THE SINS OF WASTE

by Arie J. Haagen-Smit

In December 1950, I wrote an article for *Engineering and Science* which ended this way:

> Smog elimination has entered a new phase. Careful studies have to be made of the amounts and nature of the organic material released into the air. Only in this unemotional way can we hope to bring relief to this area.

The "unemotional way" turned out to be not exactly a tea party. Apparently, the professor had never before looked beyond the walls of his laboratory. My microworld consisted of distilling liquids and crystallizing substances, and whenever a distraction threatened a discovery, I hightailed it back to the safety of my laboratory.

This time the getaway was not so easy. Too many interests were at stake, and strong medicine was needed. In 1950 all pollution was believed to be sulfur and smoke. The cleanup of refineries, steel factories and foundries, dumps, and incinerators was in full swing. So my discoveries that organic material released into the air—mostly hydrocarbons—was oxidized through the combined actions of oxides of nitrogen and sunlight to become photochemical smog did not go over very well.

The losses of gasoline into the air in the early fifties were astounding. The estimates varied between 120,000 and 240,000 gallons per day—at an average cost of $10 million to $20 million a year. This was the incentive for some soul searching by the petroleum industry, and the result was a general cleanup. By 1956, most of the hydrocarbon sources at the refineries were controlled, and the stage was set for the control of smog components from automobiles and power plants.

In recent years, pollution experts, news media, and public-spirited groups all over the world have stressed our dependence on a healthy environment. The resources for that environment are the same as the four principles of

Lecture Circuit

"The Sins of Waste" has been adapted from a Watson Lecture given by Arie J. Haagen-Smit, professor of bio-organic chemistry emeritus, in Beckman Auditorium on December 4. The new Earnest C. Watson Caltech Lecture Series is a successor to Caltech's famous old Friday evening demonstration lectures—and Haagen-Smit has given one of those about once every four years since he came here 35 years ago. In his December 4 talk, he paid this tribute to the founder of those lectures.

It has always been an adventure to follow the tradition set by Earnest Watson's Friday evening lectures. Those who knew him remember that you could not get away with just any kind of a lecture. It had to be groomed to perfection.

Experiments were a *must*. There was the resounding boom in the High Voltage Laboratory when Dr. Sorensen made his own lightning while we watched from the gallery. And there was Dr. Watson himself, whose lecture on liquid air always drew a full house. Anyone who ever saw his skill in capturing his audience remembers the case of the deep freeze: the goldfish and the rubber ball. When the fish and the ball were both frozen stiff at —180°, he threw the ball against the wall of Bridge, and it shattered like glass. He put the fish in water and, lo and behold, after a few minutes, it was swimming (I suppose, happily) around. We kept waiting for it, but he never mixed up the two experiments.

It was in 1950 that my Friday evening lecture served as a forum to tell Los Angeles what smog was all about. Following the custom of the old-style lecture, the table was crowded from one end to the other. On the blackboard I had written the master reactions leading to the typical smog symptoms: nitrogen dioxide, photochemically dissociated into nitrogen oxide and atomic oxygen. The atomic oxygen was ready to attach itself to organic compounds, gasoline and the like, and eye-irritating, plant-damaging substances were formed. All these reactions were accompanied by the formation of aerosols—that is, a haze—and, strangely enough, ozone. The ozone formation was the great stumbling block in convincing key people that something had to be done about the primary reactants: hydrocarbon (meaning gasoline), automobile exhaust and solvents, and the products of the union of nitrogen and oxygen—the oxides of nitrogen.

After exactly one hour (Dr. Watson's orders), the lecture was over, and the people had seen a demonstration of the formation of ozone from an organic compound and light (diacetyl and air).

alchemy: air, water, soil, and fire. All four are important, of course, but I would like to add another one. It is "time." For the individual, this is clearly a nonrenewable resource, and the old saying is still true: "Time goes fast; use it well."

Following time, energy is probably next in importance. If we have energy, we can reclaim water, refine our mineral resources, and have food for all.

Let us look at a key operation in our daily lives: the production of energy in a central power plant. The story of that energy began millions of years ago with the sun converting the randomly spread carbon dioxide into packages of starch, bundles of cellulose, and the like. The next step was a loss of water, coupled with hydrogenation and dehydrogenation which resulted in the formation of gas, oil, and coal. These products are converted into mechanical and, subsequently, into electrical energy in a power plant. All these conversions are governed by two fundamental laws of thermodynamics.

