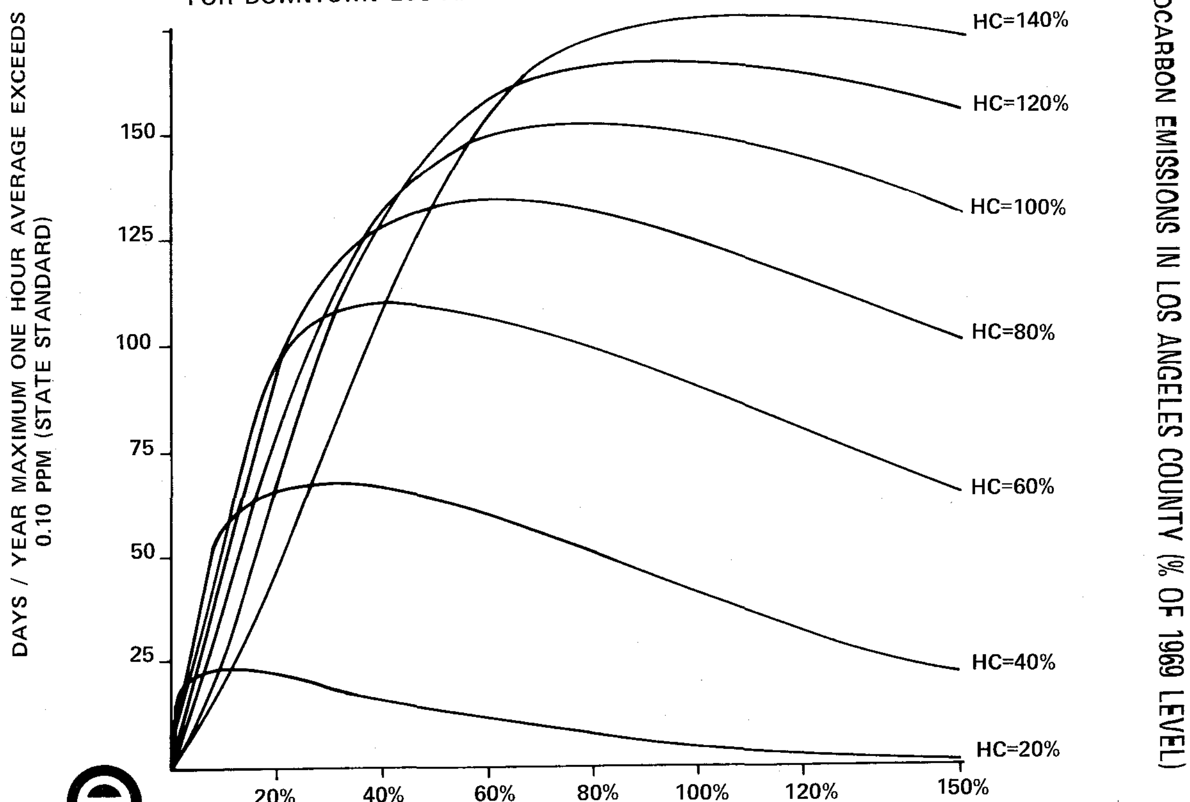


Figure 17

PROBABILITY THAT THE MID- DAY MAXIMUM ONE HOUR AVERAGE OXIDANT LEVEL IN CENTRAL LOS ANGELES IS GREATER THAN 10 PPHM (SUMMER)

Figure 18

OXIDANT AIR QUALITY VS. EMISSIONS
FOR DOWNTOWN LOS ANGELES (0.10 PPM)



OXIDES OF NITROGEN EMISSIONS IN LOS ANGELES COUNTY

Figure 19

OXIDANT AIR QUALITY VS. EMISSIONS
FOR DOWNTOWN LOS ANGELES (0.15 PPM)

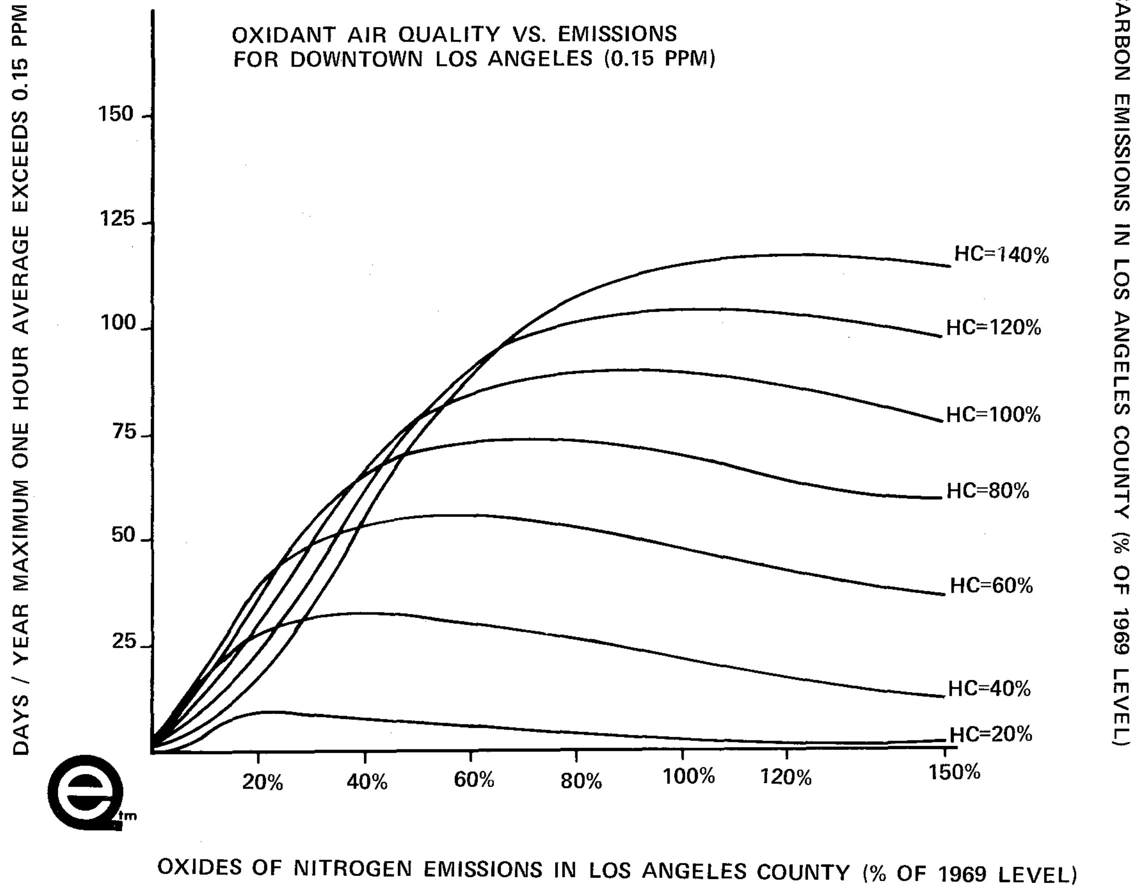
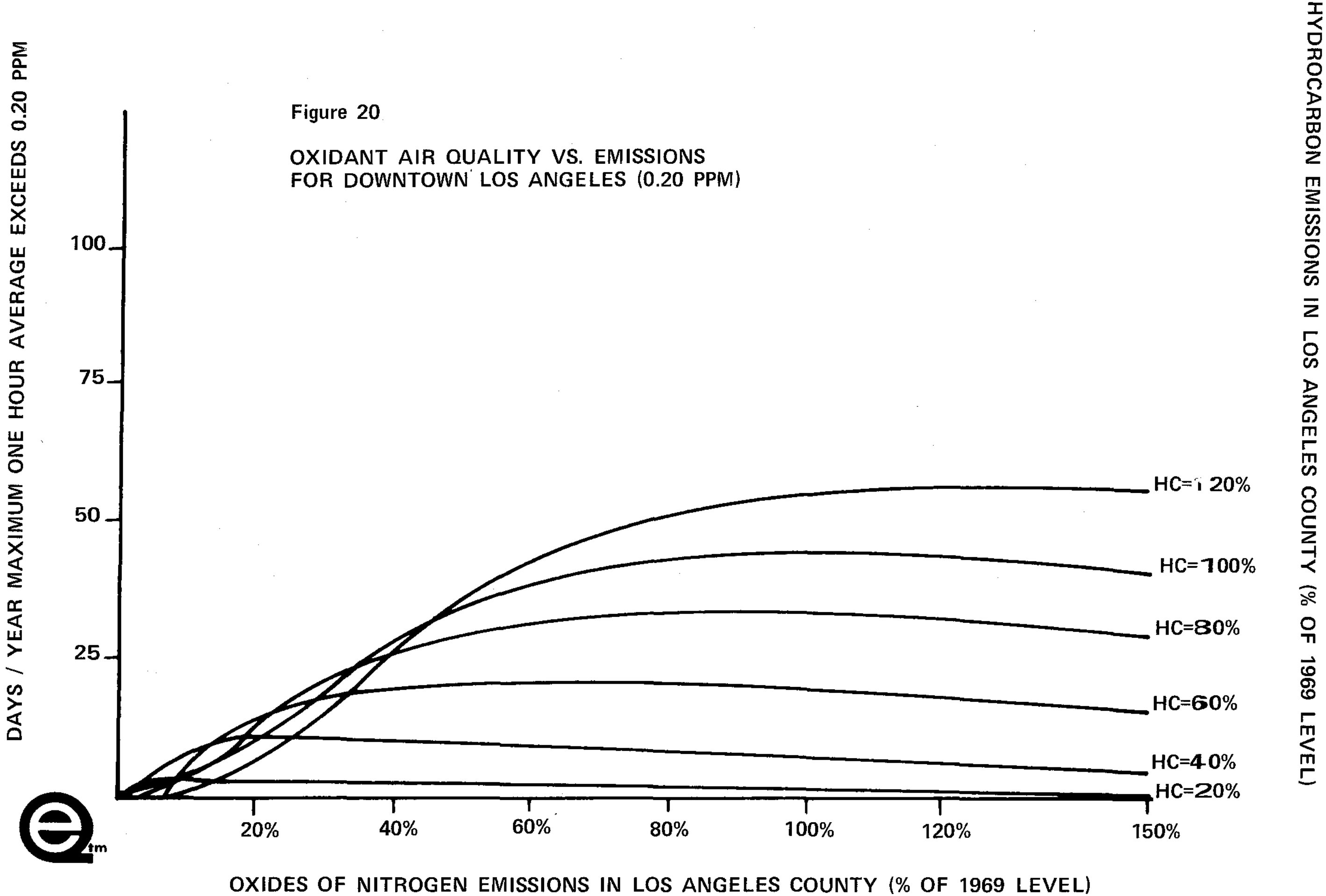


