President's Report

1956

AIR POLLUTION FOUNDATION
704 SOUTH SPRING STREET
LOS ANGELES 14, CALIFORNIA

Third Annual Report of the Air Pollution Foundation

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THIRD ANNUAL REPORT OF THE AIR POLLUTION FOUNDATION*

by

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I. INTRODUCTION

After two and one-half years' concentrated effort by the Foundation, we shall offer a diagnosis and suggest the outlines of a prescription. Diagnoses and prescriptions for smog are not new in this community. Some are based on conjecture. What I shall offer to you today we believe is based on valid scientific findings. This report is a group effort in which my associates have made the principal contribution.

We shall report two major conclusions; we shall take a look, not only at the year ahead, but ten years ahead; we shall recommend a new approach to the auto exhaust problem, and a bold but more effective program for an earlier solution of our entire smog problem.

We do not believe that smog is less, nor that a solution is in sight. While the forecast recognizes formidable obstacles, the Foundation still believes that our smog problem can be solved, provided the community wants to rid itself of smog sufficiently to marshall the forces, and to adopt measures, bearing some practical relationship to the job it wants done.

The Purposes to Which Funds Have Been Allocated

The objectives of the Air Pollution Foundation, as stated by the incorporators and firmly adhered to by the staff, have been set forth fully in our previous annual reports. The funds with which we have sought to accomplish these objectives have come entirely from voluntary subscriptions of public-spirited community leaders in business and industry. On October 31, 1956, the Foundation had received a total of $575,743 since January 1, from 136 contributors, 83 of whom were new supporters this year. Some of our contributors are trade associations and, therefore, represent a larger number of supporting companies than indicated by these figures.

Note in Figure 1 that 76 per cent goes for direct research expenses, including research by contract and research performed by the Foundation staff. General and administrative expenses amount to only 14.8 per cent, and the balance of 9.2 per cent is devoted to public information activities.

*Delivered in condensed form to the Trustees and Supporters of the Foundation at the Third Annual Meeting, Hotel Ambassador, November 14, 1956, held jointly with the Second Southern California Conference on Elimination of Air Pollution arranged by the California State Chamber of Commerce.

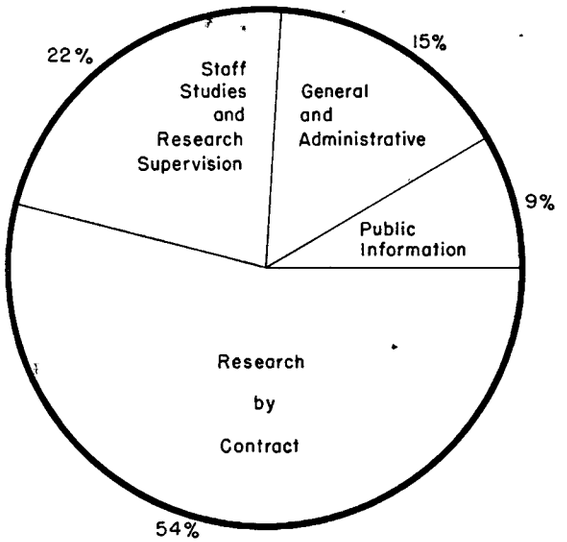


Fig. 1

Allocation of the Budget

Number of Research Projects, Current and Total

Our research dollar has been divided among the main purposes shown in Figure 2, totalling 16 active projects in 1956. Major emphasis has been given to the motor vehicle exhaust problem to which we have devoted more than one-half

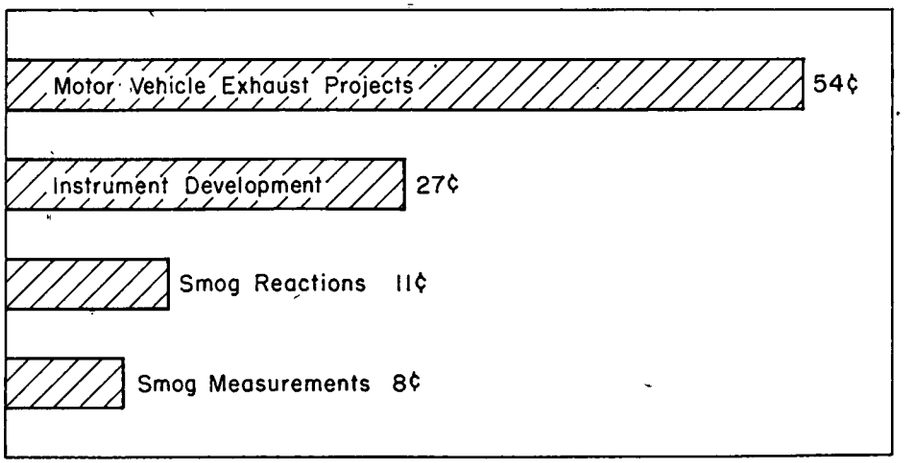


Fig. 2

Where our Research Dollar Goes

of our research dollar. The need for better measuring sticks continues, and so we have spent 27 cents of our dollar on continued instrument development. Selected smog measurements and basic studies of smog reactions account for the remaining 19 cents. The current program brings to 81 the number of projects undertaken by the Foundation since it began operations in June 1954.

Technical Advisory Committee

Selection of the most important research projects for the Foundation during the current year was made upon the recommendation of the Technical Advisory Committee under the chairmanship of Dr. William G. Young, Dean, Division of Physical Sciences, University of California at Los Angeles. This committee of eight scientists and engineers represents most of the major groups and agencies working on air pollution today. Selections, made from a much longer list of needed air pollution work, were approved by the Research Committee and the Board of Trustees up to the limit of available funds. On behalf of the trustees and the staff of the Foundation, I would like to express our appreciation to the Technical Advisory Committee for the time and counsel which its members have so generously given to the problems of this community.

II. PUBLIC INFORMATION

The Air Pollution Foundation came into being because responsible leaders of Southern California realized the need for an independent approach to the problem of smog. In the meantime, many more business men and industrialists have added their names to the roster of friends and supporters. Our public information staff has directed more than 50 per cent of its efforts toward this audience, to the end that they may become informed leaders in the battle against smog.

The Foundation believes that an informed leadership will replace futility with hope. An informed leader will be better able to pinpoint a wasteful activity. He will know that every attempt is being made to integrate research programs and avoid that waste. He will see to it that rather than too little, too late, we tackle every problem with adequate manpower and funds.

He will know that the air pollution problem is so large and complex that more than one agency is required to tackle (in different ways) the different aspects, that we seek the basic knowledge without which a program of laws and enforcement is unable to operate effectively. We have also striven to increase public understanding of the smog problem, and we believe it has increased. During 1956 the Foundation has released 18 stories reporting fact-finding progress. It has continued its series of monthly four-page NEWSLETTERS. It has prepared a series of five special reports on major phases of the smog problem and distributed them to supporters and friends of the Foundation. Speeches and lectures have been presented in response to invitations from over four dozen clubs, societies, and civic groups in Southern California. With these have been used our new visual aids, including up-to-date colored slides and colored sound movies.

During 1956 the Foundation has continued to cooperate with the Kiwanis smog information program, supplying factual materials to the active clubs for the education of their own individual members.

Finally, we have continued the distribution of our technical reports and technical papers, most widely in California, of course, but also to many others nationally and abroad. We believe that the public information staff has performed an educational service out of all proportions to its very modest and reduced budget.