The first one is known as the law of conservation of energy. It says that work produced can never be greater than the heat applied. The second law goes further and says that it must always be less. A popular version of the two laws of thermodynamics is sometimes expressed as follows: (1) You can't win. (2) You must lose.

The second law denies the possibility of converting *all* the energy in the fuel into useful work. It predicts that in all energy conversions there will be waste. Some of the energy is used up in friction, heating up the environment, in noise, and in light. The dissipation of energy to a nonusable form is measured by entropy, which increases when reactions such as the burning of fuel take place. It is more or less a measuring stick for downgrading our energy.

The statistical version of the second law says that order will tend to become randomness or disorder. This random dissipation of materials is, of course, what we do to our natural resources. We mine the pockets of pure or highly concentrated mineral resources and spread them over the earth or into the atmosphere. For example, the lead from the rich deposits in our mines goes as ethyl and methyl lead into gasoline and ends up finely dispersed all over the globe and in the ocean waters. When we want to recover the resources—lead, copper, nickel, and many other minerals—we must deal with extremely lean mixtures which take lots of labor (that is, energy and money) to recover. But we have made progress in utilizing fuel more efficiently. There has been a steady increase in the yield of useful energy from fuel in power plants, for example. In 1900, seven pounds of coal were necessary to produce 1 kilowatt; today, only four-tenths of a pound produce the same electrical energy.

But the relentless demand for power, which doubles every ten years, keeps neutralizing the gains. The energy crunch is now openly discussed, and more and more technical experts are pointing to the limitations of our fuel supplies. Faced with finite resources of fuel—gas, oil, and coal—we must now look toward a greatly increased use of nuclear power through breeder reaction and, eventually, nuclear fusion processes. The use of large-scale solar energy is no longer limited to science fiction stories. A 250-square-mile area filled with solar batteries would generate all the power now used by Los Angeles. Farming the deep heat inside our planet is under serious consideration, and deep wells are being drilled now.

Even in the use of fossil fuels, exciting new techniques are being developed. The magnetohydrodynamics process (in which a stream of ionized atoms generates electricity by passing through a magnetic field) is able to increase the efficiency of a boiler plant from about 40 to 60 percent of its fuel input. Nothing is taken for granted; losses formerly considered inevitable are now being carefully scrutinized. The transportation of electricity at near absolute zero where resistance—and, therefore, energy

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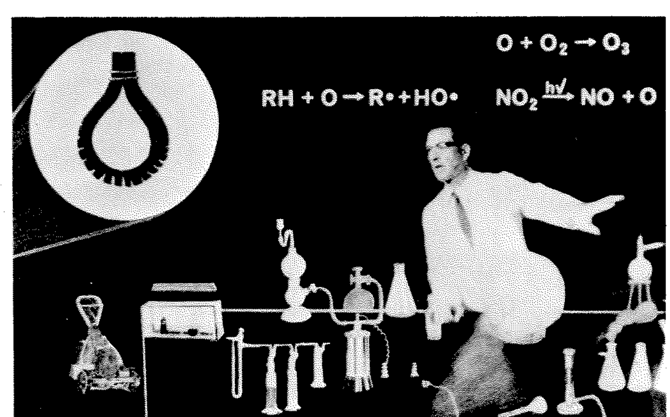
They had seen in a time-lapse film how ozone cracks rubber strips under stress. They had seen the oxidizing effects of ozone when it passed through different solutions of reagents. (One bottle turned *red*, another *white*, and a third one *blue*. Just try to figure out how to do that.) Dropping a few drops of gasoline into a bottle filled with ozone never failed to cause some excitement in the first rows. The stuff *smelled and hurt the eyes*, just like smog. But the oh's and ah's came when a solution of *luminal* (4-aminophtalhydrazide) reacted with ozone in a Rube Goldberg apparatus, giving an eerie, blue light—almost like firecrackers in a bottle.

