

# A Morphologist

## Ponders the Smog Problem

by Fritz Zwicky

Some problems are beyond the capability of mere scientific or technical specialists — streamlining the relations between nations, for example, or relations between different races; developing a truly adequate system of education; or eliminating crime.

And some problems that would appear to be solvable by known scientific and technical methods alone still cannot be liquidated satisfactorily. Among these we count the task of eliminating the smog in and around Los Angeles County.

To solve this problem, much technical knowledge about the sources and the characteristics of air pollutants is of course necessary. But, beyond that, an integrated view which relates this knowledge to political, psychological, and ethical factors is likewise imperative. All of these factors add up to a complex task which is beyond the power of ordinary scientific, technical, or managerial experts. Specialists are at the added disadvantage that they are often too set in their ways, and too prejudiced, because of being unduly impressed by their accomplishments in relatively narrow fields. The problem of smog is thus a typical one which can be solved satisfactorily only through the so-called morphological approach.

For our present purposes it suffices to state that the morphologist, before all, and without any prejudice, attempts to visualize the *totality of all interrelations* which bear on the solution of a given problem. The stress is *first* on a survey without prejudice, which is far more difficult to achieve than most will care to believe; and *second* on a survey which includes all imaginable possibilities, before one attaches himself to any particular solution.

For a number of years many specialists have been at work determining the sources and the daily input of various pollutants into the atmosphere. Also the most important reactions have been traced (especially and most successfully by A. J. Haagen-Smit, Caltech professor of bio-organic chemistry) which take place between the pollutants, the constituents of the atmosphere, and sunlight as a photochemical agent. Some of the pertinent facts found are as follows. In orders of magnitude the daily input into the atmosphere of Los Angeles County includes:

Fritz Zwicky: Morphologist



Professor of astrophysics at Caltech, and staff member of the Mount Wilson and Palomar Observatories, Dr. Fritz Zwicky has always been an independent thinker — as anyone can see by sampling the accompanying article. Here, Dr. Zwicky applies the morphological method to the problem of smog — a method that is, basically, just an orderly way of looking at things. Dr. Zwicky has written extensively on applications of the morphological method to problems in jet propulsion and in astronomy — most recently in *Morphological Astronomy* (1957). In *Morphologische Forschung* (1959) he further discussed the applications of the method to sociological as well as scientific, technical, and military problems.

Organic compounds	— 1700 tons (1100 tons from automobiles, 450 tons from evaporating solvents, 150 tons from the petroleum industry).
Carbon Monoxide	— 10,000 tons (representing the totality of the products of incomplete combustion processes).
Nitrogen Oxides	— 700 tons (450 tons from automobiles, 220 tons from the combustion of gas and oil in homes and industrial plants, etc.).
Sulfur Dioxide	— 550 tons in winter (400 tons from fuel oils, 50 tons from automobiles, 45 tons from sulfuric acid factories, etc.).
Aerosols	— 100 tons.

Because of the frequent persistence of a temperature inversion layer over southern California, and the absence of even moderately strong winds, these pollutants stagnate and may accumulate day after day.

Although these primary pollutants are disagreeable enough in themselves, they become outright dangerous as a result of subsequent reactions, many of which take place because of the photochemical action of sunlight on them. As Professor A. J. Haagen-Smit first showed through his singlehanded and profound research on this problem, a great number of the secondary reactions are triggered through the action of sunlight on nitrogen oxide. As a consequence, exceedingly active atomic oxygen is released from NO<sub>2</sub>. The atomic oxygen in turn reacts with the organic components of the pollutants in the atmosphere and leads to the formation of various intermediate oxidation and reaction products, as well as to the production of ozone. These poisonous compounds constitute severe eye and throat irritants, and worse, dangerous hazards to the health of man, beast, and plant.

Although the nitrogen oxides, together with sunlight, produce the dangerous components of smog at a fast rate, even the complete elimination of nitrogen oxides would not eliminate the formation of the vicious compounds in smog, but would only change the size of the territory over which they are spread. Indeed, the oxygen of the atmosphere itself, with the aid of sunlight, would act on the organic pollutants much as the nitrogen oxides do. The rates of reaction, however, would be slower, and the vicious reaction products would have time to diffuse or to be spread over a large area.