III. PREVIEW OF THIRD TECHNICAL PROGRESS REPORT

Evaluation and control of sources of pollution in the Los Angeles Basin are, of course, fundamental to the solution of our smog problem. Important additions to our knowledge have been made as a result of Foundation studies during the past year. I shall give you a preview of our Third Technical Progress Report, which, to include final results through the end of 1956 and permit time for their evaluation, will not appear until early 1957.

A. Wind Trajectory Studies

In my report to you last year I gave you a progress report on the important program being conducted under Dr. Neiburger's direction. Essentially the purpose of this program has been to determine the sources of pollutants reaching selected observation stations, such as the one in downtown Los Angeles, on smoggy days. This study was completed and published in the Foundation Report No. 13 in April 1956 by Neiburger, Renzetti, and Tice. Over 1,000 trajectories, or wind paths, were calculated, tracing the movements of air-borne pollution to affected areas. The conclusions are striking.

On nearly one-half of the days when substantial smog was measured in the downtown station, the air had come over the San Gabriel Mountains; about one-quarter entered the basin across the west coast. In neither case did these wind streams pass near refineries. The fact that most of the trajectories passed over regions of heavy traffic, but not over industrial plants, points to vehicular exhaust as a major contributor to smog. An interesting sidelight: seven-eights of the time smoggy air had been in the Los Angeles Basin less than 36 hours. This report is an important milestone in the evaluation of pollution sources.

B. Incinerator Studies

While public opinion seemed to have crystallized more than one year ago in favor of ending the disposal of combustible rubbish by burning, particularly in single-chamber incinerators, it is still uncertain when this desirable goal will be reached. The Board of Supervisors has banned single-chamber incinerators effective October 1, 1957, but controversy continues in major areas over collection and

disposal methods and could make enforcement impracticable at that time. Perhaps because so much attention is being given to motor vehicle exhaust, people think the incinerator problem is disappearing.

The diagnosis of incinerator effluents as important contributors to Los Angeles smog is confirmed by the Foundation project completed at Battelle Memorial Institute, Columbus, Ohio, during 1956. Over a one-year period, a single-chamber incinerator was operated under scientific control on combustible refuse representative of that burned in Los Angeles. Gaseous products were collected and analyzed. Exclusive of carbon dioxide, carbon monoxide, water, and fly ash, from 82 to 407 pounds of organic compounds were obtained per ton of refuse burned. This is a fairly wide range, showing how variable a single-chamber incinerator can be. Earlier estimates of organic material have shown values of 145 pounds of organics from incineration of a ton of paper, and 415 pounds per ton of grass clippings. All of these figures are in the same general range of values.

The average value for aldehydes, calculated as formaldehyde, is 29 pounds per ton of refuse burned in all experiments, and ammonia, 1.8 pounds. Examination of the raw effluent gases by infrared techniques showed hydrocarbons, such as methane, ethylene, benzene, olefins, and acetylene, to be present in significant quantities. The same techniques showed the presence of methanol, acetone, and carbonyl sulfide. The liquid condensate from the incinerator gases contained appreciable quantities of organic acids and phenols. Many of these compounds are highly reactive chemically and known to be smog formers.[1]

C. Motor Vehicle Exhaust Studies

As recently as 12 months ago, representatives of the automotive industry, while admitting that motor vehicle exhaust probably represented the largest source of *pollutants* in the Los Angeles atmosphere, pointed out that they had seen no conclusive evidence that this exhaust produced *smog*—that is to say, significantly added to eye irritation or oxidant, for example. Such a position undoubtedly seemed capricious to those convinced that regardless of the source or sources, certain hydrocarbons and nitrogen oxides reacted in sunlight to produce these smog effects. But there was then, and still is, incomplete information on just which hydrocarbons and their derivatives are significant smog formers. On the other hand, some limited early work indicated that per unit of organic compound content, auto exhaust produced more smog than would be expected from an equivalent amount of raw gasoline.

While raising this basic scientific question, the auto industry neverthless continued on its program of investigation and studies seeking ways of controlling motor vehicle exhaust. It seemed clear to us, however, that a conclusive demonstration of the production of smog by auto exhaust might have a stimulating effect on the programs and efforts of the industry and others. In other words, we had to find out specifically whether motor vehicle exhaust at concentrations found in the Los Angeles atmosphere on smoggy days could, *by itself*, produce eye irritation and/or oxidant, (including ozone) and if so, whether these effects could be produced at levels ap-

proximating those observed on smoggy days, or whether the effects were only minor. More than that, we hoped to find out how much the smog formers in auto exhaust had to be reduced, as a guide to the development of effective control devices.

(1) Stanford Research Institute

Accordingly, we designed appropriate experimental programs and placed two contracts in 1956, one with the Stanford Research Institute in South Pasadena and the other with the Midwest Research Institute in Kansas City, Missouri. Fumigation chambers were provided in both cases. At Stanford we used a 1954, 8-cylinder Dodge with automatic transmission, about 20,000 miles prior operation, and put in good mechanical operating condition. The engine was operated automatically on a chassis dynamometer on a fixed cycle of acceleration, cruise, deceleration, and idle. After consultation with oil industry experts, motor fuel was chosen which they considered representative of that commonly used in Los Angeles today. Exhaust from the test car was carefully metered into the fumigation chamber, along with purified air so that the mixture contained known amounts of auto exhaust in the concentration ranges known to exist commonly in the Los Angeles lower atmosphere. The mixture flowed steadily through the fumigation chamber in such a way that a uniform distribution existed. Flow rate was adjusted so that residence time in the chamber was either 60 minutes or 90 minutes as desired. In other words, the Stanford program employed what is called a "dynamic" or flowing system.

When tests indicated that a steady state had been attained in the chamber, artificial irradiation was turned on to produce radiant energy equivalent to that of noonday sun, both in intensity and effective wave length. Table I shows typical values before and after irradiation. Fig. 3 gives results of a typical experiment. Oxidant values were reached in about 15 minutes after turning on the lights, but we suspect it forms much more quickly, and that most of the delay is lag in our method of measurement.

Hydrocarbon Concentration ppm	Carbon Monoxide Concentration ppm	Oxidant concentration before arcs were turned on ppm	Oxidant concentration after arcs were turned on ppm	Rate of Formation of Oxidant ppm/minute	NO_2 Concentration before arcs were turned on ppm	NO_2 Concentration after arcs were turned on ppm	Rate of Formation of NO_2 ppm/minute
1.1	26	0.05	0.52	0.013	0.03	0.23	0.008
1.2	47	0.04	0.76	0.005	0.03	0.34	0.011

TABLE I

Rate of Photochemical Formation of Oxidant and NO_2 from Auto Exhaust*

* Auto exhaust (idle, acceleration, cruising, deceleration) from a single automobile in good condition operating on a one minute simulated driving cycle on a chassis dynamometer was diluted with purified air in a dynamic system in a 500 cu. ft. irradiation chamber. This chamber is equipped with 24 mercury arc lights. Average residence time of the gas mixture was one hour. Hydrocarbons were measured with a Perkin-Elmer infrared spectrometer; carbon monoxide with a Mine Safety Appliance Luft infrared analyzer; oxidant with a 20% buffered KI recording colorimeter; and NO_2 with a Griess reagent recording colorimeter.