Figure 20

OXIDANT AIR QUALITY VS. EMISSIONS
FOR DOWNTOWN LOS ANGELES (0.20 PPM)



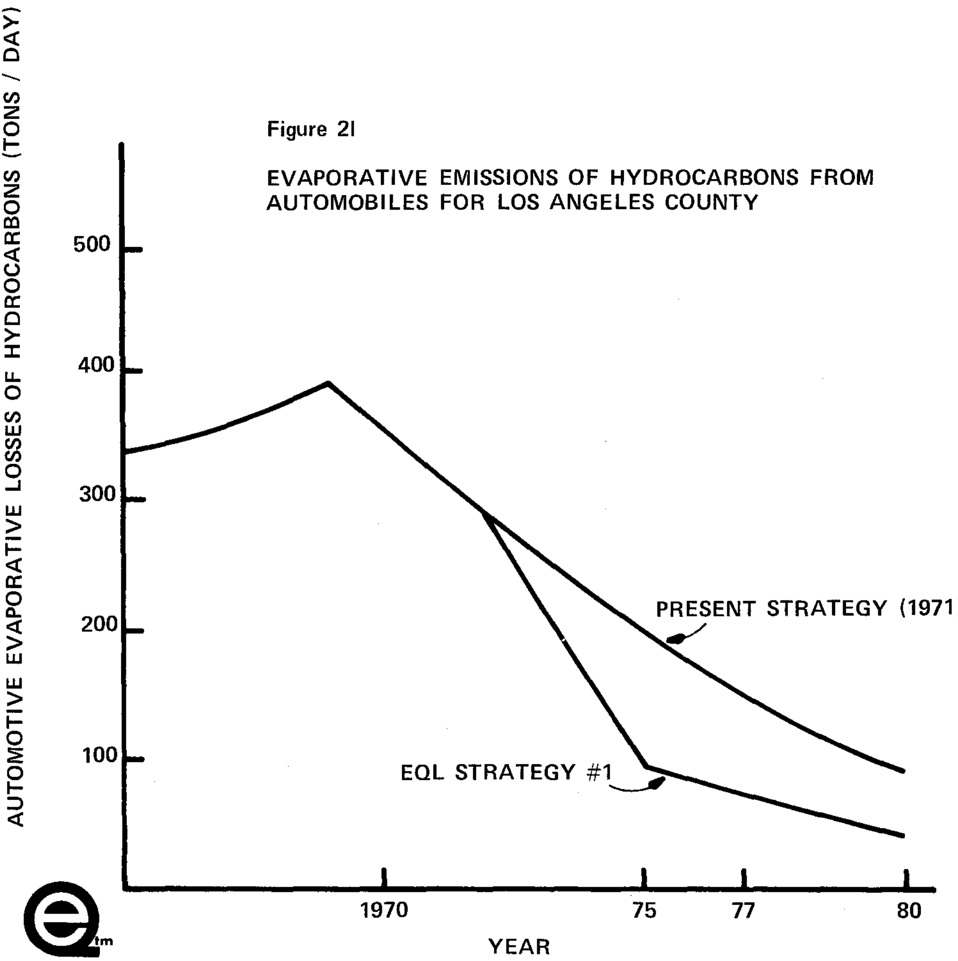


Figure 2l

EVAPORATIVE EMISSIONS OF HYDROCARBONS FROM AUTOMOBILES FOR LOS ANGELES COUNTY

Figure 22

BREAKDOWN OF IMPROVEMENT IN OXIDANT AIR QUALITY
FOR DOWNTOWN LOS ANGELES

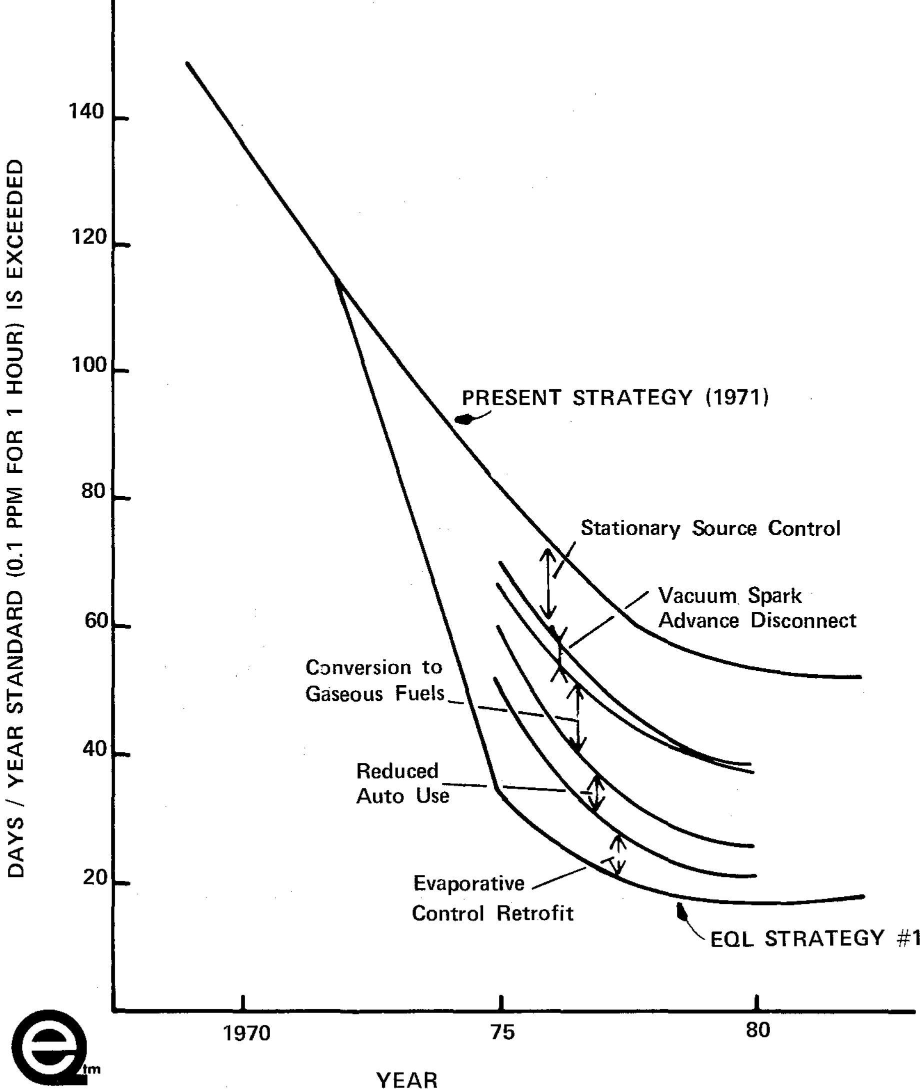


Figure 23

IMPROVEMENT IN OXIDANT AIR QUALITY FOR DOWNTOWN LOS ANGELES (0.15 ppm)