The origin of the oxides of nitrogen in high-temperature combustion was shown with the help of a bunsen burner and with a power lawnmower that appeared and started at just the critical time. The last stunt was an explosion of gasoline and ozone, a cold burning or oxidation of the gasoline in the hollow of my hand. I thought it was about as good as Dr. Watson's fish or Dr. Sorensen's thunder and lightning.

It was, of course, several days of work, but it was also a challenge, and in that early period, it was essential to get your point across. One can talk chemistry to legislators and supervisors for quite some time, but there is no better argument than fumigation with home-made smog—the stronger the better.



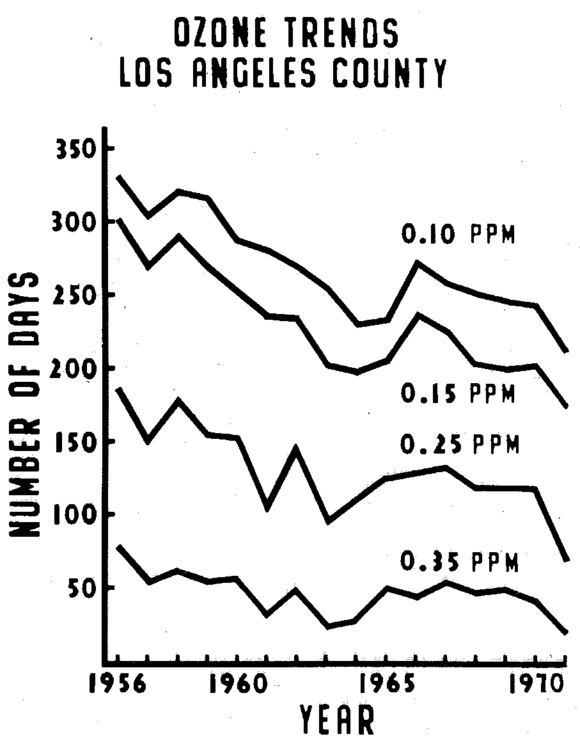
Complete with a photo of himself at the time, A. J. Haagen-Smit offers his own pop-art portrayal of what went into the 1950 lecture in which he first demonstrated the formation of smog.

heat loss—is at a minimum is being worked on with considerable success, opening up the possibility of locating power centers at a distance from the users.

We can save even more in the way we make use of our fuel. Why, for example, do we make electricity from burning fuel and then convert it back into heat? Use of waste heat for heating and cooling, agriculture, and aquatic cultures is feasible and should be promoted wherever possible. The "Save-A-Watt" propaganda deserves more than mild criticism and derision. The battle for economy in the use of energy consists of making a multitude of small gains all down the line, in industry as well as in homes.

The Automobile

One-third of all the fuel we burn is used to propel our automobiles. The energy we waste with these little power plants is way beyond reason. Not only do they use an inordinate amount of energy in moving people around, but they contaminate the air on a scale no other emissions



The number of days with abnormally high ozone concentration in the air of Los Angeles County has shown a general downward trend since 1956. Each jagged line shows the number of days in the year on which the oxidant reached the indicated values—expressed in parts per million (ppm). In 1971, for example, ozone in the atmosphere surpassed the California Health Standard of 0.10 ppm on 210 days; it surpassed 0.15 ppm on 175 days; 0.25 ppm on 70 days; and 0.35 ppm on 20 days.

source has managed to do. No wonder that after most stationary sources in Los Angeles had been controlled, the automobile emerged as a major source of trouble.