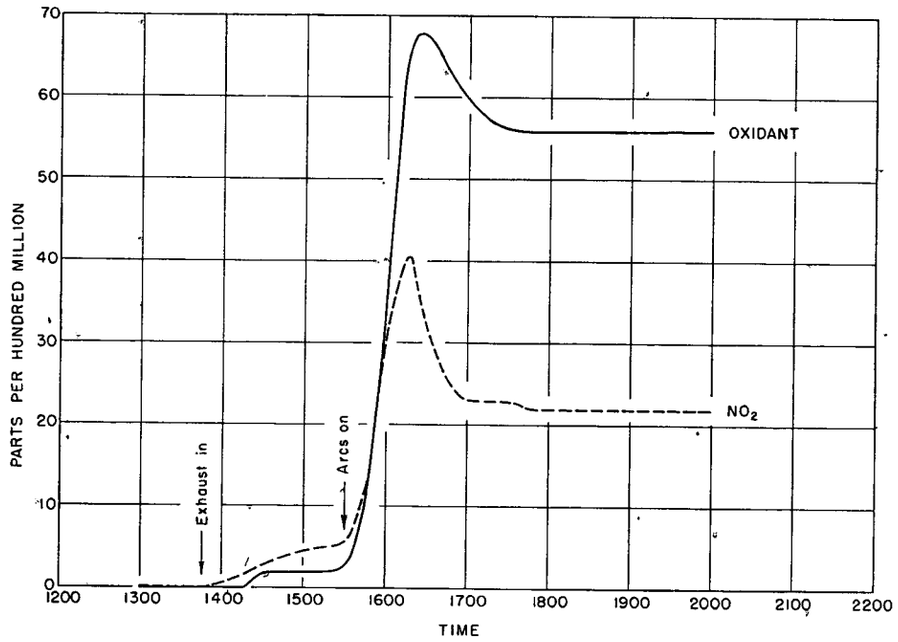


Figure 3.

Effect of Irradiation on Exhaust Gases, Stanford Research Institute.

Gases from the fumigation chamber were supplied to members of an eye-irritation panel. The panel consisted of healthy young college students from the vicinity, who were examined before and after each experiment and at regular intervals by a doctor of medicine. Subjects were seated in separate booths and supplied with fumigation chamber gases (irradiated and nonirradiated) or with pure air without having any way of knowing whether they were getting one or the other, or mixtures of both.

As a result of these tests, the Foundation found conclusive evidence that both eye irritation and oxidant values are produced from the auto exhaust from this car under these conditions; furthermore, that the levels of eye irritation and oxidant values were typical of those found in Los Angeles on a smoggy day. The full data will be published in a forthcoming scientific report of the Foundation.

(2) Midwest Research Institute

At Midwest Research Institute, different but equally realistic conditions were chosen. Here the fumigation chamber consisted of a modified glass greenhouse in which the source of radiation was the sun itself. Auto exhaust was supplied to this chamber from a Ford station wagon operated uniformly at what is known as "fast idle" of 500 or 1000 rpm. to produce concentrations comparable to those in Los Angeles air. Because these gases came from motor idling alone, they differed from normal motor vehicle exhaust, particularly by being lower in nitrogen oxides. Experiments were, therefore, conducted with idling motor exhaust to which appropriate

additions of nitrogen oxides were made. Eye irritation was observed by having personnel enter the greenhouse at regular times. As at Stanford, pollutants were regularly monitored and experiments were conducted both in the dark and under various periods of exposure to sunlight.

In each experiment at Kansas City, when the desired concentration had been reached, the gas supply was turned off and the polluted air in the greenhouse permitted to stand undisturbed, except for the minor effect of observers entering and leaving the chamber. Thus, this was a "static" experiment rather than the dynamic or flowing type used in Pasadena.

Here again when organic compounds and nitrogen oxides were at concentrations representative of motor vehicle exhaust in city air on smoggy days, both eye irritation and oxidant values were obtained comparable to those experienced in Los Angeles.[2]

The pertinence of these results to the motor vehicle exhaust problem is clear. It is possible to produce at least two important smog effects at "smoggy-day" levels from the exhaust fumes of these two cars under our experimental conditions, mixed with purified air, and with no other pollution source present. The data do not, however, justify the conclusion that auto exhaust is the sole cause of smog, nor that all cars would produce exactly the same effects. It is well known that the composition of motor vehicle exhaust varies widely from car to car and even for the same car from time to time. Nevertheless, we believe this work for the first time demonstrates conclusively that it is possible to produce significant smog effects from motor vehicle exhausts at concentrations commonly experienced in our atmosphere.

Members of the Automobile Manufacturers Association Vehicle Combustion Products Subcommittee inspected both installations in May and personally experienced eye irritation. Dr. Faith and I presented preliminary data to them at a meeting of the committee in Detroit on August 7, 1956. They then stated that they accepted the conclusion that motor vehicle exhaust did in fact produce smog and agreed that it was a "major" contributor to smog. They reserved judgement on whether is was the principal source of smog until additional data became available from traffic surveys and other studies in progress during 1956.

There is a second equally important result of the gas chamber work. These two facilities now represent proving grounds for the evaluation of various exhaust control devices which have been or may be proposed. For example, the cars can be operated under normal conditions with and without specific control devices. This avoids the necessity for speculating or theorizing as to the probable effects on smog production of a proposed device because it is claimed to reduce one or another of certain components of motor vehicle exhaust. No comparable facilities exist elsewhere. They should be of much value in facilitating and expediting the development of practical and effective exhaust control devices.

Since Los Angeles appears to be irrevocably committed to the motor vehicle as its primary source of transportation, and since it is not possible to operate an internal combustion engine without producing exhaust gases, the solution to the problem is to identify the components of exhaust which must be controlled and to determine how much they must be reduced to be acceptable.

The Foundation is proceeding immediately with experiments in which either or both organic compounds and nitrogen oxides are reduced by selected amounts. As soon as this information is available, it should be of major assistance to the companies and individual inventors who wish to develop effective control devices. If, for example, it should turn out that the removal of 75 per cent of the organic compounds alone is adequate, the answer is likely to come more easily and quickly than if the device must take out 95 per cent. Or, if it is found that removal of 50 per cent of *both* organic compounds and nitrogen oxides is necessary, again the designer is confronted with a less difficult problem than if a greater proportion were required.

Naturally, we would all like to remove 100 per cent of these culprits from the exhaust, but such an achievement would be miraculous—not one we can look forward to in the next ten years. Meanwhile, therefore, the Foundation is making every effort to ascertain how any level of practical improvement may be obtained in the interest of earlier relief. Most inventions are imperfect in their earlier forms and are steadily improved with experience. It would certainly seem unwise to refuse arbitrarily to use any device that gives relief on the grounds that a better model might be available next year.

(3) Concentrations Encountered Near Heavy Traffic

One of the many anomalies about the Los Angeles smog problem has been that values of oxidant and effects of eye irritation and plant damage have frequently been found to co-exist with values of hydrocarbons and nitrogen oxides which seem disproportionately low for the intensity of the smog effects noted. A possible explanation is that these smog-forming substances had been at higher concentrations some time earlier in the day, had reacted to form oxidant and to give these other effects, and that the concentrations of these smog formers had thereby become reduced. Since monitoring stations were located with respect to normal wind patterns rather than specific sources, it also seems probable that by the time polluted air reached these stations, concentrations of reactants had diminished due to both dispersion and chemical reaction. This would be all the more likely if the chemical reactions were relatively fast.