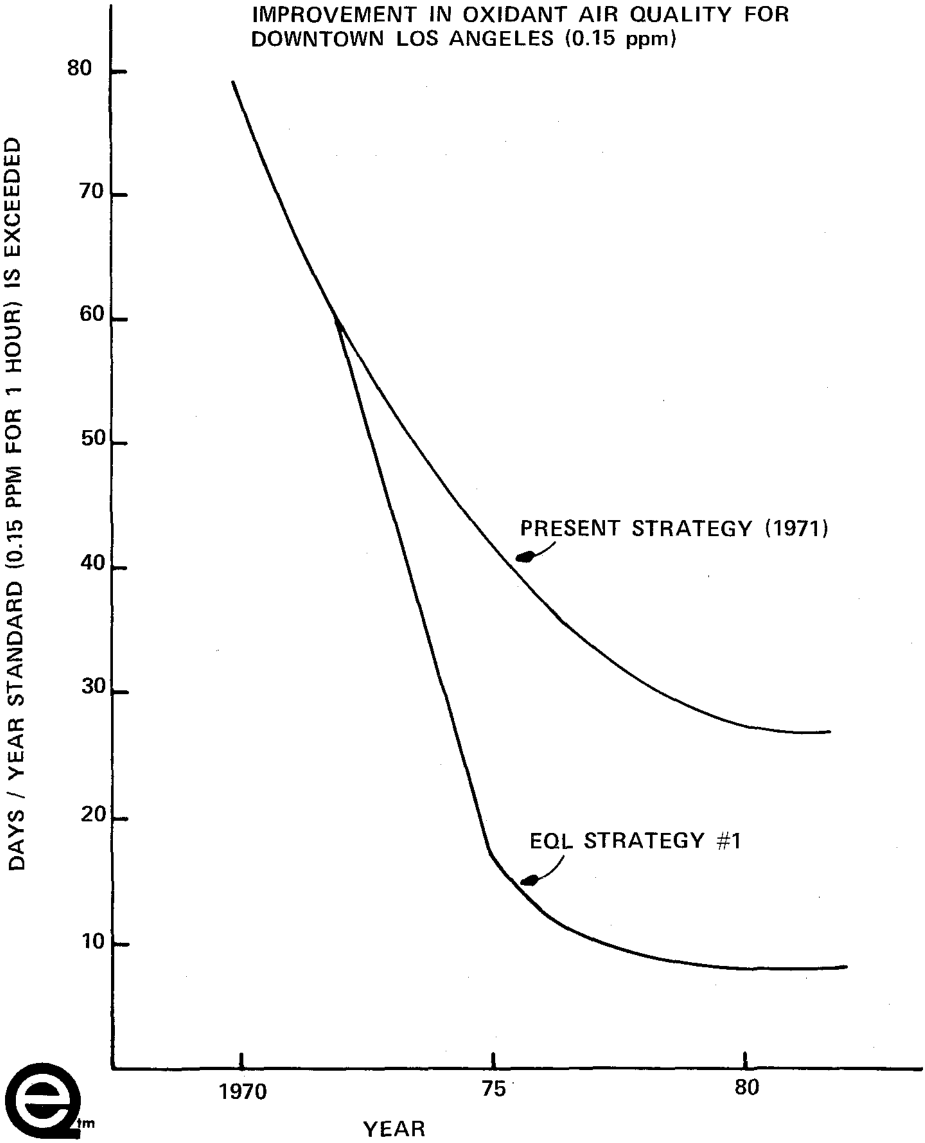


Figure 24

IMPROVEMENT IN OXIDANT AIR QUALITY FOR DOWNTOWN LOS ANGELES (0.20 ppm)

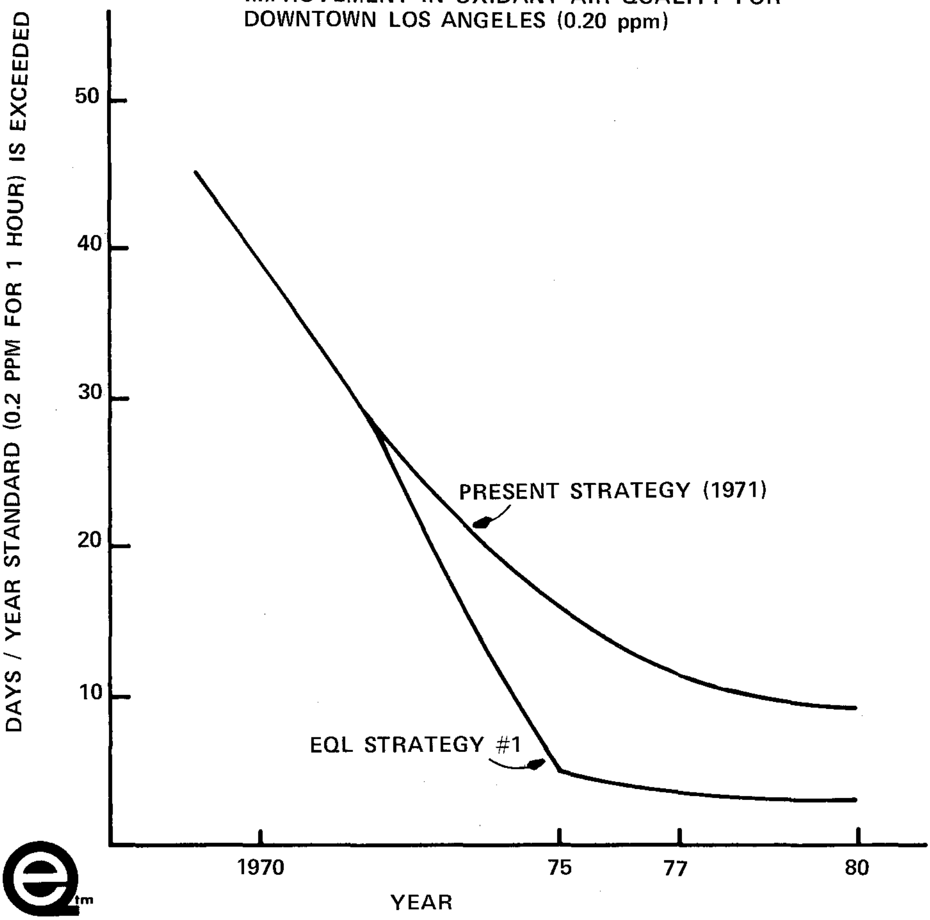


Figure 25

IMPROVEMENT IN NITROGEN DIOXIDE
AIR QUALITY FOR DOWNTOWN LOS ANGELES

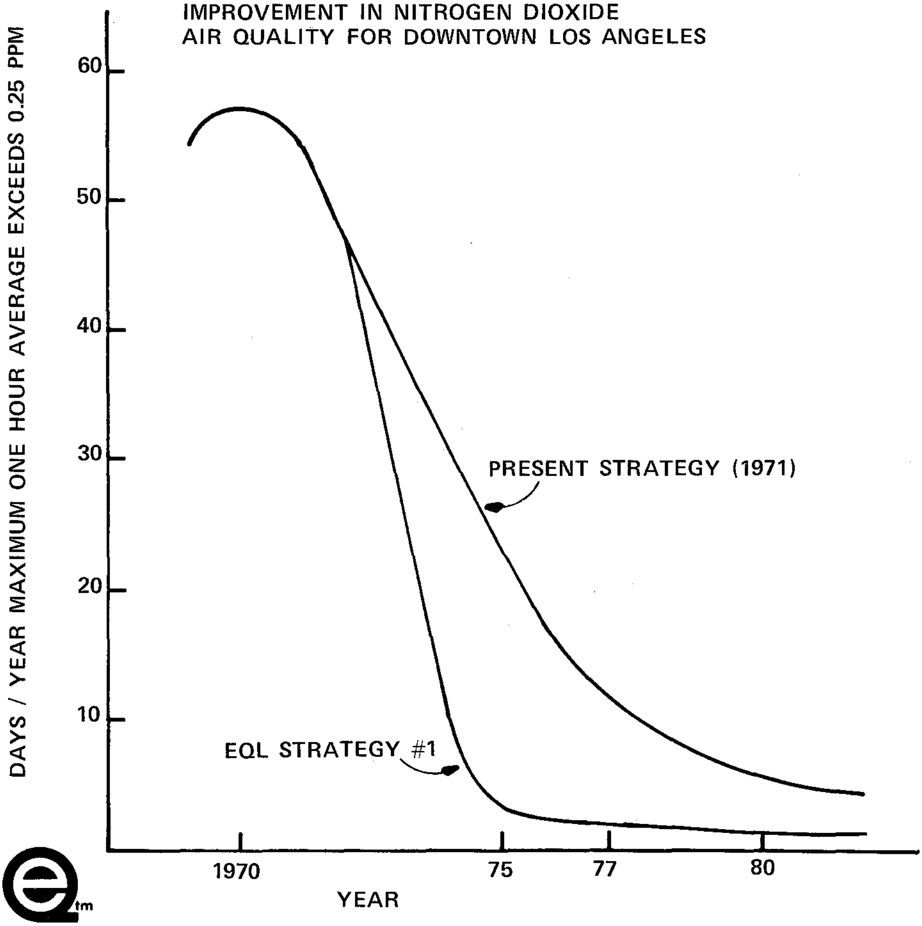


Figure 26

IMPROVEMENT IN OXIDANT AIR QUALITY FOR THE SOUTH COAST AIR BASIN (0.15 ppm)