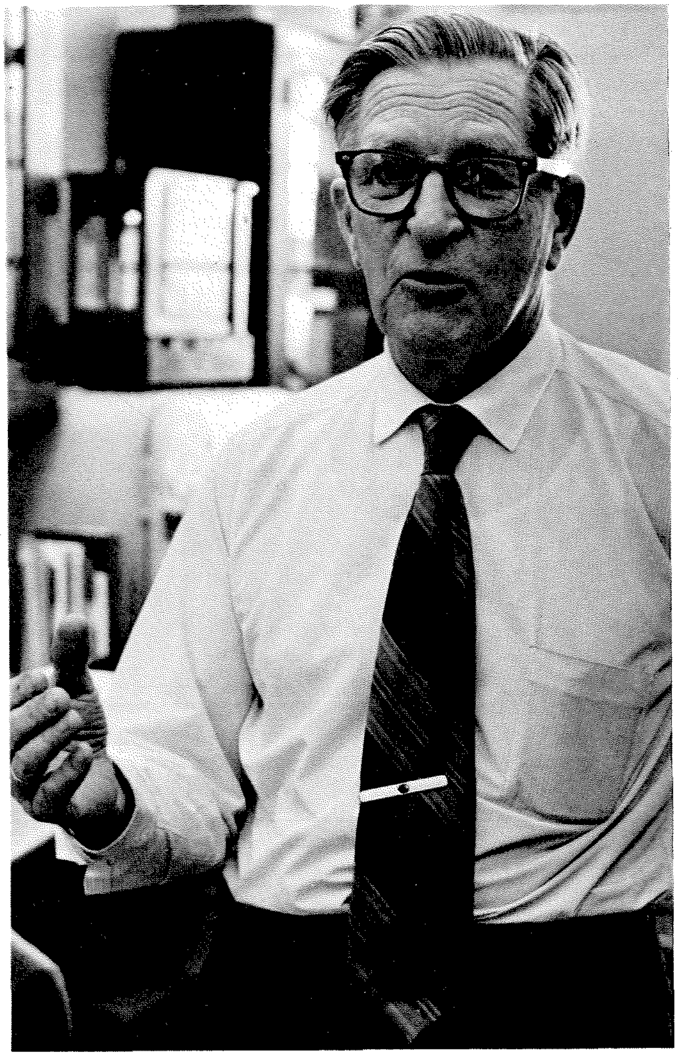
The discovery of the reactions leading to the type of smog we see in Los Angeles has prompted an intensive effort to control the emissions of hydrocarbons, oxides of nitrogen, and carbon monoxide. In the past, hardly any attention had been paid to the fate of the unburned fuel, but now it was shown that there were several escape routes for the substantial amounts of hydrocarbons that are exhausted—through the tailpipe, 65 percent; through the crankcase, 20 percent; while the remaining 15 percent came from evaporation of fuel in the carburetor and from the fuel tank. The reduction of hydrocarbons and carbon monoxide emissions started in California around 1960 with control of crankcase exhaust emission, and has continued since with control of the exhaust, tank, and carburetor emissions.

Automobile laboratories now routinely test new cars coming off the assembly line by simulating city driving on a dynamometer that has fast-turning rollers instead of a roadbed. The official federal emission test includes starting, accelerating, cruising, decelerating, and idling. The results are expressed in grams per mile. An average car, before controls were instituted, emitted through its tailpipe 17 grams of hydrocarbons, 120 grams of carbon monoxide, and 4 grams of oxides of nitrogen per mile. Our latest results from the 1972 crop of cars showed marked progress, with emission of only 3 grams of hydrocarbon, 30 grams of carbon monoxide, and 3.4 grams of oxides of nitrogen per mile.

Taking into consideration control at all emission points, the new 1973 cars have an emission reduction of 90 percent for hydrocarbons, 75 percent for carbon monoxide, and 35 percent for oxides of nitrogen.

The effect of these steps is now being recorded on the Los Angeles air-monitoring systems. The concentrations of both hydrocarbons and carbon monoxide in the ambient air show a downward trend for the second year in a row. The same is true for the number of days of eye irritation and for the amount of oxidants in the air. At the same time, random sampling of cars has shown an average 50 percent reduction in pollutant emissions. This average is compiled from 1972 cars with crankcase, exhaust, and evaporative controls, and from older cars which are not yet controlled. It is gratifying to see that our laboratory testing results confirm, and run parallel with, the analytical findings of the monitoring systems.

Refinement of controls will continue until, in 1976,



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97 percent control of hydrocarbons and carbon monoxide has been achieved; emission of oxides of nitrogen will be reduced to one-tenth that of the uncontrolled vehicles. These last few percentage points (between 1972 and 1976 standards for controls) represent major technological problems, which are as yet unresolved.

While some laboratory cars are probably coming close to the 1976 standards, the penalties for excessive control within too short a time span are beginning to appear. Complaints about poor drivability are mounting, and a fuel penalty of 10 to 20 percent will cause a decided increase in the cost of running an automobile.

