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ABSTRACT

This commentary on sources of air pollution and air purification treatments is accompanied by graphic illustrations. Sources of carbon monoxide, sulfur oxides, nitrogen oxides, and hydrocarbons found in the air are discussed. Methods of removing these pollutants at their source are presented with cut-away diagrams of the facilities and technical processes. Car pollution controls and factory flue air-filtering systems are among these illustrated. (JP)

AIR POLLUTION

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CAUSES & CURES

MANUFACTURING
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Founded in 1872,

the Manufacturing Chemists Association

is the oldest chemical trade organization

in the Western Hemisphere.

Its member companies

represent more than 90 percent

of the production capacity

of basic industrial chemicals

within the United States and Canada.

AIR POLLUTION

CAUSES & CURES

**When the canary dies,
it's time to
get out of the mine!**

That expression was all too true a few generations ago. Miners took a canary underground to monitor the air. Its death warned of potential disaster due to an accumulation of carbon monoxide since the bird's size and metabolism rate would cause it to succumb quicker than man.

Fortunately, such heartless detection methods are not needed today. We have sophisticated devices to detect air pollutants resulting from a variety of sources.

The truth is that, regardless of recent dramatization, man's pollution of the air is not new. In 61 A.D., the statesman, Seneca, complained about the *soot and stink of the heavy air of Rome*. England's Queen Eleanor moved away from Nottingham 700 years ago because of the *unendurable smoke*. And, in the 17th Century, it was written that Londoners breathed nothing but *impure thick mist*.

Eons before man added his contribution, nature was putting foreign matter into the air—for good reason. It is essential to earth's life cycle. For instance:

> Volcanic ash and dust provide the nuclei for rainfall.
>
> Pollens propagate plant life.
>
> Various gases and mists, resulting from reactions caused by sunlight, humidity and decomposition of plant and animal life are essential to the continuing renewal of life sources.

In fact, nature constantly emits a far greater quantity of so-called air contaminants than does man. Her recycling processes, however, are uncannily self-cleansing. Given time, nature maintains a tolerable balance between polluted and acceptably-clean air, even with man's input.

Therefore, today's air pollution problems result from our persistent overwhelming of nature's self-cleansing capabilities in densely populated and industrialized areas, thus creating a temporary or continuing imbalance in nature's process.

Although the analysis is simple, the effects are not. Therefore, the purpose of this booklet is to bring better understanding to this complex subject. It describes the major causes of those aspects of air pollution for which man is responsible, and some of the cures he has devised for its abatement or prevention.

