AUTOMOTIVE AIR POLLUTION

A Report

of the

PANEL OF TECHNICAL ADVISORS ON AUTOMOTIVE AIR POLLUTION

to the

JOINT STATE GOVERNMENT COMMISSION

General Assembly of the Commonwealth of Pennsylvania

1963

The Joint State Government Commission was created by Act of 1937, July 1, P. L. 2460, as last amended 1959, December 8, P. L. 1740, as a continuing agency for the development of facts and recommendations on all phases of government for the use of the General Assembly.

JOINT STATE GOVERNMENT COMMISSION
OFFICERS AND EXECUTIVE COMMITTEE

1961–1963

OFFICERS

HARRIS G. BRETH, *Chairman*
HIRAM G. ANDREWS, *Treasurer*

EXECUTIVE COMMITTEE

SENATE MEMBERS:

ANTHONY J. DISILVESTRO
President Pro Tempore

CHARLES R. WEINER
Majority Leader

JAMES S. BERGER
Minority Leader

WILLIAM J. LANE
Majority Whip

ALBERT R. PECHAN
Minority Whip

ISRAEL STIEFEL
Chairman, Majority Caucus

ROBERT D. FLEMING
Chairman, Minority Caucus

HOUSE MEMBERS:

HIRAM G. ANDREWS
Speaker

STEPHEN MCCANN
Majority Leader

ALBERT W. JOHNSON
Minority Leader

JAMES J. DOUGHERTY
Majority Whip

EDWIN W. TOMPKINS
Minority Whip

ANTHONY J. PETROSKY
Chairman, Majority Caucus

NORMAN WOOD
Chairman, Minority Caucus

Member Ex Officio:
HARRIS G. BRETH, *Commission Chairman*

GUY W. DAVIS, *Counsel and Director*
PAUL H. WUELLER, *Associate Director in Charge of Research and Statistics*
ANTOINETTE S. GIDDINGS, *Administrative Assistant*

JOINT STATE GOVERNMENT COMMISSION
OFFICERS AND EXECUTIVE COMMITTEE

1963

OFFICERS

BAKER ROYER, *Chairman*

CHARLES R. WEINER, *Vice Chairman*

WILLIAM Z. SCOTT, *Secretary*

W. STUART HELM, *Treasurer*

EXECUTIVE COMMITTEE

SENATE MEMBERS:

M. HARVEY TAYLOR
President Pro Tempore

JAMES S. BERGER
Majority Leader

CHARLES R. WEINER
Minority Leader

ALBERT R. PECHAN
Majority Whip

WILLIAM J. LANE
Minority Whip

WILLIAM Z. SCOTT
Chairman, Majority Caucus

ISRAEL STIEFEL
Chairman, Minority Caucus

HOUSE MEMBERS:

W. STUART HELM
Speaker

ALBERT W. JOHNSON
Majority Leader

ANTHONY J. PETROSKY
Minority Leader

MORTON H. FETTEROLF, JR.
Majority Whip

JAMES J. DOUGHERTY
Minority Whip

NORMAN WOOD
Chairman, Majority Caucus

K. LEROY IRVIS
Chairman, Minority Caucus

Member Ex Officio:

BAKER ROYER, *Commission Chairman*

GUY W. DAVIS, *Counsel and Director*

PAUL H. WUELLER, *Associate Director in Charge of Research and Statistics*

ANTOINETTE S. GIDDINGS, *Administrative Assistant*

MOTOR VEHICLE AIR POLLUTION

TASK FORCE: THE EXECUTIVE COMMITTEE

HARRIS G. BRETH, *Chairman*

Senate Members

JAMES S. BERGER
ANTHONY J. DISILVESTRO
ROBERT D. FLEMING
WILLIAM J. LANE
ALBERT R. PECHAN
ISRAEL STIEFEL
CHARLES R. WEINER

House Members

HIRAM G. ANDREWS
JAMES J. DOUGHERTY
ALBERT W. JOHNSON
STEPHEN MCCANN
ANTHONY J. PETROSKY
EDWIN W. TOMPKINS
NORMAN WOOD

Legislative Advisors

WILLIAM VINCENT MULLIN
GEORGE J. SARRAF
JOHN T. VAN SANT
JOHN H. WARE, III

Legislative Advisors

ADAM T. BOWER
HARRY R. J. COMER
MORTON H. FETTEROLF, JR.
J. DEAN POLEN

PANEL OF TECHNICAL ADVISORS ON AUTOMOTIVE AIR POLLUTION

LETTER OF TRANSMITTAL

To the Members of the General Assembly of the
Commonwealth of Pennsylvania:

Senate Resolution No. 2, Session of 1962, directs the Joint State Government Commission to ". . . make an investigation and study of the relationship of motor vehicle exhaust fumes to air pollution, smog, lung cancer and damage to health and property; to study the imminency of the danger of automobile exhaust fumes and to advise on the necessity of enacting legislation to require the mandatory use of a type of muffler device to remove poisonous gases escaping from motor vehicle exhausts; . . ."

To facilitate a thorough and realistic evaluation of the chemical, engineering and health aspects of the problem under review, the Joint State Government Commission on May 8, 1962, appointed a panel of experts consisting of specialists in mechanical and sanitary engineering, chemistry, and public health.

The Panel of Technical Advisors undertook an intensive study and comprehensive evaluation of the various aspects of the motor vehicle air pollution problem and, with members of the task force and legislative advisors, visited the General Motors Research Center in Detroit; the Taft Sanitary Engineering Center and the Toms River Biological Laboratory, both of the United States Public Health Service, in Cincinnati; the United States Public Health Service in Washington and its Clinical Center in Bethesda, and the Sloan-Kettering Institute in New York. In the Los Angeles area, the Motor Vehicle Pollution Control Board, two air pollution control districts, the Scott Laboratories, Stanford Research Laboratories, and the Air Pollution Research Center at the University of California in Riverside were visited. In the San Francisco Bay area, visits were made to the State Department of Health, the Bay Area Air Pollution Control District, and to the California Research Laboratory at Richmond.

In connection with the visits to the various installations, the Panel of Technical Advisors conferred with leading health, engineering and air pollution experts.

The Panel advises that its survey and evaluation of the problem "should be regarded only as a beginning in the necessarily long-range study of the subject for Pennsylvania. Based upon this initial survey the Panel has made moderate recommendations which it believes to constitute sensible first steps in any sound extended program."

I have the honor to transmit the report and recommendations of the Panel of Technical Advisors.

BAKER ROYER, *Chairman*

Joint State Government Commission
Capitol Building
Harrisburg, Pennsylvania
February 1963

CONTENTS

TABLES

SUMMARY AND CONCLUSIONS

1. It is important to note that the careful and scientific study of air pollution in general, and that from automotive sources in particular, is a relatively new field. Activity in this study is now being accelerated at a rapid rate both in this country and elsewhere.

2. Very little information now exists concerning the extent to which air pollution, within the Commonwealth, is attributable to the motor vehicle. A study of conditions pertinent to Pennsylvania is urgently needed.

3. There can be serious and damaging air pollution without the presence of smog in its visible or sensible form.

4. Automotive engines are known collectively to discharge large masses of noxious and toxic substances. This is at present a substantial source of many pollutants including carbon monoxide and a variety of hydrocarbons.

5. There is lack of agreement in the medical profession and among researchers regarding the effect of automotive emissions, in atmospheric concentrations now existing, upon human health. This is due to the large number of intangible factors and to the time which must elapse between cause and effect in any study of this nature. Intensive work is now under way or is being initiated on this subject, but the results may not be conclusive for some years.

6. The air pollution disasters which have occurred in the past are apparently due to pollutants from sources other than the motor vehicle, combined with unusual meteorological circumstances.

7. Relatively simple steps may be taken to appreciably reduce the discharge of harmful substances by the present conventional automotive engine.

8. Very little can be done further in the production of gasoline which will change the character of this fuel so as to reduce the emissions of objectionable substances from automotive engines.

9. There is every reason to believe that the automotive industry is conscious of the growing problem of air pollution and is working to improve the situation. This work, involving research and redesign, is a long-term project.

10. Reasonable controls, notably the use of effective blowby devices and periodic maintenance procedures, for the reduction of noxious emissions are justified on the basis that (a) certain emissions are known to be harmful and to be discharged in large quantities constituting, under certain circumstances, not only a public nuisance but a threat to common safety and welfare; (b) automotive vehicles are one of the major sources of air pollution which is virtually uncontrolled at present; (c) there is ample reason to suspect a relationship between automotive air pollution and human health and welfare and property damage; (d) there is a time lag between the initiation of a control program and the widespread effectiveness of such a program; and (e) a control program undertaken now will, as it becomes effective, tend to alleviate present conditions and to prevent an increase in severity of the problem as the automobile density increases in the future.

11. The mobile sources of air pollution present special control problems as compared with stationary sources.

RECOMMENDATIONS

The Panel recommends that action be taken as follows:

1. That means be provided to conduct an analytical survey of atmospheric contaminant concentrations from the automotive source in selected localities of the Commonwealth. This should be of sufficient scope to include seasonal and annual variations.

2. That a small technical group be established for an additional two years to advise concerning any technical programs, such as are recommended under paragraphs 1 and 5, as may be undertaken and in order to appraise new information, forthcoming health effect data, anticipated mechanical improvements, and field experience both in Pennsylvania and in other areas. This group would advise the Joint State Government Commission on all pertinent developments and would make such further reports and recommendations as might be deemed necessary or desirable.

3. That positive crankcase ventilating devices be required as factory-installed equipment on all new cars registered in Pennsylvania beginning January 1, 1964.

4. That the established automobile inspection system in Pennsylvania be utilized to extend the regular required semiannual inspections to include (a) a check of the ignition system with adjustments, repairs and parts replacement when necessary; (b) a check of the air cleaner and servicing as required; (c) carburetor adjustment to lean-idle and cleaning or rebuilding of the carburetor, if necessary; and (d) a check of the blowby device on cars so equipped, with cleaning or parts replacement as necessary. The Panel regards this as a highly important step but recommends that action be postponed pending the outcome of the studies proposed under paragraphs 5 and 6 following.

5. That, although in the opinion of the Panel a system requiring regular maintenance would be effective in substantially reducing emissions, provision be made to undertake a corroborating test program on passenger cars representing a cross section of makes and models. These would be subjected to periodic, expert maintenance as outlined in paragraph 4. Exhaust gas analyses would be made under road conditions before and after the maintenance procedures and at suitable mileage intervals between these operations. This program should be undertaken at an early date.

6. That concurrently with the testing program recommended in paragraph 5 the Secretary of Revenue be consulted with respect to the practicability of expanding the now-existing inspection service to include the items listed in paragraph 4. If considered feasible from other standpoints, there should be an estimate of the time required for the agency or agencies concerned to implement such a program.

7. That the Motor Vehicle Code be amended to cite such motor vehicles as operate on the highways with continuous visible emissions other than water vapor and to require the owners of such vehicles to correct the situation by such adjustments or repairs as may be necessary.

APPENDICES

APPENDIX A

THE GENERAL PROBLEM OF POLLUTED AIR

The definition of air pollution is not an easy task. The one definition which will satisfy everyone is virtually impossible of attainment. However, by convention, it is usual to consider as pollutants in the atmosphere those substances which when added in sufficient concentration produce a palpably adverse effect on man or other animals, vegetation or material. This more or less universal definition of pollutants encompasses the widest variety of substances which may get into the air. Thus, solid particulate matter, vapors, gases and liquids—either separately or in mixtures—contributing to the above effects are considered as pollutants. Air pollution experts have attempted to classify pollutants presently determinable and recognized. One such classification considered two general groups: (a) those emitted directly from identifiable sources, and (b) those produced in the air by interaction among two or more primary pollutants or by reaction of the normal atmospheric constituents, with or without photoactivation. Another classification which is more pertinent to the subject of this report may list pollutants simply in accordance with their source, as either from a stationary source, such as industrial, domestic, etc., or from a mobile source, which has to do with transportation—automotive vehicles, railroad locomotives or aircraft. This latter classification will be referred to throughout this report and pollutants will be mentioned as originating from either a "stationary" source or a "mobile" source.