### *A cooperative effort*

The few basic facts, as we have stated them, suffice to make it clear that the problem of smog is a most complex one and that, for its solution, cooperation from many quarters will be necessary. Therefore the morphologist must first list the character of these

various quarters and the contribution they might make toward the elimination of smog. The following sources of cooperation and support immediately come to mind:

1. The general public.
2. The various official agencies, including the police departments.
3. The universities, and the scientists individually.
4. Various industrial enterprises, as well as engineers individually.
5. The medical profession and public health services.
6. Certain commercial establishments.
7. The politicians.
8. The press.

These possible agencies of aid and cooperation must be appraised with a view to the following three goals:

- a. The achievement of immediate results.
- b. Results in the near future.
- c. Results of a permanent nature in a more distant future.

### *Measures for achieving immediate results*

“Immediate” implies that, in principle, the means in question could be effectively applied tomorrow. Again, in principle, these means can either be actual devices or they might be certain measures which will in one way or another regulate and streamline the activities of the public in southern California with a view towards the elimination of the smog.

I do not know of any devices which are immediately available and which guarantee the elimination of a substantial fraction of smog. On the other hand, many means already exist for influencing the daily activities of the public in such a way as to bring a marked decrease in the degree of air pollution. Among these measures the most effective would be the complete prohibition of driving any automobile with noxious exhausts, though this is hardly practicable. On the other hand, both the problem of smog and the streamlining of traffic as a whole could be substantially furthered by another plan.

With the view in mind of introducing immediately applicable measures we must try to influence the daily activities of the public as a whole — and, in particular, of the automobilists. One such measure, already passed by law, is the prohibition of burning trash in backyard incinerators. There are additional and even more effective means available. Among these, the most important and effective will be *to make it quite clear* to the public that each and every one among us must make his proper sacrifices and his contributions towards the elimination of the smog. For this reason, I advocate most strongly measures which will materially reduce the traffic through Los Angeles and, in particular, the traffic on all of the freeways.

*“Each and every one among us must make his proper sacrifices — and his contributions — toward the elimination of smog.”*

Even casual observation during our daily driving shows that the majority of cars on the road carry only a single occupant. Now it is obviously preposterous to allow a single individual to pollute the atmosphere at his pleasure with dangerous nitrogen oxides, with carbon monoxide, and with the uncombusted or partly combusted organic compounds from the exhaust, the fuel feed lines, and the carburetor of his automobile. This promiscuity in polluting the air is actually far worse than allowing litterbugs to throw their cigarette butts, matches, papers, cans and other trash on the streets and highways. Since the litterbug has already been censored, and since he can be prosecuted by law, we are obviously far more justified in stopping individual drivers from polluting the air we breathe.

As a workable and effective measure of control, which can be put into action immediately, I propose that any driver who insists on driving on a freeway without carrying any additional passengers in his car must pay a certain toll, say one dollar a day, for his extravagance. In order to collect these dollars smoothly and without the mobilization of much personnel, stickers could be issued, with the dates printed on them and with different colors and shapes distinguishing the various days. These stickers would be purchased one or two days ahead of the day in question, at stations located at strategic points. Any driver who has no passengers must display the proper sticker on the proper day on his windshield. Police officers could then easily spot those drivers who are violating the regulation. For every such violation a fine of fifty or one hundred dollars could be levied. All trucks should be charged one dollar per day for driving on the freeways, regardless of the number of passengers they carry.

For driving on the *city streets* without any passengers, three stickers per month might be issued, valid for ten days each, and at a cost of perhaps a dollar each. The period for the levy might be restricted to from 9 a.m. to 3 p.m. This would allow everybody to get to and from work without any penalty. Physicians,

of course, would be exempt at all times.

The following results would be achieved from the collection of these various levies:

- (i) An estimated 20 percent of the smog would be immediately eliminated because of the reduction of traffic.
- (ii) A sizable amount of money would become available each year for research on all aspects of the smog problem.
- (iii) The public would be dramatically impressed with the fact that each and every one of us is responsible for the problem of air pollution and that all of us can and must help in eliminating it.
- (iv) The reduction in the number of automobiles on the road would reduce the accident rate, eliminate many traffic jams, speed up circulation and deliveries, allow more people to meet their appointments on time, alleviate many psychological anxieties, and thus benefit the overall activities of the community.
- (v) Finally, and probably most important, the health hazard inherent in smog would be reduced, and valuable manpower and working hours would be saved.