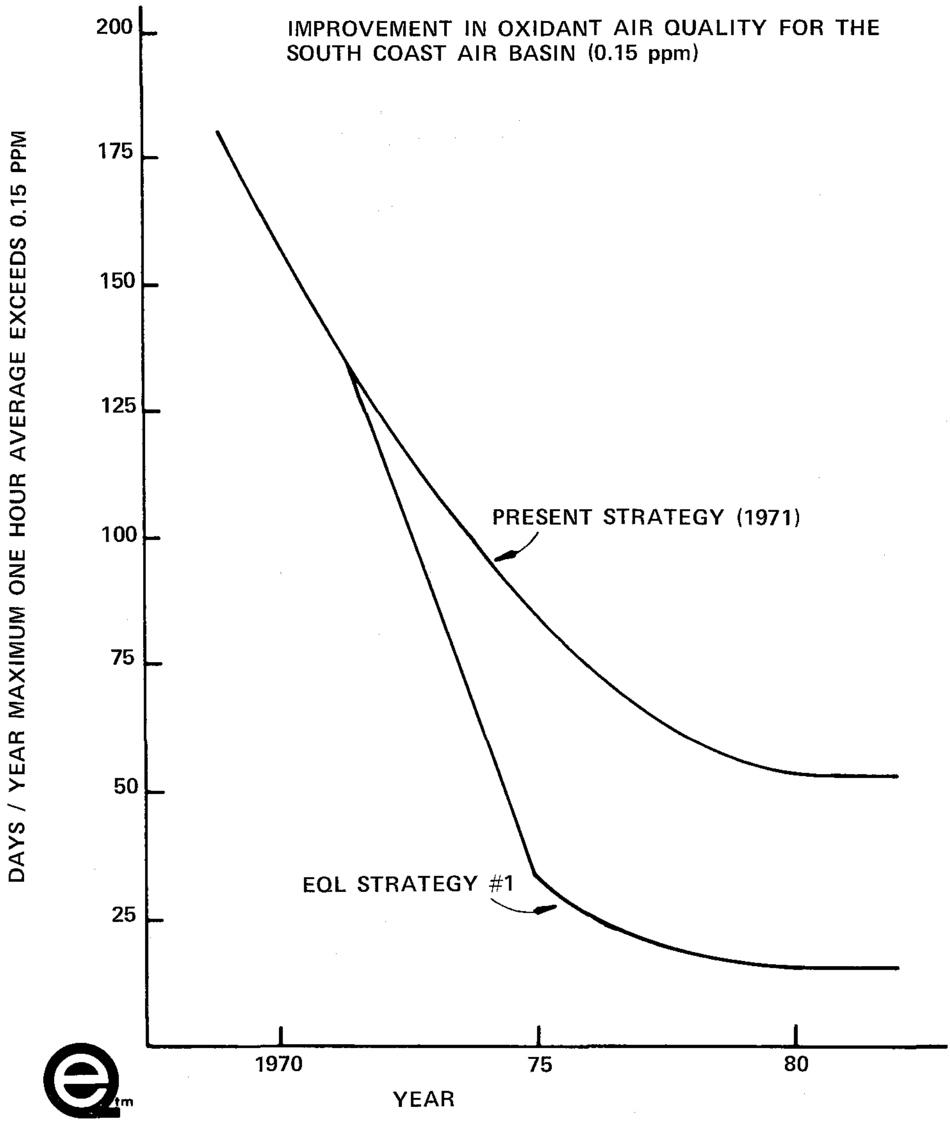


Figure 27

VARIOUS PROJECTIONS OF REDUCTIONS
IN AUTOMOTIVE REACTIVE HYDROCARBON
EMISSIONS FOR LOS ANGELES COUNTY

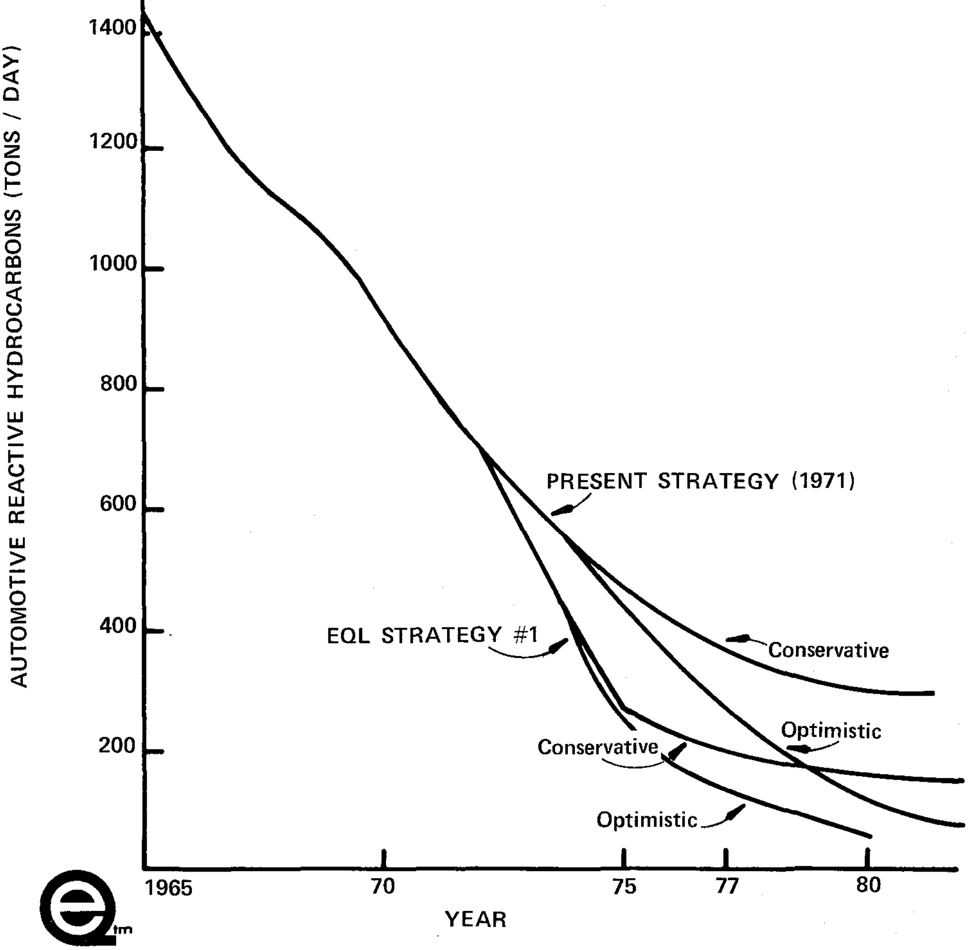


Figure 28

VARIOUS PROJECTIONS OF REDUCTIONS IN AUTOMOTIVE OXIDES OF NITROGEN EMISSIONS FOR LOS ANGELES COUNTY

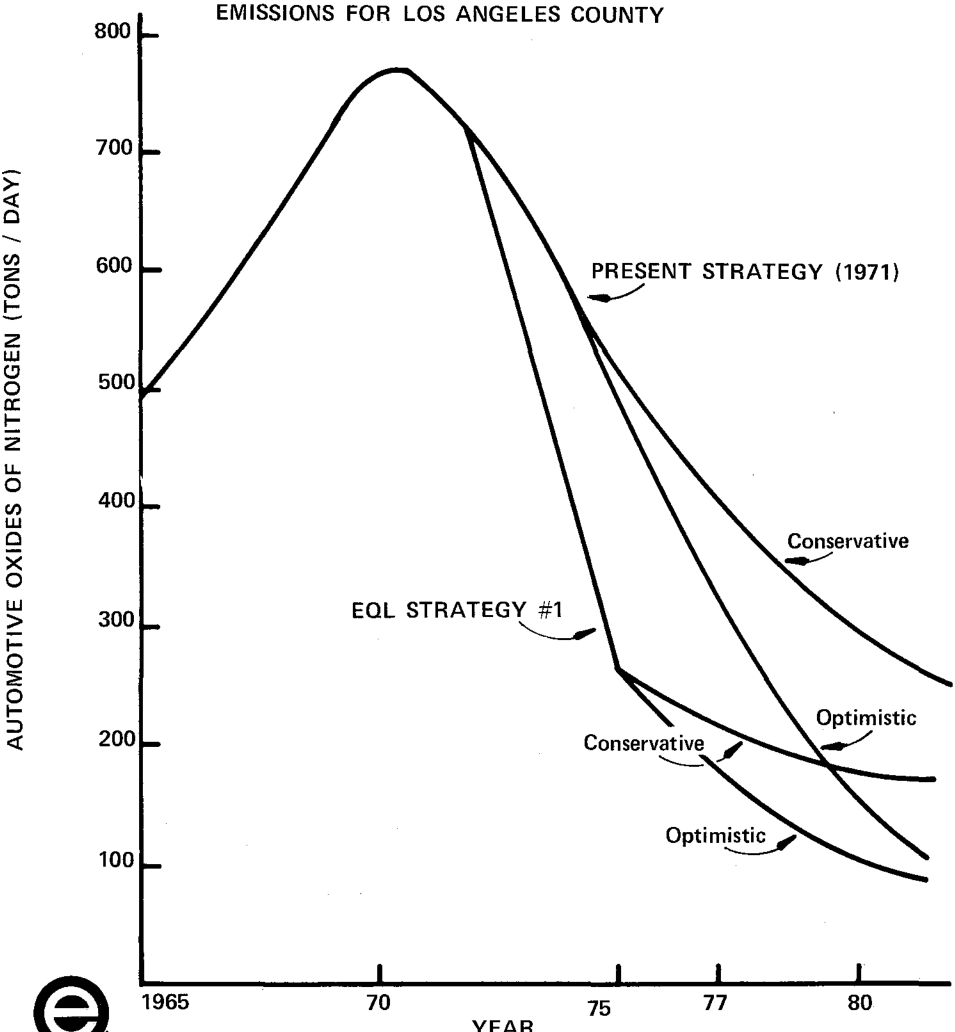