We are admonished, however, that any classification system based upon present-day sampling techniques and methods of analysis must also certainly fall short of a complete description of the qualities of polluted air. "This is true because few, if any, of the polluted entities retain their exact identities after entering the atmosphere. Thermal and photochemical reactions often catalytically facilitated by gases on solid and liquid surfaces provide a dynamic, constantly changing character to the total system and to its individual constituents."[F 24]

The problem of polluted air has been with man ever since he learned to use fire and, by burning, produced the results of combustion. Man cannot live without breathing oxygen diluted with some inert gas. In the atmosphere we have a suitable mixture of oxygen and nitrogen. However, in addition there is an assortment of gases, vapors and aerosols varying in content and concentration at different locations over the surface of the earth and these he must likewise breathe. Also there is always present in the atmosphere, to a greater or lesser degree, finely divided solid matter which is commonly referred to as particulate matter. The particulate matter is somewhat more readily separated from the air which man breathes by an efficient filtering system in his own respiratory tract. This also applies to some aerosols. The gases and vapors which he must inhale, however, are not separable and pass into the lungs together with the oxygen and nitrogen which he must have. Some of these atmospheric impurities are physiologically inert but some of them produce reactions in man which range all the way from slight inconvenience or nuisance to that of severe toxicity.

As we have found in parallel with our water resources, it is quite evident that the atmosphere in any part of the earth is polluted in varying degrees. The most famous natural air pollution episode with world-wide implications was the explosion at Krakatau in the Pacific Ocean spewing forth dust which girdled the globe many times before finally settling out or becoming dispersed. In a less spectacular manner decaying vegetable matter and animals, forest fires, etc., pollute the air with gaseous and particulate matter constantly. However, the general public's concern with air pollution only became acute as a result of the growth of science and technology and as urban centers increased in density.

As severe as air pollution could have been in very restricted areas, it was when coal was introduced as a source of heat that the public began to show its discontent. Some historians claim that air pollution as a social problem dates in Europe from the 14th century. However, for all practical purposes, the assessment of air pollution and the measurement of air quality deterioration and subsequent progress in control must be dated from 1850.

When viewing the more than 100 years since the beginning of understanding of the air pollution problem, one can witness two diametrically opposed processes in operation. On the one hand advancing technology with its various processes has introduced new and greater amounts of pollutants into the air and on the other hand the people living in towns and cities suffering from air pollution have become increasingly intolerant of the polluted air that they must breathe, see or feel. At the same time the evidence of adverse effects on vegetation, animals, and soiling of buildings and clothing provided another area of major concern.

Wherever people congregate the atmosphere in that locality is bound to become polluted. The great preponderance of man's activities results in products which pollute the atmosphere in which he lives. The simple and everyday acts of breathing, cooking food, heating his habitat, utilizing powered transportation, the production of electrical energy, change the character of our fresh air. All of the waste gases and vapors or pollutants resulting from these activities are discharged into the earth's atmosphere in the hope that they will simply be absorbed without further disturbance to the general population. The earth's atmosphere, however, though huge in volume, is not infinite and is only self-purifying to a limited degree. Therefore the introduction of pollutants in prodigious quantities is bound to reduce the pure qualities of the air worldwide and may some day become a problem irrespective of precise locality. This, however, is in the far distant future and the current problems with air pollution occur near the sources only. The solution therefore resolves itself into two phases: first, the problem of finding the most economical, least harmful and longest lasting method of disposing of our waste products without building up excessive concentrations of these contaminants, even close to the source, and, second, the problem of maintaining the mass discharge of pollutants at a minimum consistent with the carrying on of man's necessary and normal activities.

In time the pollution which may be excessive in one location may not be in another. For example, those areas in which prolonged fog, that is, lasting for more than one day, as occurred in London or in Donora, are not unusual. These result from a combination of meteorological factors that lead to temperature inversion. The final result is atmospheric stagnation in which the normal vertical air currents, or turbulence, usually stop and temperatures rise a few degrees as one ascends from ground level and may continue to rise for a height of 1,000 feet or more. The lower part of this inversion layer may be near the ground or can be well above it and in actuality may move up or down. The ceiling of the layer may vary in height from a few hundred to several thousand feet. Fogs have been famous all over the world, especially London fogs which create a condition of grime and soot which was named "smog" by Dr. H. A. Des-Voeux in England in 1903, about forty years before the lacrymatory fog of the Los Angeles area came into being. It is thus quite clear that meteorological phenomena and local conditions are highly important contributors to the problem of air pollution.

SOURCE OF POLLUTANTS

The most ancient source of air pollution in anything like disagreeable concentrations was undoubtedly that resulting from home heating. The emissions from this source have in modern days been somewhat reduced per capita by the use of better fuels and by improved techniques for burning. There remain, however, as possible domestic sources of air contamination household incineration; open burning of trash, garden products, etc.; and open dumps. Add to the domestic sources the constantly growing and currently much more important industrial sources—such as power plants, factories of various sorts, and other commercial sources—and the problem is compounded. These are all stationary sources, however, and in many densely populated areas are already under more or less rigid control by air pollution bodies deriving their authority at the local government level. The ever-increasing source of pollutants is the mobile source, of which the automotive vehicle is by far the most important. Unlike the controls that have been imposed upon the stationary sources, little or no control is exercised over the emission of contaminants by the automobile, bus and truck. Because of the mobility of this source, local control is difficult and it becomes necessary to consider a broader system of control than exists for the stationary sources.

It is to be noted that almost all of the modern pollutants, exclusive of certain kinds of particulate matter, are the product of the combustion of fuel. Therefore, it is a matter of great importance that the combustion of this fuel be carried out in such a manner as to produce the least possible air contamination. This includes the automotive engine and, owing to the large mass of emissions from this source, serious consideration must be given to reducing the quantity of pollutants discharged while at the same time not interfering with the operation of these vehicles. Later sections of this report will discuss means for reducing emissions, some of which would seem to be practicable and rather easily initiated.

THE CHANGING NATURE OF THE PROBLEM

Changes in community activities, industrialization, or a change in the use of fuel bring about continuing transformation in the nature of the source of the problem and the solution of existing situations. For example, when the railroads converted from coal-burning steam locomotives to diesel or electric locomotives, the nature and extent of this source of air pollution were greatly modified. In some communities in the Commonwealth this change coupled with other changes in fuel and the conversion of home heating equipment from high-sulfur-content coal to low-sulfur-content coal, or completely away from coal to fuel oil and natural gas, brought about a tremendous change in the magnitude and character of the air pollution problem. Industrial changes in design and processes of manufacture both remove old sources of pollution and at times develop new sources. What is of great importance is the changing attitude of the public in general and its concern with industries and their sources of pollution in particular. It is quite evident that there is an increasing public concern with regard to atmospheric pollution and new standards are demanded. The Donora incident, the London fog incidents, the continuing aspect of Los Angeles smog and other acute problems not as well documented, cause people concern and cause them in turn to demand new standards which in the future will preclude the possibility of such occurrences and in the case of Los Angeles remove the frequently-recurring smog situation. Increasingly with the preoccupation over the occurrence of air pollution episodes, the public is concerned with air pollution and its effect upon health. Many individuals are concerned with the possibility of the chronic and additive nature of air pollution insults to their own health and that of future generations. With the rapid increase in the importance of the automotive source and with the comparative lack of control over it, large segments of the citizenry, particularly in the densely populated areas, are becoming articulate, either individually or through pertinent organizations, in demanding that some improvement be instituted to at least prevent a worsening of this situation as the automobile density increases.

The wide general problem of air pollution is aptly stated in the following quotation.

"Man's existence has always depended upon the delicate equilibrium of the constituents of the atmosphere. At the present pace of technical change, and because of the growing magnitude of industrial and other operations, widespread alterations in these constituents are occurring. We now possess the capacity to determine whether the atmosphere is being used in such a way as to preserve its ability to sustain life or whether man's atmospheric environment shall continue to deteriorate to the detriment of his health and his way of life. The future of mankind depends upon the wisdom with which we conserve our atmospheric resources.

"The present state of knowledge about atmospheric pollution and its control provides a basis for predicting consequences for our air resources of certain patterns of human activity, such as transportation systems, industrial operations, energy production and weapons testing. Given this knowledge, policy decisions on matters like land utilization, fuel usage and urban organization become imperative in conserving our air resources. A sound public policy suitably implemented can protect health and economic values and can encourage technical progress."[F 25]

APPENDIX B

ATMOSPHERIC POLLUTANTS AND THEIR EFFECTS

GENERAL PHYSIOLOGICAL EFFECTS

The physiological effects of air pollutants and specifically those attributable to motor vehicle emissions have been discussed in very great detail in the Schenck Act report.[F 1] It need only be stated here that motor vehicle exhaust gases contain substances that are known to have adverse effects on animals, plants and human beings.

Essential components of the decision which faces the State of Pennsylvania are those of determining (a) what levels of air pollution attributable to motor vehicles now exist in Pennsylvania; (b) how these levels are likely to change in the future; (c) how these levels, present and future, are related to the nuisance, health and vegetation damage problems; and (d) what reasonable and logical steps should be taken now to reduce the threat of automotive air pollution.

As mentioned elsewhere in this report, a quantity of pollutants is constantly emitted from the gasoline engine during operation. There are tremendous numbers of such substances and their relative amounts vary with conditions of driving. However, three principal products make up over 99 percent of the total undesirable emissions. These are carbon monoxide, hydrocarbons and nitrogen oxides. At the present time it is generally felt that the remaining 1 percent presents relatively little, if any, significant health hazard, but this opinion is subject to further investigation. It is estimated that over the country as a whole motor vehicles emit, annually, 90 million tons of carbon monoxide, 12 million tons of hydrocarbons and 4.5 to 13.5 million tons of nitrogen oxides. The emissions in Pennsylvania could be quite accurately gaged by the proportional amount of gasoline consumed in the Commonwealth. Table B-1 indicates, quantitywise, a further breakdown of automotive emissions in the United States.

TABLE B-1
Annual Automotive Pollutant Emissions
in the United States.[F 1]

Compounds	Thousands of Tons per Year
Carbon monoxide	90,000
Hydrocarbons	12,000
Nitrogen oxides	4,500–13,500
Aldehydes	150
Sulfur compounds	150–300
Organic acids	60
Ammonia	60
Solids	9

If these massive quantities remained at their sites of origin, no one could survive. Everyone is aware of the all-too-common fatal poisonings from motor exhaust fumes emitted in enclosed spaces. However, natural air movements dissipate these pollutants and in most localities they do not accumulate in sufficient concentrations to produce adverse symptoms. However, when topographic or climatic conditions prevent natural air ventilation, the pollutants accumulate and in certain areas, such as Los Angeles, objectionably high levels are recorded during substantial portions of the year.

In addition to the above-mentioned products of the non-ideal combustion of motor fuel, there is lead—a metal that is added to gasoline in order to improve engine performance. This substance is added to the fuel in the amount of 2 to 4 cc per gallon usually in the form of tetraethyl lead and is emitted as a fine dust, composed mostly of lead chloride or lead bromide.