Now it is known that the photochemical reactions of hydrocarbons and nitrogen oxides are fairly rapid, taking place in a matter of minutes rather than hours, and that reaction rates increase with concentration, temperature, and intensity of radiation.

When it became apparent that motor vehicle exhaust is a major source of smog, we wondered whether smog formation might be starting close to heavy traffic where concentrations of reactants would be expected to be higher. We were unable to find that any systematic measurements had been made at such points.

Accordingly, the Foundation arranged with the Truesdail Laboratories to collect many air samples within 75 feet of the traffic arteries at points where from 15,000 to 35,000 motor vehicles passed daily between 6:00 and 9:00 a.m. This survey was conducted during a period of 20 week days from September 4 to October 2, 1956. Samples were analyzed for carbon monoxide, carbon dioxide, and hydrocar-

bons. Other analyses would have been desirable but facilities were not available in time. Nevertheless, these measurements enabled us to establish the range of concentrations found in the vicinity of freeways and other heavy traffic arteries.

Ranges of concentrations found are shown in Table II, together with values found concurrently for carbon monoxide at air-monitoring stations by the Air Pollution Control District. As might be expected, concentrations vary with traffic, wind, and temperature inversion. Concentrations two to four times higher exist for carbon monoxide close to heavy traffic. Levels of hydrocarbons in this survey (0.8-2 ppm) were four times those found during week-day mornings in September of 1954 at monitoring stations (0.2-0.5 ppm). While hardly unexpected, knowledge of actual values encountered is obviously essential. Concentration ranges of hydrocarbons and carbon monoxide noted in Table II are similar to those used in our fumigation chambers with auto exhaust at Stanford Research Institute and Midwest Research Institute.

D. Decomposition of Nitrogen Oxides

Nitrogen oxides have been shown to play an important part in smog formation. They enter the atmosphere among the exhaust gases of combustion processes, especially those operating at higher temperatures, such as motor vehicle engines, and steam power plants burning either fuel oil or gas. Scientists have been working for 50 years to perfect processes for fixing atmospheric nitrogen in the form of nitric oxide to increase supplies of fertilizers and nitric acid. Now they are faced with the problem of developing a simple and practical method for decomposing low concentrations of nitric oxide as one of the steps necessary to smog abatement.

During the past year the Air Pollution Foundation has searched the literature and has conferred with leading authorities in this specialized field. The few clues we have been able to turn up are largely of a theoretical nature which so far offer little practical encouragement. Thus they indicate that nitric oxide can be decomposed without catalysts only at temperatures unreasonably high for a control device. With a catalyst, decomposition may be effected at somewhat lower temperature ranges. Accordingly, the Foundation placed a project during the past summer with the Armour Research Foundation to test all catalysts which offered any promise. Among the first 20 catalysts, one composed of 98 per cent activated carbon and 2 per cent sodium oxide brought about a 49 per cent reduction in a gas mixture containing initially 0.2 per cent nitric oxide in nitrogen at a temperature of 700°C. Molybdenum sulfide gave a 20 per cent reduction at 610°C. At this preliminary stage of the work, it is not clear whether this is a genuine catalytic effect or in part chemical reaction with the catalyst.

Screening of catalysts will continue in a laboratory flow system. Various materials which have proved active in similar reactions will be tried, including Raney nickel and promoted iron. Another possibility is that of reacting nitric oxide with reducing agents present in exhaust gas, such as hydrogen, carbon monoxide, or hydrocarbons. Emphasis will continue to be on screening of large numbers of potential

LOCATIONS

Time PDT	Slauson and Figueroa 9/10/56		La Brea and Olympic 9/13/56		La Brea and Olympic 9/14/56		La Brea and Olympic 9/17/56	
	HC ppm	CO ppm	HC ppm	CO ppm	HC ppm	CO ppm	HC ppm	CO ppm
6:00 AM	2.15	45.1	0.73	16.9	1.16	73.9	0.92	26.9
6:30	2.09	41.5	0.86	28.0	1.47	47.2	0.95	28:0
7:00	1.60	30.1	1.23	46.2	1.60	34.2	0.94	22.9
7:30	1.82	44.2	1.49	54.5	1.32	30.1	1.45	51.3
8:00	1.47	29.0	1.47	49.6	0.88	37.2	1.74	65.2
8:30	1.80	44.7	0.86	27.1	0.97	47.4	1.35	39.3

Carbon Monoxide Values (ppm) Found Concurrently at Los Angeles Basin Air Monitoring Stations

Time PST	9/10/56			9/13/56			9/14/56			9/17/56		
	Down-town	Burbank	Vernon	Pasa-dena	Burbank	Vernon	Pasa-dena	Rivera	Vernon	Down-town	Pasa-dena	Vernon
5:00 AM	9	5	11	9	9	13	7	8	10	11	7	10
6:00	14	12	13	13	11	16	14	13	20	—	12	14
7:00	15	11	19	10	3	12	11	11	20	15	10	13
8:00	9	9	27	8	3	10	8	9	10	13	—	9
9:00	11	6	25	7	4	9	8	10	9	12	6	10

TABLE II

Ranges of Hydrocarbon and Carbon Monoxide Concentrations at Traffic Sampling Points

catalysts rather than on the exhaustive study of any one type at this time. If a promising catalyst is discovered, more detailed studies will be undertaken concerning the influence of other exhaust components on the catalyst, especially the effect of tetraethyl lead. Still another possibility is the oxidation of nitric oxide to a higher oxide, or conversion to some other form, so that it might be readily removed or rendered chemically inert.

The ultimate objective of this program is the development of a converter for nitrogen oxides which would be effective in a motor vehicle exhaust system and possibly in modified form on a power plant stack. Not only is no workable device for this purpose in sight, but no principle has been sufficiently demonstrated to serve as the basis for the development of such a device. Only limited work has been started on this problem, however, and there is no reason to believe that the problem cannot be solved, but no estimate of the time required is possible at this stage.

Because part of the problem is lack of basic data, a contract for basic research on nitric oxide was drawn up by the Foundation with the California Institute of Technology to be conducted under the direction of Professors Corcoran and Sage in the Department of Chemical Engineering. As the Air Pollution Control District wanted to include such work in its broad program of research at Caltech, this project was taken over by the District as sponsor.

The search for a catalyst to decompose nitric oxide, or for some other practical method of disposal, is a wide-open field. As our urban civilization increases, more combustion, and hence more nitric oxide, offers large economic rewards for a successful control device.

E. Progress in Atmospheric Measurements

Information on the composition of the Los Angeles atmosphere is still far short of what is needed for an accurate diagnosis, or to determine with any confidence downward trends in pollution levels from year to year as a result of this community's control efforts, or changes for the worse as a result of our continued growth. It is true that many measurements have been made, particularly during the last three years, and more measurements are being made all the time. This trend is in the right direction. However, it must be remembered that we are trying for the most part to measure traces of gases in very low-concentration ranges where man has had little analytical experience. Where he has had experience in such low ranges, he has usually been dealing with comparatively pure systems, whereas in an urban atmosphere, a great variety of substances seriously interfere with the determination of any particular component. Finally, as our knowledge of smog formation increases, we discover the importance of additional pollutants and so it becomes necessary to measure their concentrations too.