The need for a drastic reduction in automobile emissions, while preserving the advantages of our present cars, has stimulated the search for ways to modify the existing automobile power plant. The most successful contender is the rotary engine, which is already being produced on a mass scale and which by the mid-seventies will take an important place in the propulsion of light vehicles. Cars equipped with two-stage combustion in the stratified charge engine and its Honda-type modification will undoubtedly command a large portion of the automobile market. Less important contenders are diesels, turbines, Stirling engines, and electrically driven cars.

There is no doubt that the activity set in motion to deal with emission control will bring us many exciting innovations in the coming years. There is, however, much misinformation. It is common to hear about the terrible waste of energy in the internal combustion engine. And anything bad that is said about the so-called "infernal" combustion engine is received with applause by the old-timers who remember the Stanley Steamer.

But both the internal and external combustion engines are subject to the same energy laws. The efficiency of the power plant is dependent on high pressure and temperature. As soon as we lower these, down goes the efficiency. The limitations on the practicability of high-pressure and cooling equipment in a vehicle result in a drastic lowering of its efficiency. Thus, the efficiency of the steam car becomes comparable to that of the internal combustion engine—that is, it only uses about 10 to 15 percent of the fuel energy.

The Wankel rotary engine is not more efficient than the gas combustion engine. The peculiar form of the combustion chamber with high surface-to-volume ratio also makes for less complete combustion. Inherently, rotary engines are dirty, and they are equipped with

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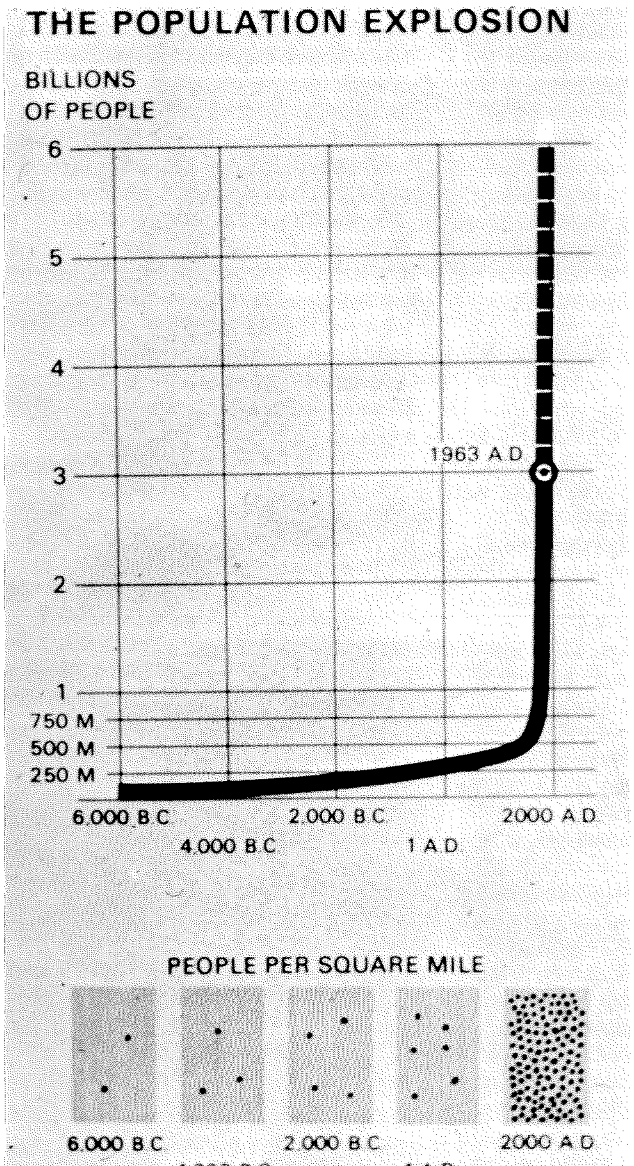
afterburners to correct their poor combustion. The advantage of rotary engines lies in their lower emission of oxides of nitrogen, but they will need additional equipment to pass the 1975-76 federal standards of performance.

I would like to see all-electric transportation inside the cities, but this would only displace our problem of building more power plants. Moreover, the public is not yet in the mood to accept the limitations of present-day batteries. Turbines, now used for long distances, seem too cumbersome for the passenger car.



The "curve" of population growth for the world has become a line heading straight for trouble. In the U.S. at present the population increases at the rate of five persons per minute; the world's population grows even faster—five per second.