Further adding to the air pollution problem is the evaporation of unburned gasoline—a highly volatile fluid which undergoes considerable vaporization during storage and handling.

Not all of these compounds are equally important as contributors to health hazards or nuisances and, furthermore, they are very unevenly distributed throughout the United States. It is a fact that insofar as Pennsylvania is concerned there is very little corresponding current knowledge on total motor vehicle emissions. It is possible to infer, however, on the assumption that there must be some correlation between motor vehicle emissions and automobile registrations per square mile, that the emission in large cities in Pennsylvania is sufficient to raise questions which cannot be totally ignored. Table B-2 shows some of these registration densities.

TABLE B-2

1960 Passenger Car Registration per Square Mile in Thirty Metropolitan Areas.(F 1)

City	Cars
Washington, D. C.	4,100
Denver	3,951
Philadelphia	3,730
New York City area	2,200
Detroit	1,580
Chicago	1,541
Los Angeles	1,350
Milwaukee	1,034
Seattle-Tacoma	820
San Francisco-Oakland	768
Cincinnati	659
Pittsburgh	650*
All others (18) less than	650

* Based upon the area of Allegheny County, not the metropolitan area of Pittsburgh. This figure would then be considerably higher were only the city itself to be considered.

The positions of Philadelphia and Pittsburgh as third and eleventh, respectively, on this list suggest that whatever the problems that arise from motor vehicle air pollution in Pennsylvania, they are likely to be centered in and around these two cities or in other localities having poor natural ventilation.

In spite of these inferences there is very little direct experimental evidence permitting generalizations as to the concentration of important pollutants likely to be found in Philadelphia or Pittsburgh. The problem is further complicated by the fact that most of these pollutants show diurnal, seasonal and annual variations; that the existing sampling stations are located at points within the cities where pollutant concentration is thought to be high and they therefore do not represent average concentrations; and that the sources of pollutants differ in different locations and the portion which should be charged to motor vehicles is uncertain.

Polynuclear aromatic hydrocarbons are of particular interest since it is known that some are potentially carcinogenic and are found in the automobile exhaust.

Other hydrocarbons, especially unsaturated hydrocarbons, are of interest because they are involved, probably with oxides of nitrogen, in a complex series of photochemical reactions which lead to the production of smog. Some of the unsaturated hydrocarbons also have a phytotoxic effect which will be mentioned later. There is abundant evidence that automobile exhausts are primarily responsible for photochemical smog and there is no question but that it is an extremely disagreeable nuisance.

There is little evidence that irreversible injuries to health result from exposure to smog. It must be remembered, however, that while smog is the type of air pollution most noticeable to the senses, there may be serious contamination without the presence of smog and in practically invisible form. High concentrations, for instance, of carbon monoxide or of certain of the hydrocarbons emitted from vehicles are injurious to health without the presence of photochemical smog. Furthermore, the carcinogens among the contaminants are not necessarily the only important constituents from the health standpoint. Various forms of pulmonary disease, other than cancer, and irritations which increase the susceptibility to disease may be the result of exposure to sufficiently high concentrations of certain exhaust gas constituents in the atmosphere.[F 38]

PHYTOTOXICITY OF AIR POLLUTANTS

It has been well known for many years that sulfur dioxide has an injurious effect on vegetation. The work of Katz and Pasternack[F 21] demonstrated that 0.3 parts per million of sulfur dioxide might be phytotoxic. Among the serious phytotoxicants are fluoride and ethylene. As little as 0.2 parts per billion of hydrogen fluoride may damage gladiolas and 1 ppb can harm peach leaves. While it has been known for some time on the West Coast that ozone and oxidants damage vegetation, more recently it has been shown that this type of damage also occurs near Eastern metropolitan areas. Investigators of the New Jersey Agricultural Experiment Station [F 22] state that with the sources of contamination—automotive, domestic, industrial, etc.—being so numerous, both in and bordering New Jersey, it is not surprising that test tobacco plants placed in fourteen different locations showed injury from oxidants in every location. It appears therefore that this is a problem which, while being most serious near such cities as Philadelphia and New York, can be expected to affect sensitive plants in all areas of the state.

Clearly such damage to plants will affect the areas in Pennsylvania bordering Philadelphia, Pittsburgh and other cities.

Very recently a study of the lead concentration in vegetation near paved roads in three areas of the United States was made.[F 23] Two of these were near Pennsylvania and vegetable samples showed lead content ranging from 10 ppm to 700 ppm, with an average of 115 ppm, in contrast to an expected background of 5 to 10 ppm. Six soil samples averaged 515 ppm of lead and ranged from 100 to 1,000 ppm. These samples were generally less than 50 feet from the road and the lead concentration appears to diminish rapidly as the distance from a traveled highway increases.

FUTURE PROSPECTS IN AIR POLLUTION

Two prospects are of importance under this heading: (a) the changes in atmospheric concentrations from auto exhaust likely to occur in the near future, and (b) the data on pollutant concentrations in Pennsylvania which are likely to become available.

If the assumption is made, and it is a reasonable one, that the total pollutant concentrations in urban areas will run roughly parallel to the rate of gasoline consumption, then it is possible to conclude that the pollution problem in Pennsylvania will not become drastically worse in the next two or three years. Table B-3 shows gasoline sales in Pennsylvania by years.

TABLE B-3
Estimated Annual Gasoline Consumption
in Pennsylvania 1945 to 1961

Fiscal Year	Millions of Gallons	Fiscal Year	Millions of Gallons
1945	1,246	1954	2,650
1946	1,653	1955	2,834
1947	1,799	1956	2,969
1948	1,952	1957	3,095
1949	2,043	1958	3,144
1950	2,210	1959	3,199
1951	2,359	1960	3,249
1952	2,467	1961	3,209
1953	2,584		

It is clear that the rate of increase in the last few years is small. This may be attributed to the popularity in recent years of compact cars with lower gasoline consumption. It now appears that the trend is toward larger cars in which case the gasoline consumption will rise again although it is not indicated that any startling increase will occur in two or three years. However, it is important to note that any air pollution control program which may be initiated takes from 7 to 10 years to become effective and the projection of fuel consumption over this period will certainly show a notable increase as will be seen later in the discussion of national automobile registration.

There is a very good prospect that within two or three years the facts about air pollutant concentration in some of the major cities of Pennsylvania and throughout the country will be much better known. The United

States Public Health Service has placed in operation continuous air monitoring stations in Chicago, Cincinnati, Detroit, Los Angeles, New Orleans, Philadelphia, San Francisco, and Washington. These stations have not been in operation long enough to have yielded a significant amount of data but there is no question that two or three years from now our knowledge will be much more adequate than at present, particularly in combination with other data collected in some areas for periods of over 10 years.

There is a reasonable prospect that within a similar period information on the biological aspects of automobile exhaust will be correspondingly improved as a result of considerable intensification of effort in this field. Types of studies now in progress or in prospect include (a) studies of special groups of patients ill with chronic pulmonary disease residing in areas where pollution is believed to be primarily due to automobile emissions; (b) studies of animals exposed to air from heavily-traveled streets and highways; (c) lifetime studies of animals exposed to automobile exhaust constituents, irradiated or non-irradiated, and in various concentrations.

It should be realized, however, that all programs of this type take time and will only produce tangible results over a period of years. The U. S. Public Health Service has become very conscious of the effects of air pollution on health and many of the studies now being conducted are being carried out under USPHS auspices. These studies will be for the most part national in scope and any state desiring specific information with regard to its own atmospheric conditions will have to carry out some investigations independently which apply specifically to the areas and to the people within that state's jurisdiction.

In summary, although there is at present little direct and unequivocal evidence of irreversible injury to humans by the inhalation of automobile exhaust gases, there is sufficient peripheral evidence to point to potential hazards which cannot be ignored. Automobile traffic densities, at least in Philadelphia and Pittsburgh, are sufficiently high to suggest that these cities constitute sites where the problem deserves close scrutiny. The health hazard wherever it is will probably not become strikingly worse in Pennsylvania within the next two or three years. There is some evidence to indicate that it should not be permitted to become worse or should even be alleviated to some degree starting very soon, in order that an effective program may be in operation to counteract the tendency of the worsening condition. It is certainly not safe to conclude that the pollution problem will not be much more serious in ten to twenty years unless steps are taken immediately to correct it. By no means all of the facts needed to reach tentative conclusions on the magnitude of the hazard in Pennsylvania are now available. Therefore steps should also be taken in the near future to determine with some degree of accuracy what the true situation now is in various urban centers. Such a program would necessarily have to cover a period of from one year to eighteen months in order to cover seasonal changes and therefore this should be initiated at an early date.

MEDICAL ASPECTS AND EFFECTS OF POLLUTANTS

The rapid increase in the number of automobiles on our streets and highways together with the steady increase in the size and urbanization of the population, have resulted in increasing concern about the potential health and economic hazards resulting from motor vehicle exhaust emissions. In the past thirty years the number of automobiles in use in the United States has increased from about 23 million to about 70 million. This is expected to reach 86 million by 1970 and 100 million by 1980. While the population increased 20 percent from 150 million to 180 million in the decade from 1950 to 1960, automobile registration increased about 44 percent from 49 million to 71 million. Motor vehicles consume approximately 60 billion gallons of gasoline annually, or about one gallon per person per day at the present time.

In Pennsylvania total motor vehicle registration increased from 2.1 million in 1945 to 4.4 million in 1960 and the gasoline consumption increased from approximately 1,200 million gallons in 1945 to 3,200 million gallons in 1961. Philadelphia has an automobile density of 3,730 per square mile, third highest of all cities in the nation. Although automobile registration density is undoubtedly not as accurate a criterion of possible air pollution as is fuel consumption in a given area, still this indicates that Pennsylvania has a potential air pollution problem and as indicated previously, this problem is bound to become worse rather than better unless specific steps are taken to prevent a worsening.

The characteristics, physiological effects and the possible or known medical problems associated with the various constituents of the gases emitted from automotive vehicles will be considered separately.

Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless gas which is poisonous at relatively low concentrations. It is to be noted from previous information that carbon monoxide is the most abundant injurious gas emitted by motor vehicles. It is harmful in that it has a high affinity for hemoglobin and other substances which, in living cells, are concerned with the utilization of oxygen; thus it kills by asphyxiation. The injurious effects of carbon monoxide are essentially the same as those induced at high altitudes where lowered atmospheric pressure results in a deficiency of oxygen. About 200 ppm of carbon monoxide is equivalent to exposure to an atmospheric pressure occurring at 10,000 feet altitude. Individuals exposed constantly to high carbon monoxide levels have a high blood hemoglobin content and a high red cell count just as do people living at high altitudes. As with other poisonous materials the effects are enhanced with increasing exposure times. An atmospheric concentration of 900 ppm for one hour causes nausea and headache and 1,600 ppm may cause death. However, much lower levels may have serious consequences. At a concentration of as low as 30 ppm as much as 5 percent of the blood's hemoglobin would be rendered inactive. In California it was found that a level of 120 to 240 ppm may cause accute illness in sensitive individuals and is considered a serious to emergency level. Such concentrations have been reported in heavy traffic.

Among the symptoms of chronic carbon monoxide poisoning are disturbances in vision and hearing, impairment of judgment, and headache. On the other hand experimental studies in which men submitted voluntarily to high concentrations for many weeks demonstrated no definite signs of illness. Likewise studies of humans chronically subjected to high concentrations of carbon monoxide, such as garage workers, traffic policemen, vehicle tunnel personnel, truck drivers, etc., who are constantly exposed to concentrations of 20 ppm and occasionally to concentrations up to the 100 ppm level, showed no definite pattern of illness attributable to carbon monoxide. Apparently chronic exposure results in the development of tolerances which may be due in part to the increase in the body hemoglobin level. Under ordinary circumstances there does not seem to be a great danger to health in chronic exposure to low concentrations of carbon monoxide as revealed by epidemiological data. However, a large increase in the use of motor vehicles may raise levels to the danger point more frequently and there is a strong possibility that acute exposure to high levels of carbon monoxide, such as occurs during heavy traffic, will cause aggravated effects in sensitive individuals suffering from already diseased heart or lungs.