There are also other measures which can be introduced with relative ease. For instance, it will eventually become necessary to get tough with all drivers of mechanically defective cars which at the present time still merrily belch clouds of noxious fumes along the streets. There is obviously little hope that any smog reduction devices, such as afterburners, will help much unless we see to it that they are all really working properly. This means control of maintenance of these devices. Today such control is not even adequately exercised with regard to the smoky exhausts.

As a further immediate measure I propose that research institutions, such as the California Institute of Technology, the University of California at Los Angeles, the Stanford Research Institute, and

others, which have for some time been given sizable grants for research on the smog problem, should be requested to produce, for each \$100,000 of grant, a usable plan for getting rid of, say, one percent of the smog at the least. If these institutions cannot come forth with such results, the grants should be diverted to other more effective people. Also, the presidents of these institutions might be expected, as a contribution to the better life of the community, to exert themselves somewhat more ardently than hitherto in animating their faculties (and their chemists, physicists, and engineers in particular) in a cooperative endeavor toward the elimination of smog.

It should also be impressed on those of our scientific colleagues who have been shouting so much about the dangers of radioactive fallout that first things should come first and that their suddenly avowed love for humanity would be more convincing if they spent some of their time and effort on solving the problems at hand—the problem of smog being a most appropriate one to tackle.

Finally, in view of the tremendous quantities of carelessly evaporated solvents (450 tons a day, or almost half as much as come from automobiles) both the housewives and the professionals (painters, cleaning establishments, highway construction crews) who use them should be instructed how to handle solvents with greater care.

### *Measures for the near future*

Among the intermediate measures which will require some time for their effective development are the devices which would improve combustion in automobile engines and cut down the excessive discharge into the atmosphere of uncombusted or partly combusted hydrocarbons, nitrogen oxides, and carbon monoxide. Many of the devices in this category, such as afterburners, catalytic devices, recirculators of the exhaust gases, and extra oxygen feeders, are now being worked upon by many agencies. Depending on exhaustive tests to be made by official and critical examiners, some of these devices might soon become applicable. Also, it should not be too difficult for the automobile manufacturers to build engines and feed systems which will not leak gasoline at the atrocious rate of most of the present machines.

Further relief might be derived from an application of the principle that whatever cars put into the atmosphere cars can also extract or neutralize. Indeed, in the course of their travel cars sweep through and stir up immense quantities of air. Thus one million cars traveling as little as one kilometer a day will sweep through a volume of air in excess of four cubic kilometers—a very respectable volume. Possibilities for cleansing this huge amount of air are easily suggested. One of these means consists in either adsorbing or absorbing the pollutants from this volume of air and decomposing chemically or cat-

alytically the noxious nitrogen oxides on specially treated external or internal surfaces in special ducts of the cars.

The second means is to let the cars, aided by differential heating through absorption of sunlight, create circulation through culverts and tunnels which already exist or which might be specifically constructed for the purpose. Also catalytic and chemical surfacing, followed by subsequent large-scale washing for removal of the smog products from the street surfaces themselves as well as from the surfaces of buildings, should be investigated in research projects. These could be amply financed by the funds collected from motorists.

### *Long-range measures*

Two outstanding possibilities suggest themselves here:

1. Without concerning ourselves at all with the sources of smog we may decide to work on large-scale means to eliminate the pollutants from the atmosphere or to neutralize them and turn them into harmless products.
2. As the second alternative we may carry out a complete survey of the sources of smog and then set out to eliminate or neutralize them one by one.

Working on large-scale means, we may either bring about reaction of the pollutants (that is, oxidize them or dissociate them) and end up with innocuous reaction products such as oxygen, nitrogen and carbon dioxide; or we may attempt to drive the pollutants out to sea, precipitate them to the ground, or drive them high enough into the atmosphere into strata where winds always blow vigorously enough to spread the pollutants over sufficiently large areas to render them harmless. Considerable research of course must be done, financed by the levies raised from the public, to develop methods which will enable us to achieve any one or all of our goals.