We cannot expect to get very far toward a solution of our smog problem until we learn how to measure hydrocarbons and nitrogen oxides and then use this knowledge to monitor at least these important pollutants regularly. A year ago, it was

thought that infrared spectrometry offered a good analytical tool for hydrocarbons. Further experience reveals that in complex mixtures at low concentrations, interference is excessive. As the best known method for total hydrocarbons today, its precision at concentrations and in the mixtures commonly found in our atmosphere is perhaps ±50 to 100 per cent.

(1) Hydrocarbons

The Foundation started early in 1955 to adapt a commercially available infrared spectrometer to the continuous analysis and recording of atmospheric hydrocarbon concentrations. The Foundation is cooperating with the Perkin-Elmer Company in the development of a small, compact, portable, infrared filter-type instrument for measuring hydrocarbons directly in the atmosphere without pressurization or other manipulation of sample.

(2) Nitrogen Oxides

Methods for nitrogen oxides are equally unreliable.

Under the direction of Dr. L. H. Rogers of the Foundation, work has continued on the development of a continuous instrument for the measurement of nitrogen oxides. The basic problem is to find a method reliable for nitrogen dioxide.

(3) Oxidants

a. Comparative Studies

Another measurement about which you have heard a great deal is the concentration of "oxidant" in our atmosphere. We now know this to be an empirical index, made up of effects contributed by ozone, nitric oxide, nitrogen dioxide, organic peroxides, possible free radicals, and in an opposite sense, by sulfur dioxide. For a given atmospheric oxidizing condition, entirely different values of oxidant are obtained depending on the methods of analysis used.

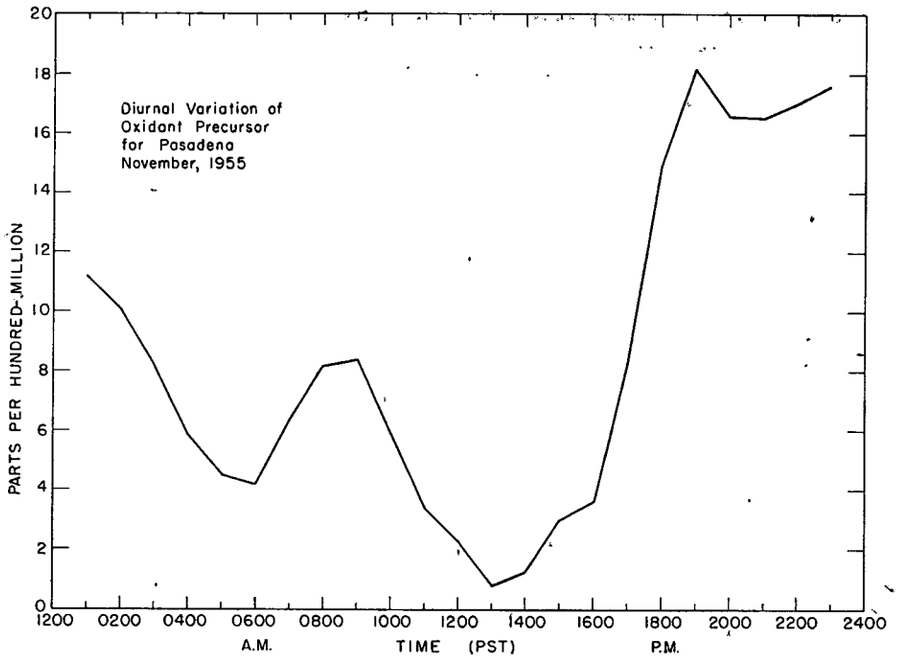
Dr. Renzetti reported comparative studies of oxidants and ozone in a current publication.[3]

b. Ferrous Thiocyanate Method

Since ozone constitutes an important but variable part of total oxidant, an oxidant recorder not responsive to ozone should also be used to monitor smog. The Foundation placed a contract this year with Dr. Robert R. Austin to develop an instrument based upon the ferrous thiocyanate method used by Dr. Todd at the University of California at Riverside. Two instruments are now operating satisfactorily.

c. Oxidant Precursor

Rogers determined oxidant precursor at Pasadena during November 1955 by measuring oxidant in the air before and after artificial irradiation. Values are shown in Figure 4.



OXIDANT PRECURSOR VALUES ARE OBTAINED BY MEASURING THE OXIDANT FORMED BY ARTIFICIAL IRRADIATION OF OUTSIDE AIR AND SUBTRACTING OXIDANT ALREADY PRODUCED BY NATURAL IRRADIATION.

Figure 4.

d. Ozone Measurements

The ultraviolet ozone spectrometer development under Dr. Renzetti's direction is being used to monitor atmospheric ozone on the Foundation project at Stanford Research Institute and by the District at 2 stations. The Foundation has also purchased an Ehmert ozone analyzer from the Max-Planck Institute in Germany. This is a small portable device weighting less than ten pounds and has been tested for us by Dr. A. L. Chaney. It has proved useful in measuring ozone, even in small quantities, when interfering substances are largely absent.

e. Trend in Oxidant

Professor Haagen-Smit's oxidant measurements by his phenolphthalin method in Pasadena represent the only smog record made in the Los Angeles Basin continuously since August 1953. These data have been made available through the courtesy of the Air Pollution Control District. There does not appear to be any significant trend. In Table III we see that average oxidant concentration was essentially the same in 1953 and 1954 for a given inversion height. In 1955 oxidant was appreciably higher. Preliminary results for 1956 indicate that levels may not be as high as in 1955, but similar to 1953 and 1954 within experimental error. Generalizations with respect to the Los Angeles smog problem are not warranted on the basis of this one observation at one point.

TABLE III

Average Maximum Oxidant Concentration for Days of Low Inversion August-November, 1953-1956

Year	Average of the Maximum Oxidant Concentration, in pphm, for the Days of Inversion Height Less than 500 feet at 7 AM PST	Average of the Maximum Oxidant Concentration, in pphm, for the Days of Inversion Height Less than 1000 feet at 7 AM PST
1953	37	40
1954	34	36
1955	56	60
1956	33*	35*

* not including November 1956

Table IV shows the frequency of low inversions during the smog months beginning in 1953. Frequency of low inversions and average winds have not varied significantly during this four-year period, and, therefore, variations in average oxidant values must have some other explanation.

TABLE IV

Frequency of Low Inversion, August-November, 1953-1956

Year	Number of Days of Inversion Height Less than 500 feet at 7 AM PST	Number of Days of Inversion Height Less than 1000 feet at 7 AM PST
1953	45	54
1954	41	48
1955	41	57
1956	32*	43*

* not including November 1956

(4) Aerosol Studies

a. Particle Counter

The development of an electronic instrument for automatically counting aerosol particles in our atmosphere seems to be nearly completed at the Stanford Research Institute under the direction of Dr. George Doyle. This is a prototype of the O'Konski particle counter, built for the Foundation by Berkeley Research Products at Albany, California, and delivered in the fall of 1955. Design and operational problems in the machine were worked on by the Department of Meteorology, University of California at Los Angeles.

b. Particle Collector

A project was placed with Dr. Goetz of Caltech in February to develop an instrument for the collection of aerosol particles. He has invented a unique device which collects smog particles in various size ranges from 0.1 to 2.0 microns. Appropriate microanalytical methods are now being sought for the determination of organic compounds, nitrates, sulfates, and lead in these different fractions.