Hydrocarbons

Motor vehicles emit an incredibly complex mixture of organic substances of which the greatest quantity is hydrocarbons. These consist of two main types: the low molecular weight aliphatics and the high molecular weight aliphatics and aromatics. Each of these classes exhibits its individual pattern of atmospheric accumulation and health hazard. The low molecular weight aliphatics are highly volatile and ordinarily disperse rapidly. They may be subdivided into two groups: the paraffins and the olefins. The former are essentially chemically inert and probably contribute no problem. The olefins, however, may undergo reactions in the atmosphere which under certain climatic conditions result in the formation of smog. The aliphatic and aromatic, high molecular weight compounds are essentially nonvolatile and remain suspended as an aerosol, either in fine droplets or attached to soot particles. These settle out in time by gravity or are washed down with rain. When inhaled, these particles enter the lungs, attach themselves to the mucous membranes and may remain for relatively long periods. They may be removed by coughing or swallowing, or they might undergo a slow metabolism. Among this class of compounds are several substances which are known to be cancer-inducing in animals and they are also suspected of causing cancer in humans.

Unsaturated Aliphatics, Ozone and Oxidants

The unsaturated aliphatics are volatile substances which would not produce a serious air pollution problem if it were not for the fact that they may under certain atmospheric conditions undergo a series of chemical reactions with nitrogen oxides also emitted from the automotive vehicle and with the oxygen of the atmosphere. These reactions are catalyzed photochemically by sunlight and are the primary cause of the well-publicized Los Angeles type of smog.

The photochemical reaction leading to smog formation results in the appearance of large quantities of ozone in the atmosphere and is thought also to produce nitro-olefin organic peroxides and probably other toxic substances or irritants. The amount of photochemical reaction products in some localities can be estimated by measuring ozone (or total oxidant) in the atmosphere. Ozone is a normal constituent of the atmosphere and is in particularly high concentration in the upper atmosphere, being formed there by the action of solar and cosmic radiation on atmospheric oxygen. Extensive studies in California have clearly shown that the accumulation of ozone at low altitudes is due to the combined effects of sunlight, atmospheric stagnation, and excessive motor vehicle exhaust emissions. With severe air pollution in the Los Angeles area, the ozone level reached 1 ppm as compared with a normal level of 1 or 2 parts per

100 million. It has been found that the high ozone levels are generally accompanied by mass eye and mucous membrane irritation, smog, plant damage and the cracking of rubber materials, such as tires. The peculiar topography of Los Angeles lends itself to this condition, owing to the frequency of atmospheric inversions which prevent natural ventilation. It has been generally thought that this condition is localized to that area, but there is an increasing suspicion that the same situation may lead to smog manifestations in other parts of the country. However, the frequency of such occurrences is still uncertain. The smog conditions which prevail in northern sections of the country in the winter and which are similar to the London-type smog probably have a different origin. It seems that this type is probably due more to sulfur dioxide air pollution from stationary sources than to automotive emissions.

When measured in most eastern cities, ozone levels are low, suggesting the absence of photochemical smog. However, in such areas, particularly those where coal and residual oil are burned for heat and power, comparatively high concentrations of sulfur dioxide (SO_2) are usually present in the atmosphere and this substance being a reducing agent might conceivably mask the analytical detection of the presence of ozone. Nevertheless high ozone or oxidant levels have been sporadically reported in such eastern cities as Washington and Philadelphia, and there is growing recognition that photochemical smog may be more widespread than was originally presumed.

Ozone itself is a toxic, reactive and corrosive gas potentially a serious health and economic hazard. It is suspected of being responsible for extensive damage to crops occurring near urban centers and along heavily traveled highways from New Jersey to California. Symptoms of acute toxic effects in humans are seen in five hours at doses of 2 ppm and serious symptoms, such as substernal pressure, irritation of eyes and mucous membranes and temporary loss of resistance to colds, were noted at 9 ppm. Although there is as yet no definite evidence that ozone in the amounts generally found in city atmospheres is harmful to humans, more information is urgently needed both on its toxic effects and the ambient levels in urban atmospheres.

Polycyclic Hydrocarbons—a Potential Cancer Hazard

Extensive chemical analyses carried out in various laboratories throughout the world have conclusively demonstrated that substantial quantities of polycyclic hydrocarbons are a product of gasoline consumption in automotive engines. To assess properly the role of the polycyclic hydrocarbons in human disease, it is necessary to recognize that these substances are formed whenever organic fuels are incompletely burned. They are inherently a product of the imperfect combustion process and the amounts are greater the less efficient the combustion. The probability that tars or soot produced by burning fuel may cause cancer was first suggested in 1775 when Percival Pott, a British surgeon, observed cancer of the scrotum in chimney sweeps. Cancer-producing effects of coal tars have been conclusively demonstrated by many experiments on animals and chemical and toxicological analyses show these effects to be due to polycyclic hydrocarbons. A large number of compounds with varying degrees of cancer-producing potency have been isolated from coal, wood and oil tars and many of these have been synthesized in the laboratory. Among these perhaps the most abundant is benzo(a)pyrene, commonly referred to as benzpyrene.

Although benzpyrene is the best known of the representative polycyclic hydrocarbons, it is important to recognize that many carcinogens occur in these tars and their effects as well as those of benzpyrene may be either aggravated or lessened by other components. It should also be kept in mind that polycyclic hydrocarbons are present in bituminous materials used for road surfacing and may also be present in rubber tires. Road and tire abrasions undoubtedly contribute polycyclic hydrocarbons to atmospheric pollution but their importance in the whole picture is still unknown.

Granting that the motor vehicle contributes cancer-producing chemicals to the atmosphere, it remains to assess this source as a public health problem. Lung cancer is the only form of cancer that has shown a striking increase paralleling the urbanization of population and has now become one of the leading causes of death in men. Approximately 36,000 per year in the United States, or about one in every twelve cancer deaths, was due to lung cancer in 1960.

Three main sources of human exposure to polycyclic hydrocarbons may be considered. These are (a) motor vehicle exhaust emissions, (b) fumes from household and industrial heating equipment and power plants, and (c) tobacco smoke. Authorities agree that all three sources represent varying degrees of lung cancer hazards to humans but they differ in their opinion as to their relative importance. Far greater quantities of polycyclic hydrocarbons are produced from furnaces and motor vehicles than from tobacco, but the degree of exposure at inhalation level is different. In the former, the fumes are dilute to a greater or lesser degree, depending on air ventilation, whereas in smoking, particularly cigarettes, the smoke is usually inhaled directly and thus comes into intimate contact with the lung surfaces. The consensus of experts is that the degree of exposure to polycyclic hydrocarbons is considerably greater in heavy cigarette smokers than in the general urban populations.

That cigarette smoking is responsible for the bulk of lung cancer deaths is deduced from a large number of independent epidemiological studies carried out all over the world. All of these, including thorough and comprehensive studies carried out by the British Empire Cancer Campaign in Great Britain, and by the American Cancer Society, agree that a large majority of the lung cancer deaths occur in cigarette smokers, particularly in heavy smokers. Still there are many lung cancer deaths among non-smokers and of these there are more than twice as many lung cancer deaths in large city than in small town dwellers. Moreover, there appears to be some correlation for non-smokers between lung cancer death rate and the size of the city. Researchers agree that there is an increased predisposition to lung cancer in city dwellers not related to smoking and which may be due to urban air pollution.

Benzpyrene Levels in Cities

The most abundant of the polycyclic hydrocarbons is benzpyrene and it is the only one of its class for which much data are available. In Tables B-4 and B-5 the concentrations of benzpyrene in various geographic areas, urban and rural, are tabulated. The concentrations range from a minimum of 0.11 in Helena, Montana, to a maximum of 61 in Altoona, Pennsylvania. When these data are examined the conclusion seems inescapable that urban atmospheres contain far more benzpyrene than rural atmospheres. Nothing in these data indicates definitely that the motor vehicle is the major source of atmospheric benzpyrene although the automobile exhaust is known to contain this hydrocarbon. Los Angeles has a tremendous population density of motor vehicles, as well as a frequently stagnant atmosphere, but is one of the cities whose atmospheric benzpyrene is low. After careful analysis of much data on air pollution in Detroit, Begemann[F 2, No. 217] of the General Motors Corporation concluded that probably less than 10 percent of the benzpyrene in the atmosphere of that city comes from motor vehicles. This opinion is concurred in by Wynder and Hammond, but is not accepted by Prindle of the U. S. Public Health Service. This is only one illustration of the disagreement between medical men on the relative importance of the various sources of air pollution.

TABLE B-4

Benzpyrene Concentrations in Urban Sampling Sites for January through March, 1959 (F 2, No. 237)

State	City	Micrograms Per 1,000 m^3 Air
California	Berkeley	2.9
	San Bernardino	2.3
Colorado	Denver	6.9
Connecticut	Hartford	6.5
Delaware	Wilmington	10
District of Columbia	Washington	9.3
Illinois	Chicago	15
Indiana	Indianapolis	26
Maryland	Baltimore	14
Massachusetts	Boston	9.6
Missouri	St. Louis	54
Montana	Helena	0.11
New Jersey	Jersey City	6.0
	Newark	4.5
Ohio	Cleveland	24
	Columbus	9.5
	Youngstown	28
Pennsylvania	Allentown	3.4
	Altoona	61
	Erie	9.5
	Johnstown	16
	Pittsburgh	5.1
	Scranton	6.1
	York	5.6
West Virginia	Charleston	14
	Wheeling	21

TABLE B-5

Benzpyrene Concentrations in Non-urban Sampling Sites (F 2, No. 237)

State	County	Micrograms Per 1,000 m^3 Air
California	Humboldt	0.21
Connecticut	Lichtfield	0.69
Delaware	Kent	0.69
Indiana	Montgomery	1.8
Maryland	Calvert	0.70
Massachusetts	Nantucket	0.43
Missouri	Shannon	0.025
New Jersey	Cape May	0.95
Ohio	South Bass Island	0.90
Pennsylvania	Clarion	1.9
West Virginia	Webster	0.89

Adding further complexity to the conflicting presumptive evidence on urban lung cancer is the apparent lack of correlation between large city pulmonary cancer mortality rates and measured benzpyrene concentrations.

It may be worthwhile to consider a rough estimate of the number of lung cancer deaths attributable to motor vehicles. On the basis of the best epidemiological data, the incidence of lung cancer is over ten times higher in smokers than in non-smokers. One may, therefore, presume that of the total of 36,000 annual lung cancer deaths in United States, about 4,000 could be attributable to air pollution from causes other than smoking. Let it be assumed that half of these, or about 2,000 lung cancer deaths annually, might be due directly to pollution from the automotive source. This number is small compared with other motor vehicle fatalities; for example, some 41,000 deaths each year due to automobile accidents. However, it is unknown how many motor vehicle accidents might be attributable to the toxic effects of automotive pollutants in heavy traffic causing temporary loss of faculties or adversely affecting the time element in reflex action sufficiently to be an important cause of accidents. If it is safe to assume that any proportion of accidents may be due to this cause, then more fatalities than the estimated 2,000 lung cancer deaths due to automobile emissions might be traced to the same source, as might a corresponding proportion of non-fatal injuries and property damage.