Figure 29

VARIOUS PROJECTIONS OF REDUCTIONS IN AUTOMOTIVE CARBON MONOXIDE EMISSIONS FOR LOS ANGELES COUNTY

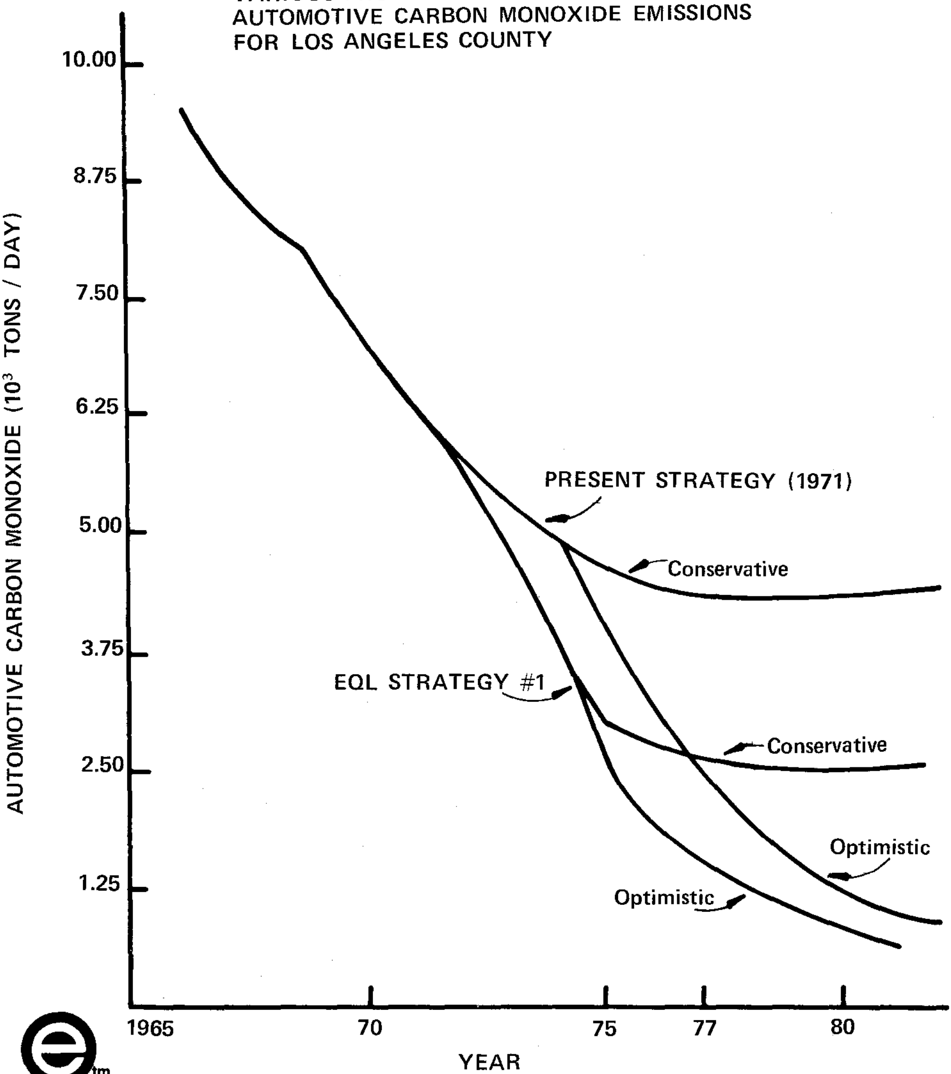


Figure 30

VARIOUS PROJECTIONS FOR IMPROVEMENT IN OXIDANT AIR QUALITY FOR THE SOUTH COAST AIR BASIN

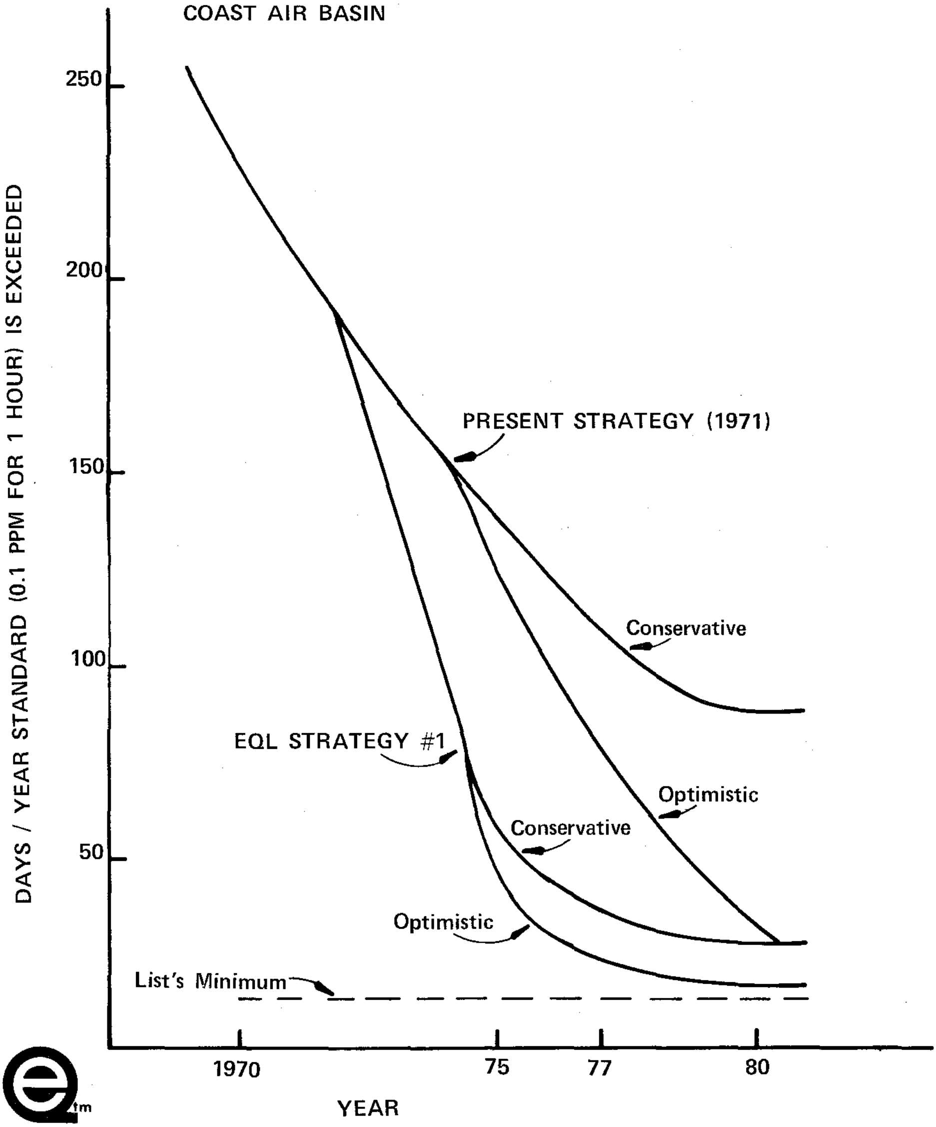


Figure 31