Fleets of vehicles and some private automobiles are being changed over to natural gas and LPG (liquid propane gas)—both low emitters. It is highly unlikely that the mandatory conversion—at a cost of $300 to $400—of all the ten million vehicles currently in use could be passed in the legislature (though conversion of fleet vehicles is well within the possibilities). And suggestions to use low-pollutant fuels, such as hydrogen or methyl alcohol, have not received much support. They involve reforming gasoline, which adds considerably to the price of the fuel and waste of reserves.

The venom sometimes directed at the internal combustion engine is actually rather silly. It is the *use*, not the instrument, that is the source of our troubles. Who determined that we should send half-a-million people to the center of Los Angeles every morning and see half-a-million (minus a few) come back every night? Who says that we must propel a 3,000- to 4,000-pound car to move a 160-pound person? Don't blame General Motors! We are the ones who make the decisions.

We make big noises about the difference of a few percentage points between the emissions of 1972 and 1973 cars. But two people in a car instead of one would bring about a 50-percent reduction in all emissions at no cost. (We would also benefit from not having to park and not wasting our minds in fighting traffic.)

Waste Makers

In recent years the sophism that the production of goods is the same as prosperity has opened a wonderland for a new industry that is based on waste. And a new profession, the "merchants of waste," has been born. With the phenomenal growth of industrial potential, new markets have to be found. Not that these markets necessarily represent actual needs. The sales departments create them by conditioning potential customers and luring them into buying things they really did not know they needed. All of this is not new, of course; only the squandering is worse—and on a larger scale.

Keynote speakers tell us that the individual should have the greatest variety of goods, services, and facilities. He should be able to choose the kind of habitat he prefers and enter many kinds of environment at will; he should have the maximum kind of personal control over his world. This is wonderful, of course, and a good election platform. Unfortunately, an average living space is now not more than 15 by 15 feet, and it gets smaller and smaller by the day. It is not only our increasing numbers that cause trouble. The higher standard of living, the social revolution, has demanded more and more energy. Today when a baby is born, the good fairy endows him or her with two gallons of fuel oil and one gallon of gasoline per day for the rest of his life. Every time a baby comes off the assembly line, three cars do the same in Detroit.

It is nice to have so much energy available. It is like having slaves. The amount of energy available to a single person, expressed in terms of human labor, would correspond to the work of 200 slaves. A simple turn of your ignition key, and several hundred horsepower—corresponding to a few thousand slaves—spring into action. The trouble is, of course, that the energy slaves are not very neat. Worse, they might ask that their wages be increased. Even worse, there might not be enough slaves to go around. What is the baby going to do when he doesn't get his "bottle" of fuel? I can tell you. He is going to kick and cry. That is how he got everything in the past. Why change a good racket?

The punishment for not solving either old or new problems may well be disastrous. Today (December 4, 1972) at 5:07 p.m. Eastern Standard Time, the demograph in the Department of Commerce building in Washington, D. C., showed that there are 210,234,507 persons in the United States. With an increase of 5 new citizens every minute, there will be a hundred million more of them by the year 2000. That is not far away, and the babies I mentioned earlier will want their food and play.

What Lewis Carroll's Alice foretold, when she said that she had to run twice as fast to stay where she was, is the effect of exponential growth: two times more power in ten years, two times more in another ten years—the relentless growth in population with all its dire consequences.

Measures designed to cope with the increase are timid and totally insufficient to keep up with the size of the problem. This goes for transportation, housing, education, health, and safety on our streets and in our homes. We can still change all this, but if we are incapable of adjusting ourselves to the pace of time, a power stronger than we will do it. The laws of nature will take over, and there is no mercy and no bargaining then.