Although the motor vehicle exhaust may not prove to be the major factor in causing lung cancer, the following reasons may be cited against a complacent attitude: (a) Carcinogenic factors in urban atmospheres may accelerate lung cancer in smokers. For example, lung cancer incidence is about 30 percent higher in dwellers in cities over 50,000 than in rural dwellers. (b) The induction of lung cancer is a protracted process, probably requiring a generation for development. We are now seeing a reflection of the relative hazards of smoking and urban air pollution as they existed twenty or twenty-five years ago. Since cigarette smoking has leveled off in the past fifteen years, while motor vehicle population has approximately doubled, an increasing number of lung cancer deaths attributable to air pollution may be expected.

The Role of Lead as a Health Hazard

As has been previously mentioned, lead in one form or another is present in the exhaust gases of a gasoline engine using today's modern fuels. The emission of lead from the exhaust can be expected to lead to pollution of the air and the heaviest concentrations are found in large urban centers, generally following the pattern of motor vehicle density. Careful medical studies extending over many years have given no indication thus far that this constitutes a health hazard. In a nation-wide study by U. S. Public Health Service levels of lead in blood and urine were highest in individuals exposed to heavy automobile traffic. However, these levels were not found to be beyond acceptable limits.

Nitrogen Oxides

Nitrogen oxides are produced in large amounts during combustion in both furnaces and internal combustion engines and are present in the atmosphere. Although these substances are considered highly toxic, they in themselves in present concentrations in the ambient atmosphere do not represent a health hazard. However, as described earlier, they play a key role in smog and ozone formation .

Sulfur Dioxide

In any evaluation of the motor vehicle as an urban health hazard, it is important to keep in mind that there are good grounds for suspecting that sulfur dioxide which is produced from coal and oil combustion, and is not emitted in appreciable amounts by automotive engines, may be a serious health problem, particularly in individuals with already impaired cardiac and respiratory functions. Sulfur dioxide is a toxic gas whose concentration fluctuates widely depending upon climatic conditions. Under certain conditions, such as during winter weather in urban areas with large coal usage for heating, sulfur dioxide can reach alarmingly high levels. Disasters such as have occurred in London in 1952 and in Donora in 1948, causing thousands of deaths over short periods, are recognized to be due primarily to the excessive build-up of sulfur dioxide. In both of these instances the presence of heavy fog and the stagnant atmosphere contributed heavily to the damaging exposures to sulfur dioxide. There was nothing in either of these instances, however, which can be laid at the door of motor vehicles since, as mentioned above, motor vehicles, and particularly the gasoline engine owing to the refinement of the fuel, are not a serious producer of this compound. It does, however, without any doubt and as heretofore outlined, produce many pollutants which are injurious and which may through irritation or otherwise render the respiratory tract more susceptible both to disease and to the sulfur dioxide type of exposure.

RELATIONSHIP OF PENNSYLVANIA TO THE PROBLEM

Reliable recording of data on vehicle emissions and reaction products in the atmosphere including "total oxidant" and ozone has only recently been initiated in our principal cities outside of California. A firm appraisal of the national motor vehicle emission problem must therefore await a reasonable time interval necessary to accumulate a background of monitoring information from the eight major U. S. cities in which the U. S. Public Health Service has established in 1962 comprehensive automatic sampling stations. Philadelphia is included in this "sophisticated" network in addition to Chicago, Cincinnati, Detroit, Los Angeles, New Orleans, San Francisco and Washington. Although these major city sampling stations are operated in fixed locations, they may be moved to other areas within the city to determine the pattern of variation in the particular metropolitan region. Mobile equipment and "satellite" stations will doubtless supply additional supporting information in many communities. Preliminary data from the above network has confirmed the belief that no other major city has a problem approaching that of Los Angeles either in frequency of occurrence or in degree of severity although reportable increases in the significant parameters have been recorded on infrequent occasions during the initial year of monitoring.

In the absence of a reliable accumulation of analytical data on the quantitative chemical content of the atmosphere over our major cities, there have been numerous attempts to relate the problem potential in various communities to such indirect parameters as motor vehicle registrations, motor fuel consumption per unit area, etc. The limitations of such postulations are immediately apparent when considering the many primary variables such as meteorology, topography, and solar energy available which control the true pollution potential of a community. However, these rough appraisals are of interest in comparing the extent of motor vehicle activity in various major cities.

Reference F 1 listed major cities ranked in order of motor vehicle density as shown in Table B-2.

The significance of this type of information is highly questionable in relation to the problem discussed here, particularly when subjective reports from these communities do not confirm any correlation with actual atmospheric conditions. Furthermore, the areas attributed to the specific metropolitan areas in Table B-2 are not consistent with the customary square miles assigned to such communities, further invalidating the basic premise of this suggested association.

Motor fuel consumption by individual states has also been cited to demonstrate that most of the nation's fuel is used in areas where the majority of vehicles are concentrated.[F 1] (See Table B-6.)

TABLE B-6
Motor Fuel Consumption by State—1960
in Thousands of Gallons

State	Consumption
California	5,691,294
Texas	3,722,452
New York	3,713,047
Pennsylvania	3,377,892
Ohio	3,146,664
Illinois	2,931,958
Michigan	2,558,065
New Jersey	1,989,030
Florida	1,799,327
Indiana	1,724,146
Missouri	1,587,632
North Carolina	1,496,639
Massachusetts	1,432,306
Georgia	1,371,372
Virginia	1,329,220

A more considered attempt to appraise the problem was suggested by Atkisson[F 27] who suggested comparison of motor fuel consumption per square mile for principal metropolitan areas. The gasoline consumption data were obtained from Bureau of the Census "service station sales" and were further refined by correcting for average wind velocity to develop "average hourly air volume." Atkisson's original data have been updated to 1960 by Heinen[F 28] employing the same basic information as shown in Table B-7.

TABLE B-7
Major Metropolitan Area Gasoline Consumption
and Estimated Distribution

Metropolitan Area	1960 Estimated Gas Consumption Millions of Gallons	Area Square Miles	1960 Daily Gasoline Consumption	
			Gallons per Square Mile	Gallons per Square Mile of Average Hourly Air Volume
Milwaukee	300	260	3,161	253
Los Angeles	2,540	4,853	1,433	231
Boston	690	787	2,402	198
Cleveland	540	686	2,157	191
Detroit	1,170	1,965	1,631	160
New York	3,200	3,939	2,250	155
Washington, D. C.	590	1,488	1,086	153
Chicago	1,850	3,617	1,401	144
Baltimore	570	1,106	1,412	142
Philadelphia	980	3,550	756	82
San Francisco	860	3,314	711	81
Minneapolis	540	1,769	836	76
St. Louis	620	2,570	661	55
Pittsburgh	630	3,053	565	55
Buffalo	350	1,587	604	35

This analysis is again subject to criticism in the selection of arbitrary "metropolitan" areas ascribed to each community. The more concentrated consumption of motor fuel in the respective downtown traffic areas would doubtless alter the conclusions. (Unfortunately precise gasoline use estimates for specific central city areas are unavailable). Moreover, the above data are based on "average" wind velocity and ignore those important stagnation periods with poor ventilation and other meteorological and topographic factors. Accepting all of these obvious limitations, it remains to be established whether any correlation will be demonstrated between photochemical symptoms, as reflected by adequate monitoring, and gasoline consumption in these communities. In any case, it is of interest to note the relatively low order of rank of Pennsylvania's two major cities on this basis.

Much emphasis has been placed on the anticipated rate of increase of motor vehicles and motor fuel consumption in the country in the coming years. There is little question that there will be a progressive incremental gain in vehicle registrations and consequently in gasoline consumption in the foreseeable future, but this increase will probably not be as dramatic or uncontrolled nationally as some popular misconceptions would suggest. According to the U. S. Bureau of Roads,[F 35, F 36] based on considered estimates by individual states, the national average annual rate of increase in motor fuel consumption for the current decade 1960–1970 is a modest 3.7 percent per year. California, with its acknowledged air pollution problem, has cause for concern with an above-average annual anticipated fuel consumption increase of 4.9 percent, while Pennsylvania predicts a below-average 2.6 percent annual rate of gain. Pennsylvania's projected gradual increase in motor fuel can hardly be cited as cause for alarm for a *rapid* increase in problem potential. These data are summarized in Table B-8.

TABLE B-8
Average Annual Motor Fuel Consumption Rate Gain
Actual and Estimated, 1950–1975

Period	United States	California	Pennsylvania
1950–1960	4.9%	5.9%	4.4%
1960–1970	3.7%	4.9%	2.6%
1970–1975	2.7%	5.5%	1.6%

Summarizing this information, vehicle registrations and motor fuel consumption figures are no substitute for actual determinations of air quality in evaluating the problem potential in specific communities. Until reliable monitoring data are available for a representative period of time, no firm appraisals of the nature and extent of the air quality problem in various Pennsylvania metropolitan areas may be attempted with any degree of precision.

APPENDIX C

THE AUTOMOTIVE ENGINE

The vast majority of motor vehicles in the United States is propelled by the spark-ignition internal combustion engine operating on a cycle patterned after the Otto cycle and using gasoline as the fuel. The remainder is powered by the compression-ignition type of engine commonly known as the diesel engine. Because these types of internal combustion engine have different characteristics from the standpoint of the emission of pollutants, they will be considered separately.

Any engine using a hydrocarbon compound or compounds as a fuel should *ideally* discard in the exhaust or stack, nitrogen, carbon dioxide, and water vapor. If an excess of air is supplied for combustion, there will also be oxygen in the waste gases. These gases are all harmless when discharged into and mixed with the atmosphere and represent the products of the complete combustion of the fuel with air.

Unfortunately, the exhaust gases of an actual engine deviate considerably from the ideal, principally for three reasons:

(1) The fuels commonly burned are not entirely hydrocarbons but contain varying small amounts of impurities, the most important from the standpoint of air pollution being sulfur and lead. The former impurity oxidizes during the combustion process mostly into sulfur dioxide and as such is discharged into the atmosphere. Lead compounds are introduced into the fuel to improve the antiknock characteristics. Thus, lead in one form or another, will be emitted with the exhaust gases.

(2) A small amount of the nitrogen supplied with the combustion air is oxidized during the high temperature process to form oxides of nitrogen. These are undesirable in the atmosphere mainly because they are among the ingredients which contribute to the formation of photochemical smog.

(3) The combustion in an actual engine is in many cases imperfect and incomplete either because the fuel and the air are not properly introduced for effective particle contact when combustion is initiated, or the burning is quenched before completion by contact with cool surfaces, or because insufficient air is supplied to provide the necessary oxygen for

complete combustion of the fuel. These result in the appearance in the exhaust of carbon, carbon monoxide, and a complex variety of hydrocarbon compounds, some of which are known to be injurious. The first of these, namely, the carbon, is usually in the form of a visible emission as smoke which does not otherwise contribute to harmful air pollution. The last two are dangerous in sufficiently high concentrations. In addition, certain of the hydrocarbons are active with oxides of nitrogen in the formation of photochemical smog.