1969 SEASONAL VARIATION IN NATURAL GAS DEMAND FOR THE SOUTH COAST AIR BASIN

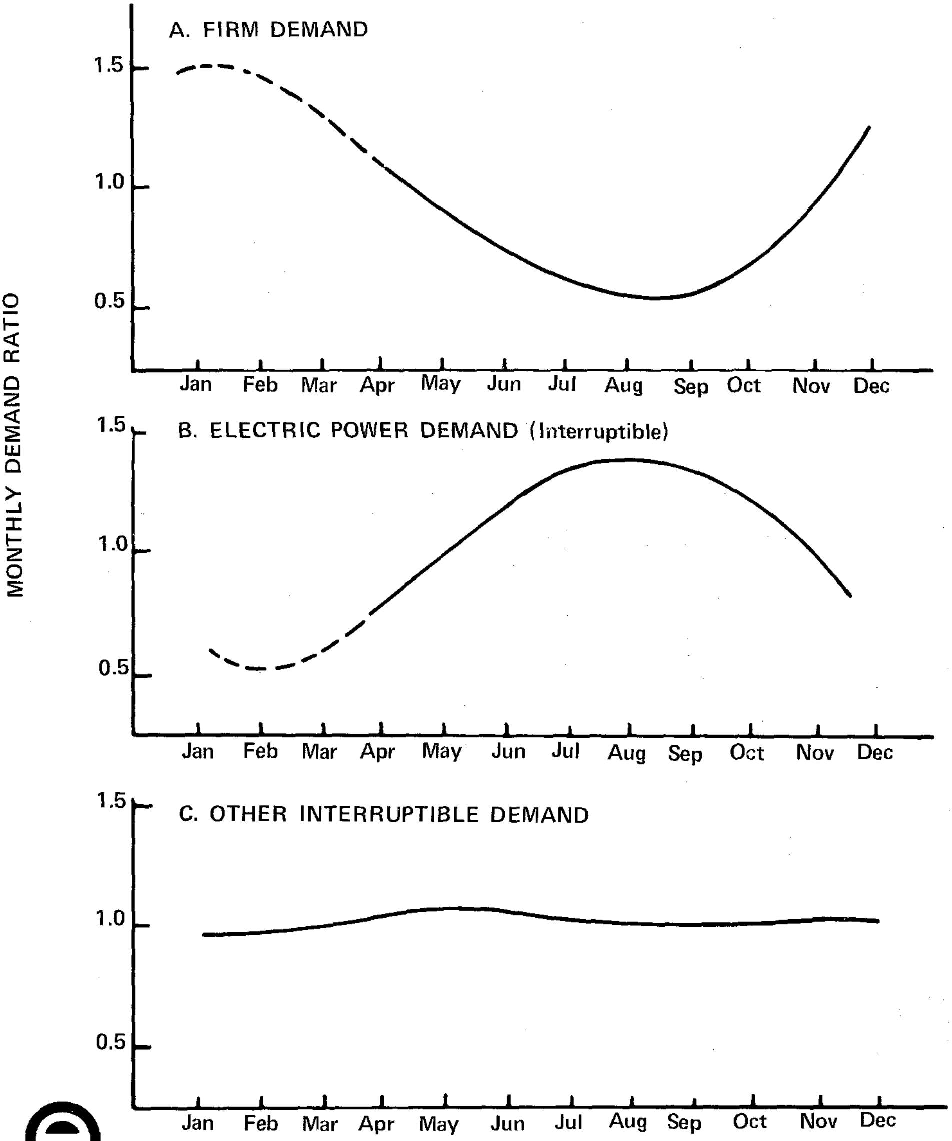
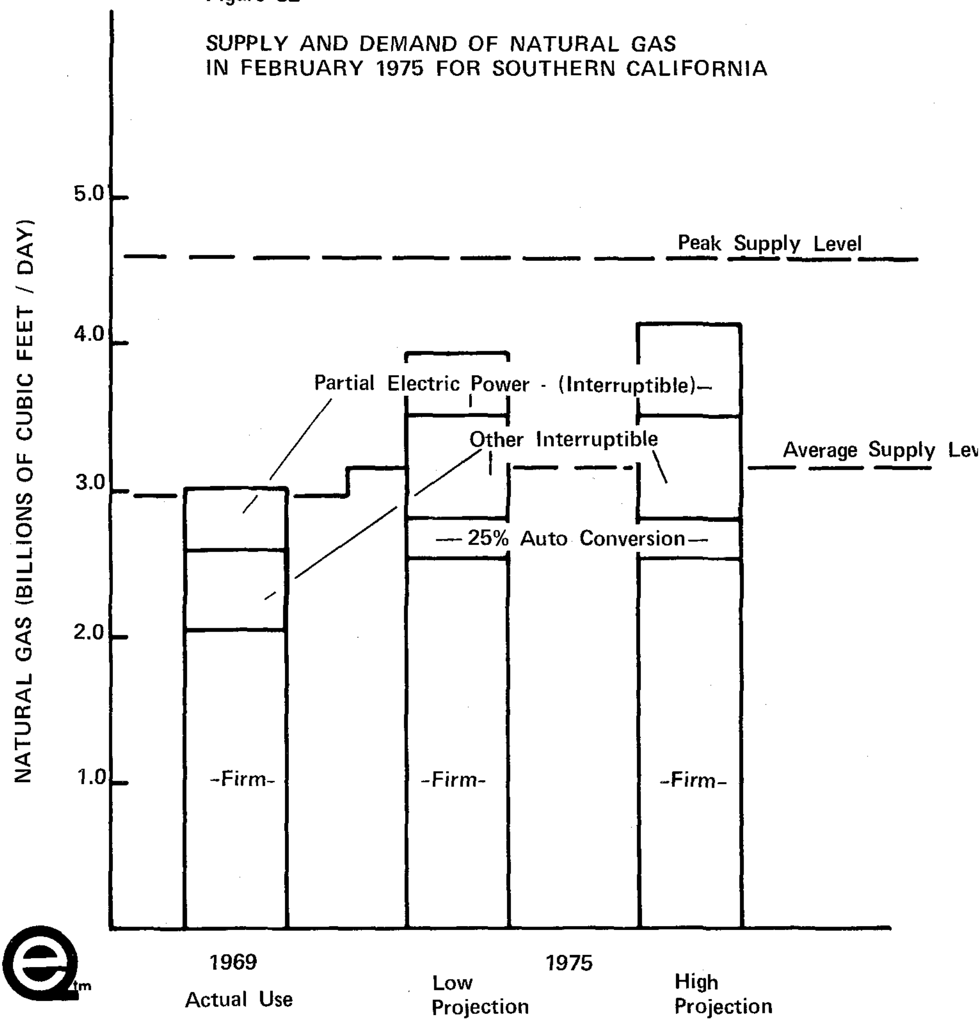


Figure 32

SUPPLY AND DEMAND OF NATURAL GAS
IN FEBRUARY 1975 FOR SOUTHERN CALIFORNIA



TYPICAL VACUUM SPARK ADVANCE
DISCONNECT INSTALLATION

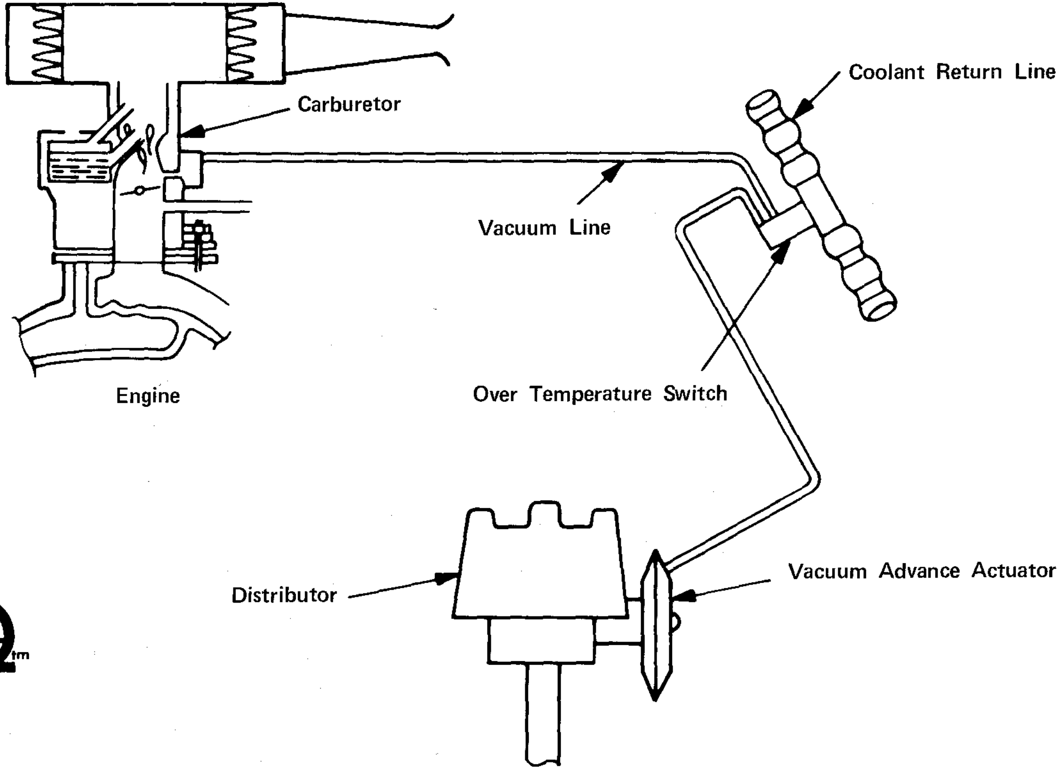
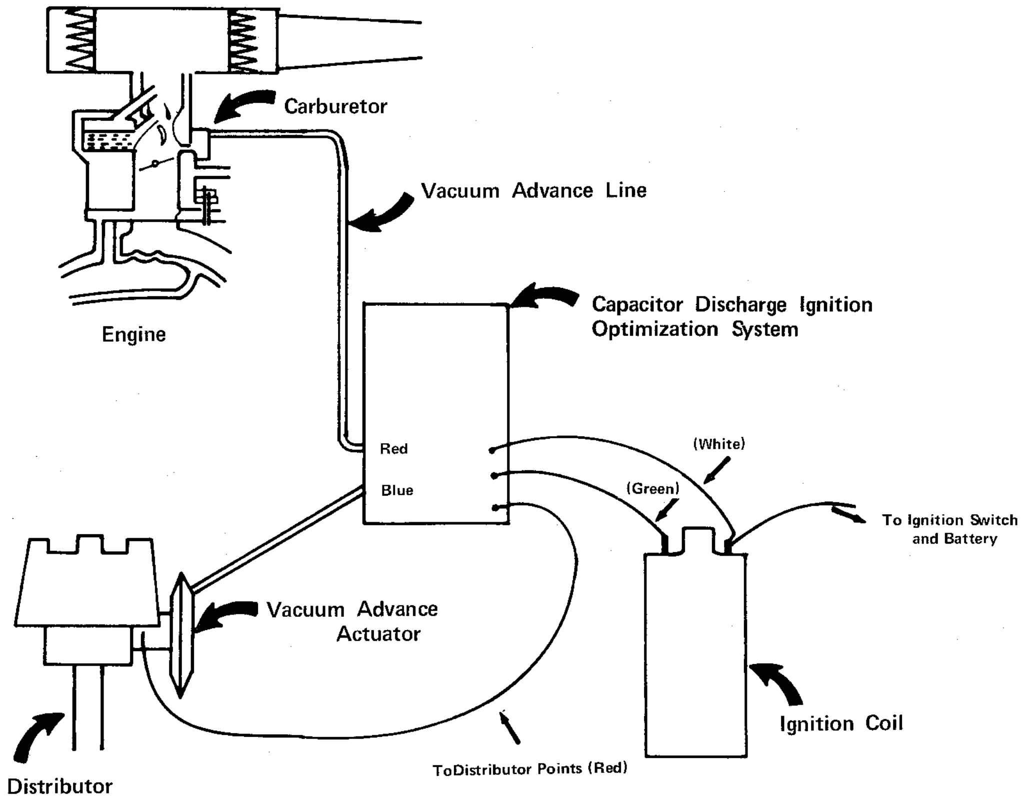