Continued research on our smog-forming aerosols with these new tools could provide extremely important information.

c. Organic Aerosols

There are indications that our atmosphere contains a large number of tiny oil particles which may be lubricating oil, atomized in the course of motor vehicle operation. Daily consumption of lubricating oil in Los Angeles County has been estimated at approximately 85 tons per day. Unconfirmed estimates indicate that perhaps one-half of this becomes air-borne. Calculations by Dr. Langmuir and Dr. Goetz indicate that such quantities, if present in small particles in the light-scattering range, would account for major reduction in visibility. Electron photographs of aerosol material from the Los Angeles atmosphere made by Professor Bush and associates in the Department of Engineering of the University of California at Los Angeles, and studies of Dr. Cadle and associates at Stanford Research Institute, indicate the presence of micron and submicron size particles having oil-like properties. Ether-soluble aerosols which would, of course, include oil, are being studied by the Air Pollution Control District, Air Pollution Foundation, and others. Chambers and associates reported[4] an average content of 57.3 micrograms per cubic meter of organic particulate matter in the Los Angeles atmosphere, higher than any other major city in this country. If one assumes that this concentration exists uniformly over the 1,600 square miles of effective basin area under an inversion height of one-tenth of a mile, it amounts to 42 tons of organic particulate matter. It may be merely a coincidence that this is approximately one-half of the daily estimated consumption of lubricating oil. For the time being this aspect of smog must await further research.

(5) Eye Irritation

The Foundation has continued to monitor eye irritation during the smog months in 1955 and 1956 in Pasadena. Eye irritation in 1955 was found to be equal to or greater than that for 1954. The Foundation in 1956 has monitored eye irritation with the assistance of volunteer panels in the vicinity of 15 stations in the basin where the Air Pollution Control District has been measuring pollutants which may provide some clue to the substances causing eye irritation.

(6) Carbon Isotopes from Fuels and Rubbish

Fossil fuels, such as petroleum, can be distinguished from those of recent vegetable origin, such as wood or wood products like paper, by mass spectrometer analysis of the types of carbon atoms (carbon isotopes) present. Likewise, carbon dioxide produced by the combustion of such fuels can be distinguished. A Foundation project placed at Caltech early in 1955 under the direction of Professor Samuel Epstein in the Division of Geological Sciences reveals (1) that carbon dioxide in our Los Angeles atmosphere increases mainly as a direct result of combustion and not the respiratory processes of growing plants, and (2) that approximately two-thirds of the carbon dioxide is traceable to the combustion of petroleum products. The balance

derives from the combustion of material of vegetable origin. Insofar as other gaseous pollutants bear a certain ratio to carbon dioxide at the sources, their distribution between petroleum and vegetable fuels would correspond.

In other words, approximately two-thirds of the gaseous combustion pollutants in our air come from our use of fuel oil, gasoline, or gas, and the remainder from burning rubbish. Clayton, Arnold, and Patty[5] reported that approximately 75 per cent of the carbonaceous particulate matter in our atmosphere appeared to be of petroleum origin and the balance of wood or vegetable origin.

(7) Basic Research in Photochemistry of Polluted Atmospheres

a. Conference on Chemical Reactions

In the oxidizing type of smog which characterizes the Los Angeles air pollution problem, photochemical reactions are of primary importance. To aid in bringing together the latest information, a conference was organized by the Foundation with the assistance of the National Science Foundation and the American Petroleum Institute in February, attended by 40 of the country's leading authorities. Proceedings are summarized in the Foundation Report No. 15.

Haagen-Smit discussed his work on ozone, plant damage, and hydrocarbon-nitrogen dioxide photochemical experiments with rubber cracking and auto exhaust experiments. He concluded that a 75 per cent elimination of both nitrogen oxides and hydrocarbons would effectively control eye irritation, plant damage, and high concentrations of ozone.

Cadle summarized Stanford Research Institute's studies on dark reactions, reactions in smog itself, and photochemical reactions in highly purified Los Angeles air with addition of one or two known contaminants. Cadle suggested a free radical mechanism in explaining smog reactions.

Scott described the work at Franklin Institute on photochemical reactions of nitrogen dioxide with various hydrocarbons and organic compounds using long path infrared absorption spectroscopy. Early experiments were done with relatively high concentrations, but more recent work was done at concentrations of a few parts per million. The rate of formation and decay of ozone and nitrogen dioxide were studied. Other products in addition to ozone which were found included aldehydes, alkyl nitrate, formic acid, carbon monoxide, carbon dioxide, and water. In addition, a new group of materials identified as "Compound X" was reported, later identified as peroxy acyl nitrogen compounds.

Calvert of Ohio State University discussed the role which particulate matter plays in smog formation. Known photocatalytic oxidation on zinc oxide, titanium oxide, antimony oxide, and other metallic oxides makes it appear likely that similar reactions may have some importance in smog reactions. The major metallic constituents present in the particulate matter of the Los Angeles atmosphere are lead, iron, magnesium, sodium, and potassium. In view of the reported lead concentrations, further work on gas-phase photosensitized oxidation of PbO and other solids are desirable.

Reports presented by Professor Leighton, and Drs. Miller and Brown of the Armour Research Foundation, are summarized below.

b. Work of Professor Leighton

The important role of sunshine or solar energy in promoting certain smog-forming reactions has been appreciated for a number of years, without being understood in any quantitative or useful way. Early in 1955 the Foundation retained Professor Philip A. Leighton of Stanford University, internationally known authority in the field of photochemistry, to make a thorough review of all available information to determine which of our common atmospheric pollutants were capable of photochemical reaction sufficient to produce the observed smog effects such as ozone, and which pollutants, therefore, we would have to control if we wished to prevent photochemical reactions.

The result of his first year's labors resulted in the publication of the Foundation's Report No. 14 in March 1956. This report is an outstanding scientific achievement not only as a thorough and systematic analysis but as a pioneering study of its application of photochemical principles to an urban air pollution problem. In the light of presently available data, this report supports the conclusion that although other primary processes may contribute, the photodissociation of nitrogen dioxide into nitric oxide and oxygen atoms is a photochemical primary process of major importance in smog formation. Among a variety of substances which may contribute to the enhancement of smog, other possible contributors are organic nitrites and diketones, and he recommends that the concentrations of these substances be determined. He finds that reactions initiated by absorption of sunlight by other ketones, peroxides, and sulfur dioxide are too slow to contribute significantly to smog formation. In short, his first report clearly places nitrogen dioxide at the top of the list of substances which we must remove from our atmosphere.

The second year's study by Dr. Leighton is concerned with the photochemical secondary reactions. Some of the findings: During smog-forming periods in Los Angeles, oxygen atoms may be photochemically produced at rates of about 100 pphm per hour; by far the fastest secondary reaction which these oxygen atoms undergo is with molecular oxygen to form ozone; unless some unknown and very rapid reaction of oxygen atoms remains to be discovered, it is concluded that over 99 per cent of all oxygen atoms formed in urban air will produce ozone.

With regard to the reaction of hydrocarbons with oxygen atoms, the reaction with olefins is much faster than with paraffins. For example, their reactions with the butenes is from 140 to 600 times faster than with normal butane. Reaction of oxygen atoms with saturated hydrocarbons is probably of slight importance in smog formation. The rate of reaction between oxygen atoms and olefins is about 0.1 pphm per hour.

The reaction of *ozone* with olefins, however, will proceed at rates of 10 pphm per hour.