THE GASOLINE ENGINE

The conventional gasoline engine as used in passenger cars, trucks and buses operates on a carbureted mixture of gasoline and air. It is intended that this mixture be homogeneous when it enters the cylinders and the gasoline must be vaporized before burning. Both the rate of burning and the ignition characteristics of the mixture are governed within rather narrow limits by the proportions of fuel and air in the mixture; that is, by the air-fuel ratio (or the fuel-air ratio). These limits extend on both sides of the chemically correct, or stoichiometric proportions. Neither too rich nor too lean a mixture will ignite. But, further, it so happens that maximum power, such as is desired for acceleration, is obtained in this type of engine with a mixture rather rich in fuel, while best fuel economy, as for cruising, results when approaching the lean limit of flammability. Smooth idling requires a relatively rich mixture and, since this is at closed throttle, the same rich mixture prevails during deceleration as a matter of course. Thus it may be seen that for top performance in the standard engine, for three of the four principal modes of operation—idling, acceleration, deceleration—the engine is provided with a mixture which is deficient in air, while only for steady load or cruising may an attempt be made to furnish a leaner mixture with sufficient air to theoretically burn the fuel with a consequent reduction in pollutants. Even with a slight excess of air, which is all that can be tolerated under best conditions, there will still be incomplete combustion owing to several factors, such as lack of proper mixing, partial vaporization of the fuel, surface quenching, etc. Another factor which prevents the use of very lean mixtures is the imperfect distribution of the fuel-air mixture to the various cylinders in a multi-cylinder engine. This necessitates a carburetor setting which will supply a suitable mixture to the leanest cylinders, resulting in a mixture to the other cylinders which is richer than desired.

The foregoing brief exposition sets forth the reasons why any conventional gasoline engine emits contaminants with the exhaust gases. To these must be added the pollutants which are vented from the crankcase. No pistons and piston rings can completely and perfectly seal the cylinder contents against leakage. This leakage passes the pistons and enters the crankcase and is commonly known as "blowby." The blowby gases consist principally of the carbureted mixture, rich in hydrocarbons. The remainder is similar in analysis to the exhaust gases. In the passage through the crankcase a certain amount of lubricating oil mist is added to the blowby gases and, with them, is vented to the atmosphere. The crankcase has in the past normally been ventilated by the use of a road draft tube which provides a certain amount of aspirating action, depending upon the air flow past this tube. The crankcase gases constitute an important source of emissions and, together with the exhaust, will make up approximately 90 percent of the pollutants coming from the motor vehicle.

Minor sources of pollution in the gasoline automotive vehicle are the carburetor and the fuel tank, both of which are vented to the atmosphere. The proportion of total emissions from these sources, however, is so small that no further attention will be given them in this report. On the other hand crankcase and exhaust emissions, as indicated above, and the means of reducing them, are of such importance as to deserve careful study.

In summary, it may be seen that the conventional gasoline automotive engine is inherently a potent source of air pollution, even at its best. When the adverse factors are permitted to become more emphasized, this type of engine will be a highly productive source of undesirable emissions. The effect of this pollution, its importance in relation to stationary sources, and possible means of abating it will be discussed elsewhere in this report.

THE DIESEL ENGINE

Unlike the spark-ignition gasoline engine, the compression-ignition or diesel engine does not operate on a carbureted, homogeneous mixture of fuel and air. Instead, this engine draws in and compresses air only. At the proper time, after this air is compressed in the cylinder, fuel oil is injected in atomized form, and in a quantity to meet the load requirements, and is ignited by contact of the particles with the high-temperature compressed air. Because there is not a homogeneous mixture to be ignited, there are no upper limits, with regard to flammability, to the air-fuel ratio which may be used. Therefore, this engine may be operated, even under full-load conditions, with an excess of air which would render the mixture nonignitible in the conventional spark-ignition engine. Since the amount of fuel injected per cycle varies with the load requirements, while the air supplied is unrestricted and not a function of load, the full-load condition (maximum fuel) produces the lowest air-fuel ratio. At lighter loads the excess air increases, so that in the well-designed engine there is always ample oxygen to burn the fuel completely, and, as a consequence, the exhaust gases contain a relatively small proportion of unburned hydrocarbons and carbon monoxide. There will be oxides of nitrogen present in the diesel exhaust in varying concentrations, particularly at or near full load, since these are products of high temperature combustion. At part loads, however, the increased proportion of excess air present will tend to depress the maximum temperature and may reduce the formation of these oxides to a degree where on the average they could become relatively unimportant.

The blowby gases in the diesel engine present no air pollution problem because, unlike the gasoline engine, the material in the cylinder which might leak past the piston is air only on the compression stroke and on the power stroke the pollutants are relatively dilute.

The diesel engine then should not be regarded as an important source of injurious contaminants. It does, however, have adverse characteristics which are most noticeable to the public in general and lead the layman to believe that this type of engine is a prime offender. These are a potent exhaust odor and the emission of smoke, particularly at high loads. The odor is a result of the formation of certain compounds during the combustion process which is peculiar to this type of engine. It may not only constitute a disagreeable nuisance, but may, in higher and prolonged concentrations, cause temporary headache and nausea. No satisfactory cure has as yet been devised to eliminate these emissions. The discharge of visible smoke, other than a light variety, occurs principally as a result of overloading or lack of proper maintenance of the fuel injection system, or faulty design of the combined combustion chamber and injection system. The production of observable or dense smoke is largely preventable by proper attention to the first two factors mentioned above; i.e., by preventing engine overload and by regular and proper maintenance of the injection system. The design characteristics of most modern diesel engines on the road today are such that they will not be serious offenders if proper attention is given to these factors.

It may be concluded from the foregoing that while the diesel engine may constitute a nuisance to the senses by the emission of odor and smoke, it is much less important as a source of injurious pollutants than is the gasoline engine. The gasoline engine also ranks high as an important source because of the great preponderance on the United States highways of this type of power plant. It is to be noted that in the diesel engine some considerable abatement of the nuisance value is possible. It is, then, the gasoline engine which must at present receive the most attention in any study relating to the serious effects of automotive air pollution and to the means of decreasing the emission of contaminants.

APPENDIX D

RELATIONSHIP OF MOTOR VEHICLES TO OTHER SOURCES OF POLLUTION

In order to properly assess the role of the motor vehicle in relation to other sources of possible pollution in a particular community, it is first necessary to define the nature of the problem. There is a prevailing temptation to oversimplify the evaluation of a specific locality by the simple expedient of presenting emission totals from various domestic, commercial, and industrial sources and to rely on the impressive weight of such background data to establish a need for concern and subsequent control. Unfortunately such an elemental approach represents only the beginning of a meaningful appraisal of whether or not a community has a real problem and if so, what the problem is.

For purposes of this discussion, the definition of the U. S. Surgeon General's Ad Hoc Task Group of Research Goals (1960) will be helpful: "Air pollution is . . . the presence in the ambient atmosphere of substances put there by the activities of man in *concentrations sufficient* to interfere directly or indirectly with his health, safety, or comfort, or with full use and enjoyment of his property." In other words, the release of emissions by community activity does not establish a prima facie case for "pollution." It is the subsequent persistence, or dissipation, of these releases and their observed concentrations in the atmosphere of a particular locality that determines if an objectionable condition exists. With this understanding, examination of the emission from motor vehicles relative to other sources is helpful in determining the potential significance of various contributors.

Motor vehicles release quantities of hydrocarbons, carbon monoxide, and nitrogen oxides when fuel is consumed. In addition, relatively smaller quantities of sulfur oxides, aldehydes, organic acids, ammonia, particulates, and products resulting from additives such as lead will be found. The contribution, in the atmosphere, from individual vehicles is highly variable, but is generally so minute as to require specialized microanalytical techniques to accurately measure the actual concentrations present. However, heavy concentrations of vehicle activity, coinciding with poor atmospheric ventilation, such as the Los Angeles situation, may result in an accumulation of these emissions to an objectionable level. Any discussion of motor vehicle emissions must include consideration of other community sources of the same contaminants.

Hydrocarbons

Hydrocarbons are generally not considered pollutants in the primary sense. In their unreactive state, gasoline vapors have little toxicological significance. According to the American Conference of Governmental Industrial Hygienists, the threshold limit concentration is 500 ppm. Even under the country's severest combination of atmospheric stagnation and motor vehicle density, Los Angeles' highest reported hydrocarbon concentration through 1961 was 4.66 ppm.[F 1] These trace organic gases are a problem only when their more reactive components, principally olefins, exist in sufficient concentration with nitrogen oxides under the influence of solar energy to produce the objectionable reaction products described in Appendix B. Total hydrocarbon emission data for a particular community must therefore be regarded as an indirect parameter at best. Fortunately Los Angeles County data[F 4, F 29] describing the olefinic content of total hydrocarbon releases from all sources are available for estimating reactive hydrocarbons in other localities. Thus, the relative contribution of motor vehicles to total hydrocarbon releases in a community is dependent not only on vehicle activity per se but also on the addition of similar emissions from other sources. For example, motor vehicles are believed to contribute up to 67 percent of the total hydrocarbon content in the atmosphere in Los Angeles County, approximately 30 percent in the San Francisco Bay Area, and 40 percent in Philadelphia. A comparison of the relative contribution of *total* hydrocarbons from all sources in Philadelphia[F 30] and Los Angeles County is shown in Table D-1.

TABLE D-1
Source of Total Hydrocarbon Emissions—1961
Los Angeles County and Philadelphia

	Los Angeles		Philadelphia	
Source	Tons Per Day	% of Total	Tons Per Day	% of Total
Motor Vehicles Private	1,038	57	500	37
Commercial Transport	240	13	70	5
Petroleum Operations	245	13	200	15
Combustion of Fuels (Stationary)	5	0	160	12
Incineration	0	0	150	11
Industrial and Commercial Processing	315	17	270	20
Total (Rounded)	1,840	100	1,350	100

SOURCES: Report of Los Angeles Air Pollution Control District—January, 1962.
1961 Annual Report of Philadelphia Air Pollution Control Section.

Reliable data on olefin emissions from vehicular and non-vehicular sources are available only for Los Angeles County. Approximately 40 percent of the Los Angeles vehicular hydrocarbon emissions are olefinic, whereas only 5–10 percent of the non-vehicular hydrocarbons are believed to be unsaturates.[F 29] Applying these relationships to the Philadelphia total hydrocarbon data provides a rough order of magnitude of the olefinic releases in the latter community. (The 10 percent olefinic factor has been selected since this was representative of 1950 conditions prior to imposition of stringent controls on stationary sources of hydrocarbon emissions in Los Angeles.) As shown in Table D-2, the estimated total hydrocarbon and olefinic component emissions in Philadelphia in 1960, 1,350 and 310 tons per day respectively, are considerably less than the total attributed to Los Angeles during the same period and in fact are comparable to the levels reported in Los Angeles in the mid-1940's.

TABLE D-2
Estimated Olefinic Hydrocarbon Emissions—1960
Los Angeles and Philadelphia

	Tons Per Day			
	Los Angeles		Philadelphia	
Source	Total HC	Olefin HC	Total HC	Olefin HC*
Motor Vehicles	1,235	485	570	230
Non-Vehicular	618	31	780	80
Total	1,853	516	1,350	310

* Estimated at 40% of vehicular HC and 10% non-vehicular HC (1950 Los Angeles basis).