Figure 34

TYPICAL CAPACITOR DISCHARGE IGNITION
OPTIMIZATION SYSTEM INSTALLATION



TYPICAL EVAPORATIVE EMISSIONS CONTROL SYSTEM

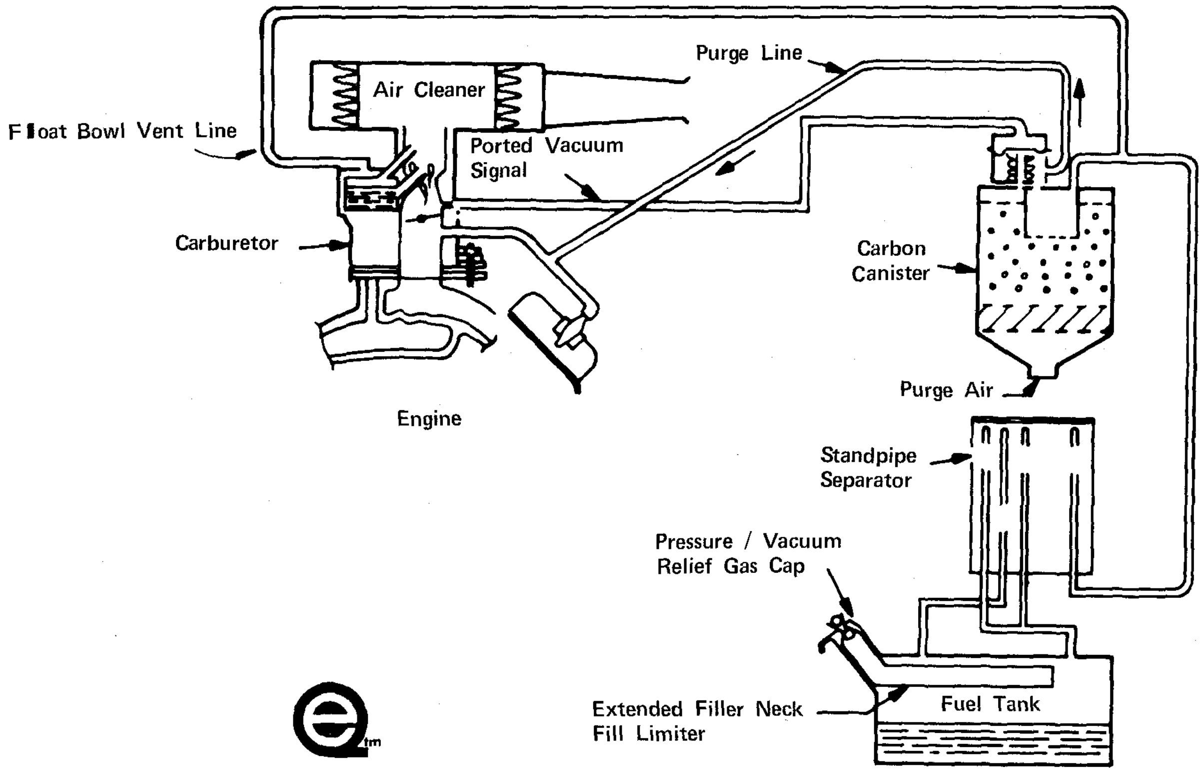
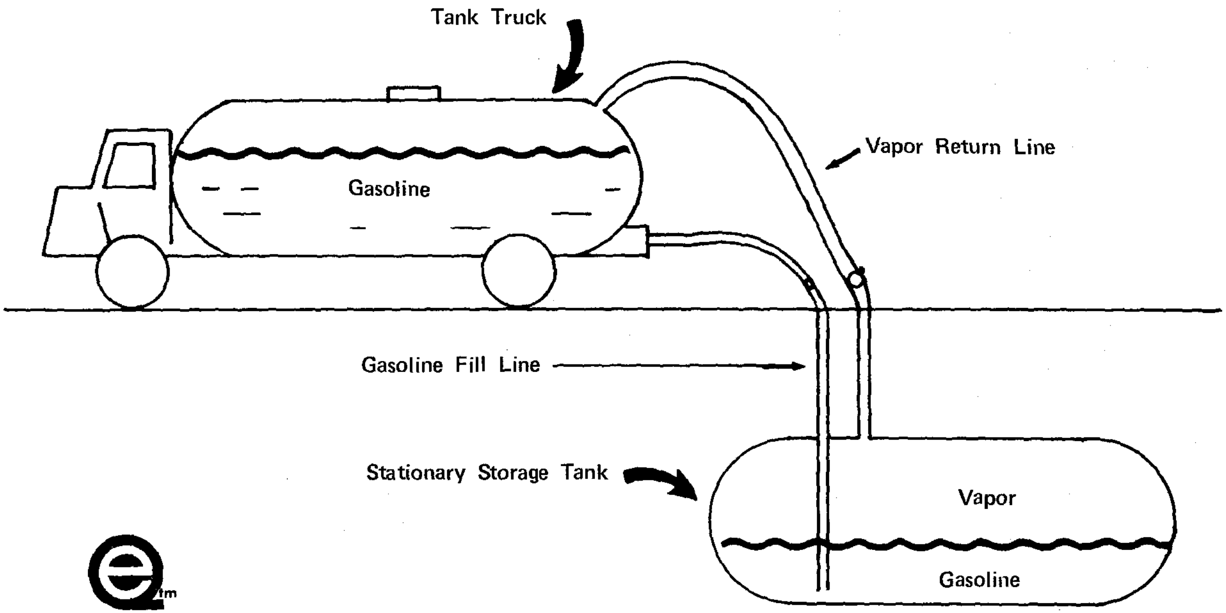
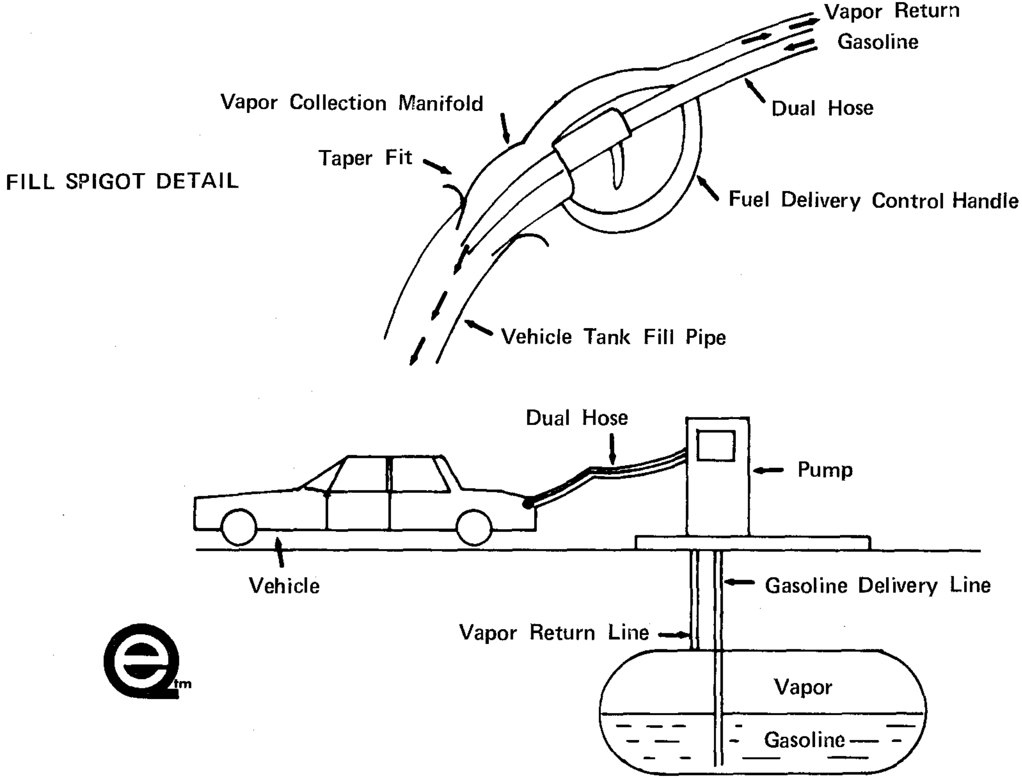