Actually, in working towards these goals, the smog itself should be of considerable assistance since, speaking energy-wise, it is potentially quite capable of exploding and thus destroying itself! Indeed, smog represents a chemically endothermic state and thus is literally an explosive. Actually, the oxidation of the 1700 tons of organics and the 10,000 tons of carbon monoxide into water and carbon dioxide would release daily 22 million and 29 million kilowatt hours of heat respectively. From the dissociation of the 700 tons of nitrogen oxides into nitrogen and oxygen an additional 650,000 kilowatt hours could be obtained daily. Figuring a thermodynamic efficiency of 25 percent for the conversion into mechanical or electrical power, about thirteen million kilowatt hours are therefore wasted daily through the discharge of unreacted fuels and of endothermic compounds into

the atmosphere in and around Los Angeles. It is clear that it would be best to save this energy by not discharging it into the air at all. As a second best solution we might use it with a sufficiently cleverly conducted series of operations to extract the smog from the atmosphere.

### *Tracking down the sources*

Our *second* alternative must be to track down the sources of smog and to eliminate them one by one. Automobile exhausts being by far the worst and most persistent offenders, let us survey what might be done about them.

The most radical solution would be to outlaw automobiles altogether and to construct a general transportation system, such as underground electric subways. With a view to survival in a possible nuclear war, a solution of this character has much to recommend it and should therefore be analyzed in detail.

Working on the automobile engines themselves, the exhausting of dangerous pollutants could either be eliminated completely, or greatly diminished by one of the following developments, which are of immense interest for the generation of power from carbon or hydrocarbons in general. The first possibility refers to the use of *fuel cells* which generate electricity *directly* from the oxidation of the fuels in electrolytic reactors. How to accomplish such reactions with high efficiency has been attempted for over a hundred years, but only recently have successful inroads been made. Replacement of the internal combustion engine by fuel cell electric generators would eliminate all vicious gaseous exhaust products altogether.

Much cleaner exhaust products could also be achieved through a combustion which approximates a more isothermic character, in contradistinction to the conversion of heat into mechanical power by adiabatic expansion of the combustion gases, which necessitates high combustion pressures and temperatures, and which, because of the rapidity of the processes involved, always leaves unreacted products. In this connection it may be pointed out that the oxidation of food in living bodies takes place isothermally. One way to approximate isothermal combustion was pointed out many years ago as a consequence of my work on power conversion in jet engines. The processes to be used are a succession of combustions and expansions or, in other words, so-called *reactions on the flow*. In fact we successfully operated such jet engines with hydrogen and oxygen as the propellants. Our attempts to interest the builders of combustion engines in the principles of reactions on the flow, however, have mostly fallen on deaf ears.

Our experiences in this respect call for a few comments on some aberrations of the human mind which have been greatly responsible for our failure to deal effectively with the problem of smog, or, for

that matter, with such problems as an adequate civilian defense and the issues involved in our competition with the communists. Indeed, in the present case, the automobile industry, instead of developing better engines and smog suppressors, concerned itself largely with the styling of mammoth cars, which are about as useful as the towering and elaborate hairdos preceding the French Revolution, but which are much more wasteful and dangerous.

As director of research of the Aerojet Engineering Corporation in 1943 I attempted to obtain from the automobile industry information about the topological performance characteristics of automobiles. No pertinent information could be obtained about how far a car of given weight could be driven with one liter of gasoline on a road of given characteristics. That is, the industry had never concerned itself with the exact evaluation of the maximum thermodynamic efficiencies possible; with the minimum heat and fuel losses; with the minimum possible transmission losses from the engine to the wheels; with the rolling friction losses of various types of tires; with the aerodynamic drag; or with the characters of the various parasite losses. In fact, I wonder if such an overall evaluation of the automobile as a complete propulsive power plant is even available today.

### *Who's to blame*

It is, however, not only the moguls of industry which are to be blamed. The scientists themselves and, in particular, the administrators of scientific institutions, both governmental and private, have dismally failed in their responsibility to organize their manpower and technical resources toward making a concerted attack on such problems as the elimination of smog. Individuals like Professor A. J. Haagen-Smit are therefore highly to be commended. Individual efforts alone will, however, not be sufficient for success, although they must act as the indispensable spearheads. What is needed is the cooperation of scientists, engineers, the public, the press, and the various agencies of the local, state and federal governments.

In conclusion I therefore suggest that, as a first step, the presidents of the local universities call some of their men together to work out an overall morphological attack on the problem of smog. I have attempted to point out a few promising avenues, but far more can and will be done if a group of men of good will and of technical knowledge can be called together to make an uncompromising attack on the problem of smog. The success of such an attack will in my mind not only be of immense economic value; it will also eliminate a tremendously growing health hazard; and it will, directly and indirectly, aid our efforts in stemming the tide of communism through the proof that ours is an immensely sounder world than theirs.