As mentioned in Appendix B, another category of hydrocarbon release from combustion which has recently received interest because of carcinogenic properties is the polynuclear aromatic hydrocarbons (PAH). These higher molecular weight compounds may originate from combustion of any fuel or organic material, and there are doubtless many potential domestic, commercial, industrial, or vehicular sources. Their formation is influenced by the size and efficiency of the combustion unit and the type of fuel burned. The polynuclears are found in small concentrations in urban atmospheres and at this writing their importance requires further definition. A current study by the U. S. Public Health Service is expected to develop additional information on the relative contributions of various sources.[F 31] A recent extrapolation analysis of auto exhaust content estimated that between 2 and 10 percent of a common polynuclear found in the air over urban centers may be attributable to motor vehicles.[F 2, No. 217]

Carbon Monoxide

Carbon monoxide is unique among common urban emissions in that it originates almost solely from the motor vehicle. Recent Los Angeles County estimates (1961) attribute 95 percent of the region's carbon monoxide emissions to the motor vehicle. Since Southern California has experienced moderately high concentrations of carbon monoxide in the atmosphere, 5–60 ppm with a recorded maximum of 72 ppm,[F 1] this contaminant is included in the West Coast motor vehicle control program. Fortunately such high concentrations are a rarity in other cities except for purely local traffic situations. Philadelphia, for example, reported an average carbon monoxide concentration of 7 ppm in 1961.[F 30] Maximum readings of 25 to 35 ppm have been obtained in the same city.[F 37]

Nitrogen Oxides

Nitrogen oxides are not considered primary pollutants in the sense that they are objectionable in their unreactive state in the low concentrations normally found in urban air. For example, the recorded concentrations of 0.01 to 0.3 ppm of nitrogen dioxide in major U. S. cities[F 1] are well below the threshold levels of 5.0 ppm suggested by both the California ambient air quality standards[F 29] and the Conference of Government Industrial Hygienists. The role of nitrogen oxides becomes important only in those areas with an acknowledged photochemical smog problem where their role as a precursor to the formation of oxidants, ozone, and other intermediates has been demonstrated.

Nitrogen oxides are produced during combustion of fuels when some of the oxygen provided for reaction combines with the nitrogen present. Formation of nitrogen oxides is influenced primarily by the air-fuel ratio and the temperature of combustion. There is currently no known practical means of controlling nitrogen oxide formation in motor vehicles.

The contribution of the motor vehicle to the total nitrogen oxide discharged from community activity is dependent on the amount and type of energy fuels used for other purposes. For example, in Los Angeles approximately 65 percent of the 900 tons per day total nitrogen oxides originate from motor vehicles.[F 32] In Philadelphia, transportation accounts for only an estimated 14 percent of a total of 300 tons per day of nitrogen dioxide.

Sulfur Oxides

Oxides of sulfur are formed when sulfur-bearing fuels undergo combustion. Since motor fuel normally contains only trace amounts of sulfur, motor vehicles are not considered a significant source of this combustion product. For example, Philadelphia reports that all transportation activity contributes only 2 percent of the total sulfur emissions from all sources.[F 30]

APPENDIX E

MEANS FOR REDUCING AUTOMOTIVE EMISSIONS

The principal atmospheric contaminants emitted by the gasoline engine are a complex variety of unburned hydrocarbons originating from the fuel, and other organic products resulting from incomplete combustion of these hydrocarbons; carbon monoxide; and nitrogen oxides. The sources of these contaminants are the exhaust, the crankcase (or blowby), the fuel tank and the carburetor. Approximately 65 percent of the total pollutants come from the exhaust, 25 percent from the crankcase and 10 percent from the fuel tank and carburetor.

Basically there are six potential methods for reducing automotive emissions:

(1) By redesigning certain components of the engine to effect more complete combustion of the fuel.

(2) By modifying the existing conventional engine in such a manner as to reduce emissions. This will be known as the "modified engine."

(3) By the use of an effective positive crankcase ventilating (or blowby) device.

(4) By periodic attention to maintenance requiring, if necessary, repair or adjustment of certain engine components. Of particular importance are the carburetor, the ignition system, and the condition of pistons and piston rings.

(5) By adapting special devices to the exhaust system which oxidize the organic compounds and carbon monoxide to harmless gases and under certain conditions convert nitrogen oxides to nitrogen and oxygen.

(6) By departing radically from present conventional engine design or by the substitution of a different type of power plant.

Another potential measure which has been adopted in California is the reduction of the olefin content of gasoline on the premise that the olefin concentration in the exhaust gases would be reduced and therefore reduce the smog-forming potential of these gases. However, the evidence to support this premise is contradictory and inconclusive.

REDESIGN OF ENGINE COMPONENTS

Changes currently being considered or being investigated in order to promote better combustion in the conventional engine include redesign of the combustion chamber to produce better mixing and more complete vaporization of the fuel and to reduce the surface-to-volume ratio; redesign to produce more effective and positive ignition systems; improvements in the conventional carburetor to provide more favorable air-fuel ratios during the various modes of operation; and alternative methods for admitting the fuel to the combustion chamber, such as fuel injection.

All of these factors, plus others that may not have been disclosed to the public, are being investigated by automobile manufacturers who must balance the benefits accrued, regarding emissions, by any one or more changes against both increased cost to the buyer and possible adverse effects on the engine performance to which the American public has become accustomed.

These are all to a certain degree engine design characteristics and can only be carried out after thorough consideration and research and study have been conducted on the proposed change.

MODIFIED ENGINE

It would appear from research[F 3, No. 59] which has been conducted that certain relatively simple modifications of the present conventional engine could effect a considerable reduction in noxious emissions. These modifications consist of carburetor adjustments to provide operating mixtures with the maximum tolerable air-fuel ratio over the various modes of operation, and a modification of the ignition system to provide a beneficial retarding of the ignition timing under certain modes, while rendering the optimum advance for other conditions.

The report on this same research indicates that an adjustment of ignition timing as described above and the use of a carburetor with lean-limit road-load jets and a relatively lean idle adjustment would produce results when applied to the present conventional engine which approach or are within the California limit for exhaust emissions (275 ppm hydrocarbons as hexane and 1.5 percent CO by volume).

CRANKCASE VENTILATION DEVICES

In the 1920's automobile engine designers began to vent crankcase gases, which are largely blowby (unburned mixture and exhaust gases that blow past the piston rings from the combustion chamber to the crankcase), to the atmosphere through a road draft tube. As mentioned earlier, these blowby emissions contain about 25 percent of the total contaminants from the gasoline engine. Consequently, their control must be considered as an important factor in the overall reduction of automotive emissions.[F 38]

The principle of crankcase ventilating devices is to provide positive crankcase ventilation and to return the blowby gases to the combustion chamber in order to burn the combustible constituents.

There are three design types of blowby devices. One vents the crankcase fumes to the intake manifold, the second vents the fumes to the carburetor air horn or the air cleaner, and the third divides the flow from the crankcase between the intake manifold and the air cleaner.

The first and third types have a variable-orifice valve between the crankcase and the intake manifold which regulates the flow rate of crankcase fumes and the ventilating air through the crankcase so as to provide satisfactory flow irrespective of load and manifold vacuum. This valve will need cleaning or replacement at regular intervals depending upon the condition and the usage of the car. Otherwise the efficiency of the blowby device will be impaired.

All of these types, but particularly the second, must be installed with attention to the effect on carburetion and will require a carburetor which is adapted to use with the device. The result otherwise is to upset the mixture control with an adverse effect upon engine performance or to increase the exhaust emissions owing to the lack of extra air to burn the blowby gases. It would, therefore, appear at this time that the blowby device, while readily installed on new cars at the factory with the corresponding carburetor modifications, is not so easily adaptable to old cars which were not originally provided with such a device.

The cost of the blowby device is relatively small—under ten dollars when factory installed. The maintenance cost on such a device is estimated at approximately .06 cents per mile. As previously indicated, a properly designed and installed device could eliminate a worthwhile proportion of the total gasoline engine emissions.

SYSTEMATIC MAINTENANCE

Although the conventional gasoline engine, even when new, is inherently an important source of air contaminants, as the engine and its auxiliaries wear or become dirty or get out of adjustment through operation, it is likely to become much worse an offender than in the new condition. It is known, for instance, that a single missing spark plug will increase exhaust emissions many fold. Therefore, periodic inspection, repair and adjustment of certain engine components is a highly important factor in maintaining a relatively low emission rate of contaminants.

In the report[F 3, No. 59] covering the findings of the research cited in a previous section (Modified Engine) the authors concluded, in summarization of the first report of the series[F 3, No. 29] "(a) Reduction in hydrocarbon and carbon monoxide emissions of the order of 60% appear to be possible by regular maintenance; (b) A rough calculation . . . shows that adjustments of carburetion would show an approximate reduction of 60% carbon monoxide . . . ; (c) Field inspection is practical by present methods."

The important inspection and servicing adjustments or repairs on the standard engine would consist principally of (a) carburetor adjustment to as lean as possible idle mixture consistent with smooth idling; general carburetor maintenance including cleaning or rebuilding when necessary; (b) a check of the air cleaner and servicing, if necessary; (c) a check of the ignition system with necessary adjustments as recommended by the factory and the replacement of defective parts; depending upon their condition, plugs would be either cleaned and re-gapped or replaced; (d) a check for visible exhaust emissions (smoke) under various modes of driving. Evidence indicates that while the smoke in itself may be more of a nuisance value than injurious, a badly smoking gasoline engine indicates worn pistons and rings, or other parts which are not functioning properly. An engine in such mechanical condition undoubtedly produces a higher emission rate than would an engine in good repair.

In connection with periodic inspection and proper maintenance, Pennsylvania is fortunate in having already in effect regulations requiring semi-annual inspection—mostly for safety reasons—and in having authorized inspection stations throughout the state to conduct this work. The checking of ignition systems, air cleaners and carburetors might advantageously all come within the scope of this inspection and conceivably could be carried out, for the most part, with equipment already in the possession of the authorized stations.

EXHAUST EMISSION DEVICES

The principle on which the exhaust emission device is based is the oxidation of organic compounds and carbon monoxide to carbon dioxide and water with either a special catalyst or a flame. Catalytic converters are specially designed mufflers containing a catalyst bed through which the exhaust gases pass before they are discharged to the atmosphere. The flame type, known as an "after burner," is a special device attached to the exhaust system and is provided with a spark or a flame to burn the combustible constituents in the exhaust gases before they are discharged. Both of these types require an engine-driven air compressor to supply the additional oxygen necessary for converting the combustibles and both are rather sensitive to temperature conditions which vary widely over the various modes of operation. An adverse factor in connection with these devices is the fact that they *must* have periodic attention from the maintenance standpoint or they become inoperative. The State of California is presently aiming at a useful life of 12,000 vehicle miles. It is somewhat doubtful if this has yet been achieved. Work has been done in the automotive industry and is currently being done in California on the durability of these devices and more information will be forthcoming in this regard after a few months.

The first cost of the exhaust emission control device would appear to vary from 70 to 150 dollars. Including maintenance, it is estimated that this device would cost the motorist on an average of approximately .44 cents per mile—roughly the cost of tires. It must be emphasized that this cost estimate is based upon average driving conditions in California and is not necessarily applicable to Pennsylvania where topography, driving habits, "average" car conditions and other germane factors may be significantly different. The public reaction in Pennsylvania to the required installation of an exhaust device is open to question, since it is unknown what the average Pennsylvania driver would consider to be an "undue" cost with respect to the control of air pollution. An important consideration in this connection is the Pennsylvania motorist's attitude toward increased cost that he cannot define in tangible terms such as by car appearance and performance.

There appears to be a general consensus, particularly among the members of the Technical Panel, that exhaust emission control devices are temporary expedients to meet an emergency and that this should be required as a last resort only if other and more rational means of control prove inadequate.

ALTERNATIVE AUTOMOTIVE POWER PLANTS

Because the gasoline engine is inherently a producer of air contaminants, consideration should be given to the adoption of either a completely redesigned engine or a different type of automotive power plant.

The diesel engine, which is in an advanced stage of development, still does not appear to be desirable or satisfactory for passenger car installation. Undoubtedly, its use will increase, as it has already increased, in commercial transportation such as trucks and buses. It is true that the general use of this type of engine would materially reduce the emissions of certain contaminants which are considered injurious. However, the fact that while the diesel engine is adaptable to commercial uses as stated above but not to passenger cars, it would seem that this is not going to be an important factor in the reduction of automotive air pollutants.