Figure 36

VAPOR RETURN SYSTEM FOR STATION FILLING



VAPOR RETURN SYSTEM
FOR VEHICLE FILLING



ABOUT THE AUTHORS

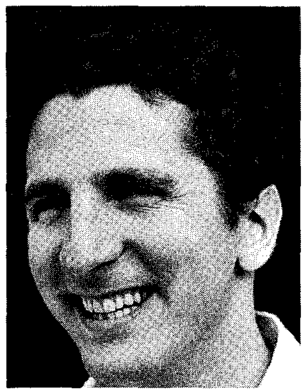
LESTER LEES, director of the Environmental Quality Laboratory, is professor of aeronautics and environmental engineering at Caltech. He is the author of numerous papers on problems of high speed flight, especially entry of missiles and spacecraft into planetary atmospheres. He has also worked on the identification of such objects by means of their wake signatures. He is a consultant to the aerospace industry and to several government agencies. In the last two years his main interests have shifted to large-scale environmental problems. He is a member of the National Academy of Engineering.

MARK BRALY is administrative assistant to the director of the Environmental Quality Laboratory. He has an M.A. degree in political science and another in public policy and administration from the University of Wisconsin, Madison, where he was a Ford Foundation fellow in 1968-70. Following a tour of news reporting in Houston, he served as Assistant U.S. press attache in Bangkok and director of two United States Information Service branch posts in South Thailand.

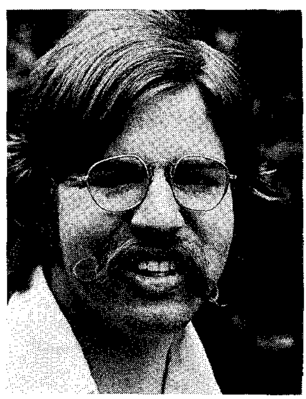
MAHLON EASTERLING is a senior member of the technical staff at the Caltech Jet Propulsion Laboratory. His work has been in telecommunications, developing ranging systems, planetary radar and telemetry systems. He has published a number of papers in his field; is the co-author of one book and contributor to two others; and holds four United States patents. At present he is on leave from the JPL to serve as senior staff member with the Environmental Quality Laboratory, where he co-authored the first EQL Report, *People, Power, Pollution.*

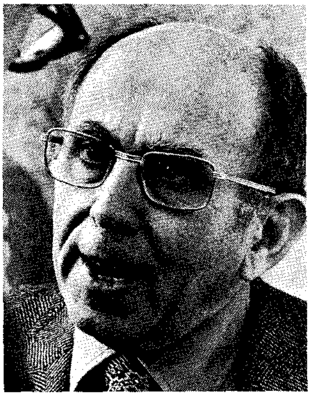
ROBERT FISHER is a graduate of the University of California, Los Angeles, Law School where he served as senior editor of the UCLA *Alaska Law Review.* He served as research assistant at the Environmental Quality Laboratory.

DR. KENNETH HEITNER trained as a naval architect and marine engineer at the Webb Institute of Naval Architecture, graduating in 1964. He received a Ph.D. degree in applied mechanics from Caltech in 1969 and then joined the Institute Earthquake Engineering Laboratory until 1970 when he entered the Department of the Navy for a year of underwater research. Dr. Heitner joined the Environmental Quality Laboratory in early 1971 where he is involved in evaluating air pollution control techniques and in studies relating to the energy crisis in California.

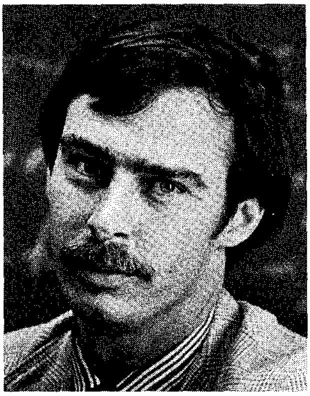


JAMES HENRY began working on automotive emission control technology in 1970 as an undergraduate participant in the cross-country Clean Air Car Race jointly sponsored by MIT and Caltech. Drawing on a background that includes both formal engineering training at Caltech and practical auto mechanics in high school, he has been able to bring theory and hardware together in his work as a full-time staff member of the EQL-sponsored Clean Air Car Project. The project tests and evaluates automotive emission control techniques.





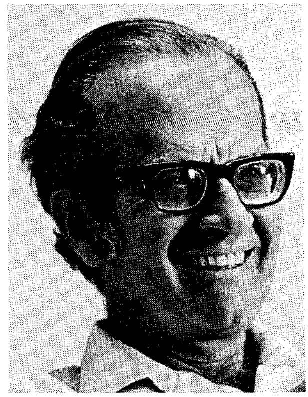
BURTON H. KLEIN is a professor of economics at Caltech. He was formerly head of the Economics Department at the RAND Corporation and has been consultant to numerous federal government agencies. He served as a staff member on the President's Council of Economic Advisers and as a special assistant to the Secretary of Defense. He is the author of **Germany's Economic Preparations for War** and of two new books awaiting publication.



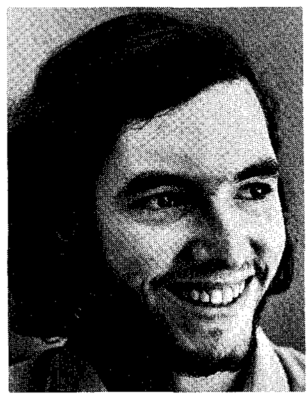
JAMES E. KRIER is professor of law at the University of California, Los Angeles, and a consultant to the Environmental Quality Laboratory. He is author of a number of articles on housing law and environmental law and of the recent book **Environmental Law and Policy.** Before joining the faculty at UCLA, Professor Krier practiced law in Washington, D.C.

DR. DAVID MONTGOMERY is an assistant professor of economics at Caltech and a member of the Environmental Quality Laboratory's staff. He was a Fulbright Scholar in economics at Cambridge University and subsequently received his doctorate at Harvard University, where his dissertation examined various possibilities of using economic incentivies to control air pollution in an efficient manner.

GUY PAUKER is a senior staff member of the Social Science Department of RAND Corporation. He is author of numerous papers on Southeast Asia, especially Indonesia, and was formerly chairman of the Center for Southeast Asian Studies, University of California at Berkeley. Recently he has become interested in the political and social problems posed by environmental constraints and changing human values, and he is now spending a portion of his time with the Environmental Quality Laboratory.



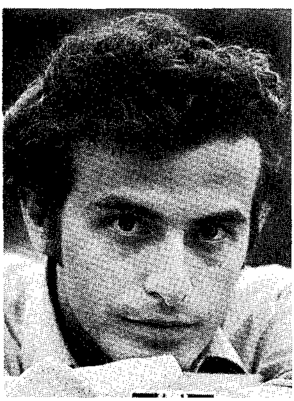
GARY RUBENSTEIN, student manager of the EQL-sponsored Clean Air Car Project, is a junior majoring in engineering at Caltech. He is co-author of **Gas Power—The Fleet Owner's Guide to Gaseous Fuels,** a booklet written as an introduction to natural gas and propane motor vehicle operation.



JOHN TRIJONIS, a Caltech graduate student in environmental engineering science, has worked with the Environmental Quality Laboratory for two years. He has just received his Ph.D., having completed work on his dissertation, "An Economic Air Pollution Control Model-Application: Photochemical Smog in Los Angeles County in 1975." His work will appear as an EQL report in 1972.

ART DIRECTION, PHOTOGRAPHY

PATRICIA J. HORNE, art director of the Environmental Quality Laboratory, graduated from California State College at Los Angeles and holds a secondary teaching credential from the State of California. For her work as director of the Caltech Environmental Action Council's Reclamation Center, she was designated co-ordinator for the information collection on glass at the University of Southern California's World Game. She interrupted subsequent work on an M.A. and her work at C.E.A.C. to join the EQL staff as research assistant.



WALT MANCINI is a recent graduate of California State College at Los Angeles. He has worked for the past few years as a free-lance photographer. Currently he is the photographer for the Environmental Quality Laboratory.