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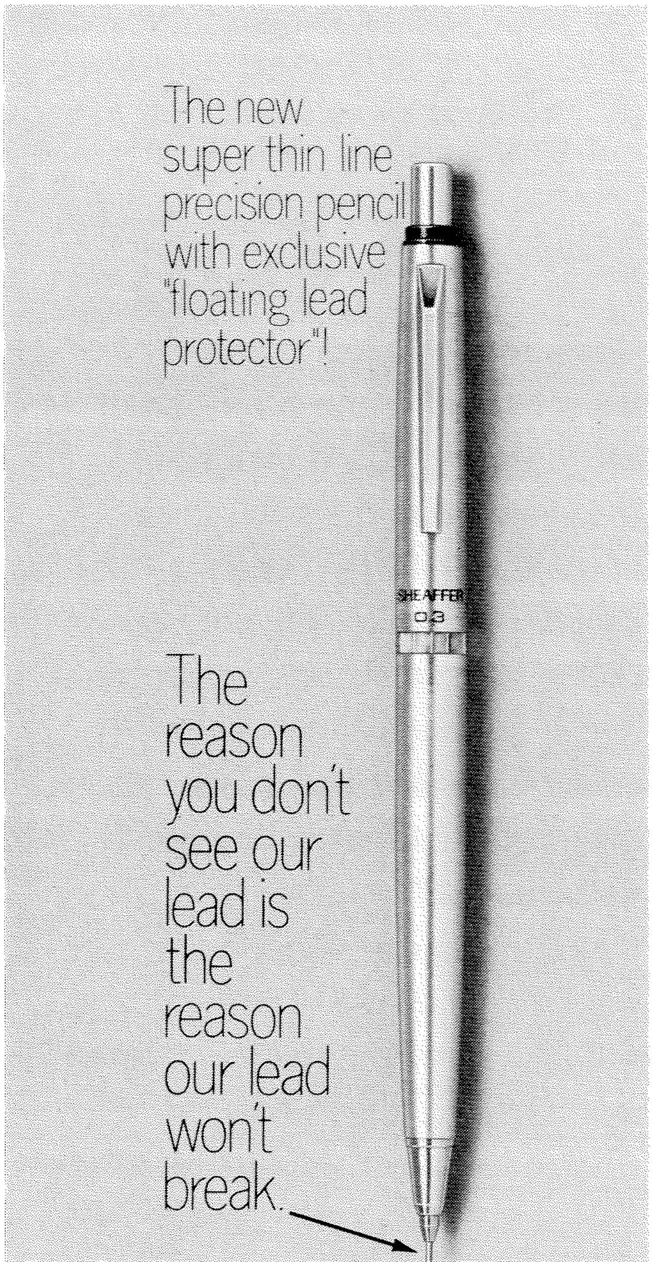

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We need to educate, to inform people, to present them with alternatives. We need to create public awareness of the pressing problems. We need to tell people that we *can* afford clean air and clean water, that cities don't have to look like overgrown parking lots—punctuated with towers that allow the inmates to look down upon the mess they made.

And I am not downhearted. A beginning has been made! All over the country, for the first time in history, plans have been drawn up about what to do about our problems. These plans have a tight schedule and an impressive program of enforcement. One can quarrel, and even be skeptical, about levels of control, thoroughness of implementation, and the time allotted for it. Nevertheless, the programs indicate for the first time what it is that has to be done and how gigantic the task is.

As my favorite statesman, John W. Gardner, once pointed out:

> There is something disheartening about the modern scene—the confusion, the disorder, the changing values, the constant push-and-pull of conflict, the vastness and impersonality of the systems that govern our lives.
>
> But at the same time, the possibilities of an improved life for mankind are more exciting than ever in the long history of the race. We hold in our hands the tools to build the kind of society our forebears could only dream of.
>
> We can lengthen the life span as they could not. We can feed our children better and educate them better. We can communicate better among ourselves and with all the world.
>
> We have the technology and the means of advancing that technology. We have the intellectual talent, and the institutions to develop it and liberate it. We have, or we can build, the systems and organizations, public and private, through which our common goals can be pursued.
>
> We have these things not because we are any smarter than those who came before us but because we can build cumulatively on their creative effort and achievements.
>
> Far less than any other generation in the history of man are we the pawns of nature, of circumstance and of uncontrollable forces—unless we make ourselves so.
>
> We built this complex, dynamic society, and we can make it serve our purposes. We designed this technological civilization, and we can manage it for our own benefit.
>
> To do this takes a commitment of mind and heart—as it always did. If we make that commitment, this society will more and more come to be what it was always meant to be: a fit place for the human being to grow and flourish.

And I add: No generation before us had a greater responsibility and no one had a greater opportunity to better our life on earth. Let us all join hands in this wonderful goal!