Certain radical changes in the design characteristics of spark-ignition engines are possible and might reduce the potential of this type of engine as a source of pollutants. The stratified charge engine, for instance, which still operates on the same basic cycle but not on a homogeneous mixture of fuel and air, has possibilities as exemplified by certain working engines which have already been constructed and are in operation on an experimental basis. This would permit the use of excess air beyond that possible in a homogeneous air-fuel mixture and might under proper conditions, therefore, reduce the unburned constituents in the exhaust.

The use of the gas turbine, a completely new type of automotive power plant, is being investigated by automobile manufacturers. Because of the very large quantities of excess air used in this type of power plant for cooling purposes, there is very small probability, given proper design characteristics, that any great quantity of unburned hydrocarbons or carbon monoxide would appear in the exhaust. Even the production of oxides of nitrogen might be substantially reduced as compared to the present gasoline engine. However, the characteristics of the gas turbine are such that this type of engine is not particularly well fitted for automotive use. This, however, was originally true also of the gasoline engine but was overcome by the use of various transmissions and clutches. The same may occur insofar as the gas turbine is concerned. If such an engine were to be universally adopted, it would undoubtedly eventually result in decreased contamination from automotive sources.

It must be remembered that developments along any of the lines involving new types of power plants must be considered as long-range and of limited interest insofar as the objectives of this report are concerned. Nevertheless, the State Government, from the standpoint of air pollution control, should keep fully informed about such developments.

FUEL COMPOSITION

When it was established by California researchers that certain of the hydrocarbons in vehicle emissions were more active than others in contributing to photochemical smog, it was assumed with some logic that alterations in motor fuel composition might appreciably reduce the undesirable components in auto exhaust. While early studies indicated that some relief could be achieved by this mechanism, more extensive investigations have demonstrated the limitations of this approach, and it is now generally accepted that fuel modification will not significantly influence either the quantity or the quality of exhaust emissions with respect to smog-forming potential. There appears to be no practical substitute for adequate maintenance of the current internal combustion engine if exhaust components are to be minimized.

Gasoline is a complex mixture of hydrocarbons, consisting of varying concentrations of (1) saturated or paraffinic compounds, (2) unsaturated or olefinic hydrocarbons, and (3) ring-type or aromatic compounds. A fourth group, the naphthenes, have a single-bonded ring structure and generally display similar characteristics to the saturated hydrocarbons.

Gasoline has a boiling range of approximately 100–400°F, a category in which the hydrocarbons have from 4 to 12 carbon atoms per molecule. Because of the multiplicity of possible combinations of molecular structure even in this limited range, literally hundreds of different individual compounds may be found in today's motor fuel. In order to meet the demanding performance requirements of modern vehicles and the motoring public, the above fuel categories are carefully blended to adjust the proportions in finished gasoline to achieve the desired broad range of characteristics. Straight-chain paraffins have low octane numbers; naphthenes have intermediate values, while branched paraffins, aromatics, and certain olefins have higher ones. While there is considerable variability between geographic areas and specific brands, typical gasolines will have varying percentages of all categories. In addition to the hydrocarbon composition of motor fuel, trace quantities of various additives are added for specific purposes such as antiknock qualities, antioxidants, deposit modifiers, antirust agents, detergents, anti-icing compounds, and dyes.

As described elsewhere in this report, only the more reactive hydrocarbons, principally the olefins, have been found to participate in the so-called atmospheric photochemical smog reaction. Although some specific aromatic and paraffin hydrocarbons have been shown to display some activity, these classes are relatively stable and are not currently considered significant precursors of the complex atmospheric chemistry that results in smog. Since automotive exhausts are responsible for most of the olefins found in the atmosphere, early control efforts in Los Angeles were directed toward selectively reducing these unsaturated hydrocarbons in motor fuel. This move was based on the belief that the composition of vehicle exhausts closely parallels that of the motor fuel itself. As described below, detailed studies subsequently established, however, that olefins in the exhaust derive not only from olefinic fuel but also from other categories including the paraffins and even aromatics during combustion in the engine. Moreover, the quantity of exhaust emission, which is relatively independent of fuel composition, exerts greater influence than the quality from an air pollution standpoint.

With respect to the characteristics of the exhaust during different modes of operation, the hydrocarbon component of exhaust produced during deceleration is closely related to the fuel. However, acceleration and cruise may produce exhaust hydrocarbons that bear little similarity to the original fuel. For example, during the important acceleration period as well as cruise, exhaust olefins are substantially independent of fuel olefins, and an increase in paraffin content actually increases olefin emissions. The only note of anticipated consistency is found in the proportion of aromatics in the exhaust which generally follows the aromatics in the fuel during all operating modes. However, even fuels of high aromatic content produce some olefins. The reader is referred to the excellent referenced literature for a more detailed explanation of this complex aspect of the problem.[F 3, No. 40, F 33, F 34]

In summary, it may be concluded that exhaust composition may be influenced somewhat by fuel modification. This approach, however, does not address itself to the fundamental problem of achieving more complete combustion of the induced fuel. Moreover, selective removal of the objectionable olefin category in the feed fuel does not result in comparable reduction of this class of hydrocarbons in the corresponding exhaust gas.

APPENDIX F

BIBLIOGRAPHY

1. Terry, Luther L. (Surgeon General), *Motor Vehicles, Air Pollution, and Health.* A report of the Surgeon General to the U. S. Congress in compliance with Public Law 86-493, the Schenck Act. U. S. Department of Health, Education and Welfare, Washington, D. C., 1962, 459 pp.

2. Terry, Luther L. (Surgeon General), *Motor Vehicles, Air Pollution, and Health.* Bibliography of Part II. U. S. Department of Health, Education and Welfare, Washington, D. C., 1962, pp. 219–238.

3. Terry, Luther L. (Surgeon General), *Motor Vehicles, Air Pollution, and Health.* Bibliography of Part III. U. S. Department of Health, Education and Welfare, Washington, D. C., 1962, pp. 451–459.

4. California Department of Public Health. *California Standards for Ambient Air and Motor Vehicle Exhaust,* December 4, 1959, 16 pp.

5. California Department of Public Health. *Additions to California Standards for Motor Vehicle Emission* adopted by the State Board of Public Health, December 2, 1960, 1 p.

6. California Department of Public Health. *California Standards of Ambient Air Quality* as amended March 16, 1962. California Administrative Code, Title 17, Chapter 5, Sub-chapter 5, Article 1, 2 pp.

7. *Pennsylvania Air Pollution Control Agencies and Their Powers.* Based on the "Air Pollution Control Act" 1960, P. L. (1959) 2119, 35 P. S. Sec. 404, 7 pp.

8. Clarkson, Diana, and John T. Middleton, *The California Control Program for Motor Vehicle Created Air Pollution.* Presented at the 54th Annual Meeting, Air Pollution Control Association, June 11–15, 1961, New York, N. Y., 20 pp.

9. Goldsmith, John R., M. D. *Some Implications of Ambient Air Quality Standards.* Archives of Environmental Health, February, 1962, Vol. 4, pp. 151–167.

10. Goldsmith, John R., M. D. *Health Effects of Motor Vehicle Exhaust.* A report presented to the Motor Vehicle Pollution Control Board, Los Angeles, August 11, 1961, 25 pp.

11. Hueper, W. C., M. D. *Carcinogens in the Human Environment,* Archives of Pathology, Parts I & II, March 1961, Vol. 71, pp. 237–267, Part III, April, 1961, Vol. 71, pp. 355–380.

12. Maga, John A., Chief. *Progress Report of the Bureau of Air Sanitation on Air Pollution from Diesel-Powered Vehicles.* California Department of Public Health, before the Motor Vehicle Pollution Control Board on September 19, 1962, San Francisco, California, 3 pp.

13. Maga, John A., G. C. Hass, and Harmon Wong Woo. *California Standards for Ambient Air Quality and Motor Vehicle Exhaust,* Supplement 1. Crankcase Emission Standard. California Department of Public Health, August, 1961, 13 pp.

14. Lodge, J. P., Jr., G. S. Bien, and H. E. Suess. "The Carbon-14 Content of Urban Airborne Particulate Matter," *International Journal of Air Pollution,* **2,** 309–312 (1960).

15. Kotin, P., and H. L. Falk. "Atmospheric Factors in Pathogenesis of Lung Cancer," *Advances in Cancer Research,* **7,** (1963) in press.

16. Smith, R., Chief. "Air Quality—An Approach for Philadelphia," Air Pollution Section, Philadelphia Department of Public Health.

17. Caplan, J. D. "The Automobile Manufacturer's Vehicle Emissions Research Program," report presented at 1962 Annual Meeting of Air Pollution Control Association, May, 1962.

18. Gross, Paul M., Chairman. "Report of the Committee on Environmental Health Problems to the Surgeon General," Public Health Service Publication No. 908 (1962).

19. Tuesday, C. S. "Atmospheric Photo-oxidation of Olefins. The Effects of Nitrogen Oxides." Paper presented at the Research Conference on Motor Vehicle Exhaust Emission and Their Effects, December 5–7, 1961. Los Angeles, California.

20. "Pure Air for Pennsylvania," a joint study of the extent and nature of air pollution in Pennsylvania, by the Pennsylvania Department of Health and the Public Health Service, U. S. Department of Health, Education and Welfare.

21. Katz, M., and D. C. Pasternack. *National Research Council of Canada,* **14,** 369 (1938).

22. Leone, I. A., E. Brennan, and R. H. Daines. *Plant Disease Report,* **46,** 140 (1962).

23. Cannon, Helen L., and Jessie M. Bowles. *Science,* **137,** 765 (1962).

24. Chambers, Leslie. *Air Pollution,* edited by Stern, Academic Press, 1962.

25. *Science,* July 6, 1962, Vol. 137, 3532, Editorial.

26. *Power,* McGraw-Hill Book Company, December, 1960.

27. Atkisson, A. A., Jr., "An Evaluation of Blowby Controls as a Means of Reducing Vehicular Contaminant Emissions," *Journal of the Air Pollution Control Association,* May, 1962.

28. Heinen, C. M., Private Communication, October, 1962.

29. "Technical Report of California Standards for Ambient Air Quality and Motor Vehicle Exhaust," Supplement No. 1, Crankcase Emission Standard, State of California, Department of Public Health, Berkeley, California, August, 1961.

30. "1961 Annual Report," Air Pollution Control Section of the Division of Environmental Health, Philadelphia Department of Health.

31. "Carcinogen Appraisal Study," Report of Division of Air Pollution, Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, 1960, unpublished.

32. "Total Air Pollution Emitted and Prevented in Los Angeles County," Los Angeles County Air Pollution Control District, January, 1962.

33. Stephens, E. R., and W. E. Scott, "Relative Reactivity of Various Hydrocarbons in Polluted Atmospheres," Proceedings API, 27th Midyear Meeting of the American Petroleum Institute, May, 1962.

34. Hurn, R. S., C. L. Dozois, J. O. Chase, C. F. Ellis, and P. E. Ferrin, "The Potpourri That Is Exhaust Gas," Proceedings API, 27th Midyear Meeting of the API, May, 1962.

35. "Highway Use of Motor Fuel by Month" Table G 23, (Annual Reports 1947–1961), U. S. Department of Commerce, Bureau of Public Roads.

36. "Public Roads, A Journal of Highway Research," February, 1960, Vol. 30, No. 12, p. 273, U. S. Department of Commerce.

37. Joint State Government Commission Public Hearing on Motor Vehicle Air Pollution, Philadelphia, Penna., June 8, 1962, p. 96, testimony of Raymond Smith.

38. Joint State Government Commission Public Hearing on Motor Vehicle Air Pollution, Philadelphia, Penna., June 8, 1962, testimony of Dr. Richard Prindle.