The conclusions suggested by these figures is that ozone, rather than atomic oxygen, is the major participant in reactions with hydrocarbons in urban air. The reaction of oxygen atoms with saturated hydrocarbons is so slow as to be insignificant, while that of oxygen atoms with olefins is only of marginal significance.

c. Armour Research Foundation

Photochemical studies on formation of oxidant with nitrogen dioxide were carried out by Dr. Arnold Miller and Dr. Callaway Brown at Armour Research Foundation. Ozone formation following the irradiation of traces of nitrogen dioxide and 3-methyl heptane in oxygen was examined critically. The results showed that nitrogen dioxide was consumed in the photochemical reaction. Considerable attention had to be paid to the experimental procedures, including the achievement of uniform and intense radiation, adequate analytical methods, and methods of preparing very low dilutions of reactants. It was concluded that the increase in ozone concentration in these experiments, together with the parallel loss of nitrogen dioxide, was due to a secondary reaction of nitric oxide with peroxide radicals to form nitrates or other organic nitrogen compounds.

The results of this study confirmed that nitrogen dioxide plays an important role in the formation of ozone. The elimination or reduction of this component would, therefore, be expected to reduce other smog manifestations.

IV. FINDINGS

A. Introduction

The Foundation has refused from the beginning to make recommendations looking toward the abatement of the Los Angeles smog problem until sufficient scientific evidence existed to support the findings upon which such recommendations could logically be based. To borrow medical phraseology, we said that diagnosis must precede prescription. Tentative diagnoses of the smog problem in 1954 did not appear to us to be scientifically justified in view of the disagreement then exisiting between competent scientists on such a basic issue as the photochemical formation of ozone from hydrocarbons and nitrogen oxides.

Since then we have digested the results of a large volume of research performed in many laboratories in this country and abroad, including Foundation projects undertaken to fill blank spots, to confirm crucial experiments of a single investigator, or to resolve disagreements. Our findings, therefore are based on a comprehensive review of the work of a great many people.

In venturing of offer this "diagnosis" of the Los Angeles smog problem, we are well aware that most of what we shall say will have a familiar ring. This is inevitable where so many theories have been advanced in recent years. Distinguishing fact from theory becomes a vital necessity when remedies are being proposed which will cost millions, when the stakes include the future of Los Angeles.

B. Reactive Gases

It is clear now that photochemical reactions involving nitrogen oxides and organic compounds produce oxidant and ozone, and that the effects of eye irritation and plant damage are closely associated with these reactions. The identity of the specific substances responsible for either eye irritation or plant damage, or both, are still unknown, but the principal sources of nitrogen oxides and organic compounds are adequately identified. These are described collectively as all combustion processes and evaporative losses. Among the combustion sources the largest is motor vehicle exhaust; others include industrial combustion processes which are mainly for power generation, incineration and domestic heating.

Evaporative losses contribute organic compounds from the gas tanks and carburetors of motor vehicles, from the storage, refining, and distribution of motor fuel and miscellaneous solvent losses as from dry cleaning and painting operations. It is estimated that the approximately 2,500,000 motor vehicles in Los Angeles County contribute a greater daily tonnage of organic compounds by simple evaporation when they are parked with engines shut off, than the total organic pollution attributable to the storage, refining and distribution of motor fuel.

C. Liquid and Solid Particles

Other smog effects commonly objected to are reduced visibility and dirt. These are due to air-borne liquid and solid particulate matter known collectively as aerosols. Chambers' data indicate that organic matter comprises only about one-fifth of the total aerosol collected in his studies. The total atmospheric loading reported compares closely with that found in Chicago and New York. Content of nitrates is several times higher than found in 30 other cities in the survey. While sources of our aerosols cannot be determined from present data, it is probable that a large part of it results from combustion processes. Carbonaceous particulate matter is about 75 per cent of fossil origin, and 25 per cent of recent wood or vegetable origin, i. e., from incineration.

D. Sources

(1) Motor Vehicles

The evidence supporting the conclusion that motor vehicles are the principal contributor to smog is as follows:

1. Over one-half of our total air pollution comes from motor vehicles.
2. Three-fourths of the hydrocarbons in the air come from motor vehicles.
3. Two-thirds of the oxides of nitrogen come from motor vehicles.
4. Nitrogen dioxide, together with hydrocarbons and their derivatives, are the principal smog-forming air contaminants. In the presence of sunshine these materials react to form ozone. No other method of forming significant amounts of ozone in the lower atmosphere is known.

5. Typical smog damage to vegetation has been duplicated by subjecting plants to a mixture of ozone and hydrocarbons in amounts similar to those found in the Los Angeles atmosphere on smoggy days.
6. Scientific studies show that the only material in the air that is both capable of absorbing energy from sunlight, and present in amounts sufficient to cause observed smog effects, is nitrogen dioxide.
7. Tests in large chambers have demonstrated that auto exhaust, in quantities similar to those in the Los Angeles atmosphere, produces oxidant and eye irritation when subjected to sunlight.
8. A study of wind trajectories in the Los Angeles Basin shows that air masses high in ozone values and eye irritation in downtown Los Angeles and in Pasadena nearly always passed over heavy traffic areas and in many cases did not pass over any other major pollution source.
9. Scientific experiments have also shown that oxides of nitrogen at very low concentrations will react with hydrocarbons to form an aerosol capable of restricting visibility, even in the absence of sunlight.
10. A major portion of the carbon dioxide in our air derives from fossil fuels, i. e., petroleum.
11. A major portion of the carbonaceous particulate matter in our air is of fossil origin.

(2) Incinerators

Evidence supporting the conclusion that incinerators are an important source of air pollution include:

1. Incinerator gases are rich in known smog-forming organic compounds, totalling several hundred tons per day.
2. Approximately one-third of the carbon dioxide in our air is of wood or vegetable origin.
3. Approximately one-fourth of the carbonaceous particulate matter in our air is of wood or vegetable origin.

(3) Industry

Nitrogen oxides and organic compounds resulting from industrial activities must be held to be, as important as from any other source, in proportion to their amount. The petroleum industry in Los Angeles County has made the only notable reduction in its contribution of organic compounds of any major source. Whether still further reduction is either feasible, or would have any significant consequences so long as other much larger sources exist, is a subject of continuing study.

Stack gases from the operation of public and private steam power plants is a subject of much current concern, based on the content of nitrogen and sulfur oxides. Extensive scientific research has not yet shown that sulfur dioxide (1) is responsible

for any smog effects in present-day concentrations; or (2) forms any significant quantities of sulfuric acid. Nevertheless, the Southern California Edison Company is conducting a major research and development program, in cooperation with a joint council which includes representatives of the Air Pollution Control District, municipal power plants, and the Edison Company, to find some way of reducing either or both nitrogen oxides and sulfur oxides.

There are a large number of other miscellaneous sources of air pollution in our community, but we have no evidence that they include any one group or category responsible for an important contribution today. When our present major sources are substantially reduced, and as the community continues to grow, these miscellaneous sources could become relatively more important.

V. THE LOS ANGELES SMOG BATTLE

A. The Second Decade

The Los Angeles smog battle is entering its second decade. A conclusion that victory will be achieved by 1966 cannot be supported by any sober appraisal of where we stand today.

The Board of Supervisors of Los Angeles County appointed the first air pollution director on February 20, 1945. The Air Pollution Control District was officially created on October 14, 1947. Since that date and through June 30, 1956, it has spent $7,270,743. Over one-half of this total was spent in the last two years. Roughly 20 per cent has been devoted to research and allied technical activities. In two and one-half years, the Air Pollution Foundation has spent $1,915,000 on research. The oil industry in Los Angeles County has spent in excess of $30,000,000 on both air pollution research and installation of control equipment. The metallurgical industries and other local firms have spent approximately $12,000,000 on control equipment.

Beyond question, these measures—totalling approximately $52,000,000 during the first ten years — have substantially curtailed emissions of air pollutants from the particular sources where ways and means could be found and installed. What our air pollution problem would be like today if these measures had *not* been taken can only be imagined. The fact remains that in spite of them, no proof exists that smog today is less. During this same decade, industrial and human activities have increased at the highest rate in the nation. Forecasts predict that this rate will continue during the coming decade. What is the outlook for the smog battle?

B. The Outlook for Victory

We know of no way today to control our principal source — motor vehicle exhaust. As the number of vehicles increase, our smog will increase. If a perfected

control device for motor vehicles were handed to us tomorrow, automative engineers have estimated that it would take three years to mass produce, deliver, and install these devices on 2,500,000 motor vehicles.

There is an old rule of thumb in industry that on the average it takes seven years from the time laboratory work is started on the development of a new product, until the product is in commerical production. Many of our new products have taken longer; a few have taken less. This rule of thumb is tested and tried. We know of no better estimate to place upon the time required to develop a successful exhaust control system. Sporadic inventions and data-gathering so far represent only the usual reconnaissance, preliminary to the development period. If we count this year as the first, six more years for development, and three years for mass production and installation brings us to 1966 before we can see any relief from our number one source. Projections of our motor vehicle population growth of the decade just ending indicate that we will have 4,000,000 vehicles in 1966 — an increase of 1,500,000 above the present number, or 60 per cent more.

If the suggestion that we may not solve the motor vehicle exhaust problem for ten years seems inconceivable to you, recollect that Raymond R. Tucker, nationally known smoke expert from St. Louis, was brought to Los Angeles as a consultant ten years ago, and recommended at that time incinerators be prohibited. Their number has multiplied many fold during the past decade and they are still with us.

Recollect, also, that Dr. Edward Weidlein, who led the cleanup of Pittsburgh atmosphere, told us in this hotel two years ago that it took Pittsburgh 35 years, and the problem was simple compared to ours. Remember, also, that our present-day water and sewage sanitation has taken since 1890, a period of 66 years, to reach its present stage of development. Urban air sanitation is still in its infancy.

From such a point of view, a prediction that the Los Angeles problem will be solved by 1966 might seem optimistic.

C. A New Battle Plan

But I have been dealing with averages, with man's past performance in the absence of extraordinary incentives. One of man's most intensive development drives on record, what was known as the Manhattan project, resulted in the first A-bomb in much less than seven years at a cost of something like two billion dollars. Perhaps an attack on the smog problem, administered with comparable foresight and intensity, could reach a solution to this problem as quickly for two per cent of this figure — or forty million dollars, exclusive of control equipment. Los Angeles has already spent about ten million dollars on smog research and development alone.

Looking back over the record of the past ten years, it seems very much as though the battle against smog has been fought as a series of skirmishes in the belief that success was just around the corner, or coming "next year." We know now that the problem is of greater magnitude and more complex than anyone had any idea, even as recently as 1953.

What is needed now is a battle plan worthy of the foe and appropriate to the breadth of the battle front. It should be organized on a ten-year basis, not a ten-month basis. It requires the equivalent of a general staff; it requires a task force, which in comparison to our present skeleton troops, would be an army of scientific and engineering workers. It requires a budget for this research and development battle substantially greater than at present.

In round figures, the automobile industry reports its present preliminary activities are proceeding at the rate of about $1,000,000 annually; the District is planning roughly $500,000 on automotive research during the present fiscal year; the Air Pollution Foundation is devoting something like $300,000. So at the present time, not including scattered projects in universities and other private and industrial laboratories, about $1,800,000 per year is being spent on the motor vehicle exhaust problem. This is approximately 70 cents per year per motor vehicle in Los Angeles County.

D. A Joint Council

Because of the magnitude of the motor vehicle exhaust control problem, and the need for integrating a variety of expanded resources and facilities, the formation of a joint council would bring together all those primarily concerned with the work on this program. The council would presumably include representatives of the automotive industry, oil industry, Air Pollution Control District, and the Air Pollution Foundation, together with such technical assistants as the council requires. The principal purpose of this council would be to coordinate and unify the constructive efforts of all concerned. A similar council already exisits in Los Angeles County with respect to power plant emissions. Beyond question, our number one problem could be solved much sooner under the united direction of such a body supported with a war chest adequate to its needs.

This is not a job that can be done by county government or any other government alone. It requires in addition the experience and resources of the automobile and oil industries; it requires the participation of a group like the Air Pollution Foundation, subject neither to politics nor to special interests, as an independent, scientific body to assist in planning and carrying out a program that does not deviate from the shortest line to the goal. The District, the industries, and the Foundation all have valuable resources needed in the battle. Uniting these through a full-time joint council would reduce costly dissension and delays and concentrate forces in a way most likely to produce success in the shortest time possible.

VI. RECOMMENDATIONS

We submit these recommendations as the basis for the accelerated, more intensive, and more effective program which could hope to overcome the smog problem in substantially *less* than ten years. Recognizing that the cost might be something

like $40,000,000 (four times the research cost in our first decade), we further submit that this is small in comparison to the health and economic benefits which such a program could make possible.

Recommended that:

1. Ways and means be found to reduce the emissions of nitrogen oxides and organic compounds from their known sources.

2. Emphasis in the development of ways and means be placed upon major sources rather than minor sources.

3. Where remedies exist for a known pollution source, as in the case of incinerators, adoption of the indicated remedy be not delayed.

4. Research and development work be greatly accelerated on the search for ways and means for controlling pollution of two major sources, namely motor vehicles and industrial stacks.

5. Encouragement be given to companies and inventors interested in developing exhaust control devices.

6. With respect to ways and means for reducing organic compounds and nitrogen oxides in motor vehicle exhaust, the most promising leads be intensively pursued; including:

   a. Afterburners for all motor vehicles

   b. Catalytic converters for organic compounds on passenger cars and perhaps larger automotive engines

   c. Catalytic or other converters for nitrogen oxides on all motor vehicles

   d. Combination catalytic converter for both organic compounds and nitrogen oxides

   e. An induction-system device which may supplement the effect of any one of the foregoing devices

   and that possibilities which are more speculative be further explored, including:

   f. Combustion catalysts as fuel additives

   g. Modified or special fuels not relying upon minor additives

   The development of a radically new type of automotive power plant not emitting significant quantities of organic compounds or nitrogen oxide is, of course, theoretically possible, but such a development requires a much longer time.

7. Ways and means be found for reducing nitrogen oxides in industrial stacks; this development might well be integrated with similar work directed at motor vehicle exhaust, at least until such time as it is clear that two quite different devices are required.

8. Because of the magnitude of the motor vehicle exhaust control program, and the need for integrating a variety of resources, knowledge, and facilities, a Joint Council on Motor Vehicle Exhaust be formed to integrate all work on this program, representing at least the automobile industry, the oil industry, the Air Pollution Control District, and the Air Pollution Foundation, together with such technical assistants as the council requires. The principal purpose of this council would be to coordinate and unify the constructive efforts of all concerned.

V

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VII. APPENDIX

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by the

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since October 1, 1955

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PAPERS RESULTING FROM RESEARCH

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