W J Driver

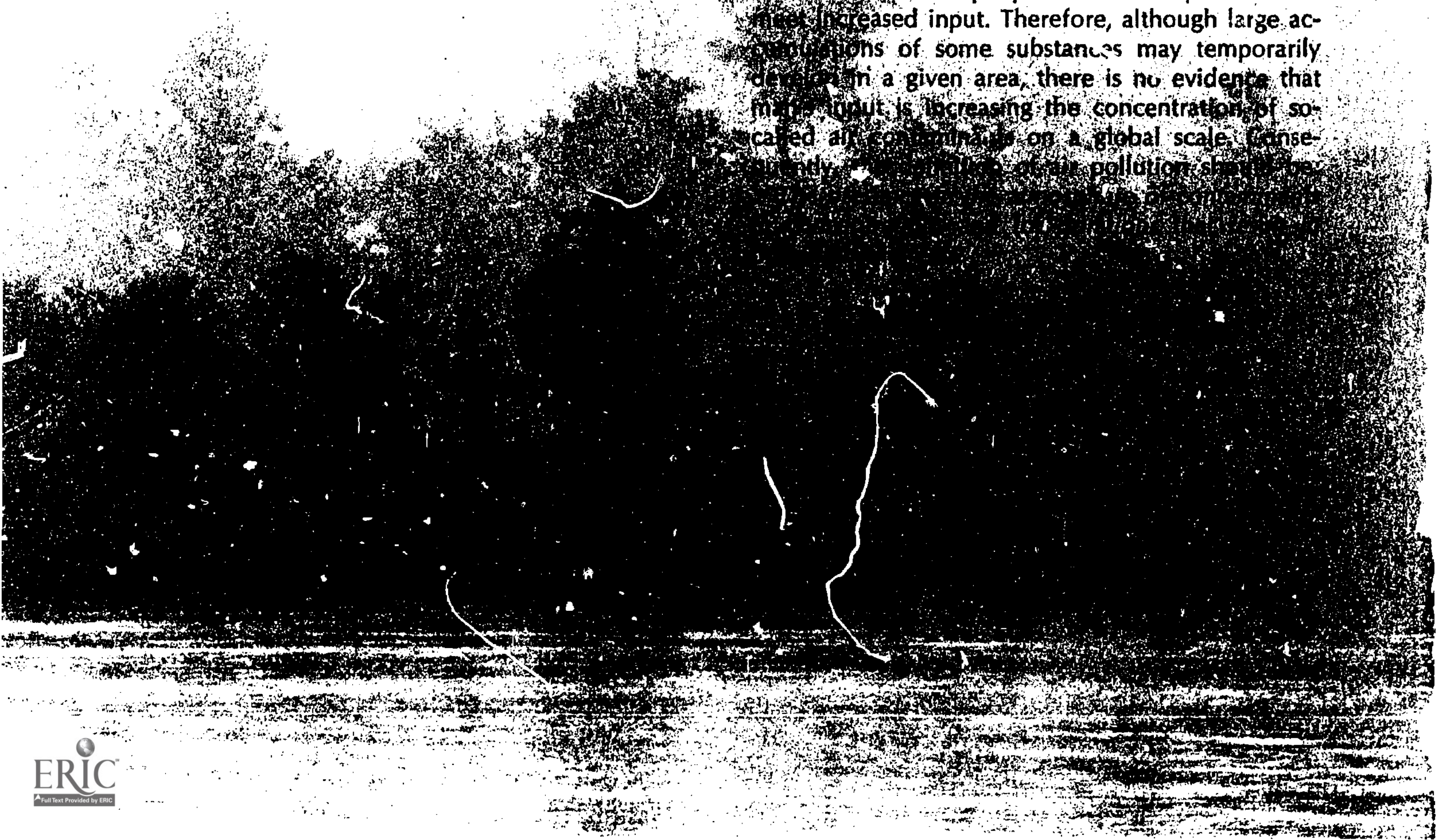
**William J. Driver
President
Manufacturing Chemists Association**

THE ATMOSPHERE

Clean dry air, by volume, is composed of slightly more than 78 percent nitrogen and nearly 21 percent oxygen. The less-than-one-percent remainder is made up of carbon dioxide and such rare gases as argon, neon, helium, krypton and xenon. Normal atmospheric air also contains water vapor—from trace amounts up to three percent, depending on locale. It is important to understand, however, that an atmosphere composed solely of these gases and moisture is really not natural.

Natural atmosphere also contains a variety of other substances—gaseous, liquid and solid—albeit in very small amounts when compared to the entire air mass. These substances may react among themselves, chemically or physically, and are transported by air currents. For the most part, they do not remain in the atmosphere indefinitely. Some, like helium, escape to outer space. Most are neutralized or are carried to the earth by rainfall to take part in nature's recycling processes.

One widely-held misconception is that some substances are entering the atmosphere at a faster rate than they are removed. The fact is that nature's built-in controls step up her removal processes to meet increased input. Therefore, although large accumulations of some substances may temporarily develop in a given area, there is no evidence that man's input is increasing the concentration of so-called air contaminants on a global scale. Consequently, [illegible] of air pollution should be [illegible]



PHOTOSYNTHESIS

Some understanding of this natural phenomenon is essential to a discussion of air pollution because of its effect on certain man-made contaminants.

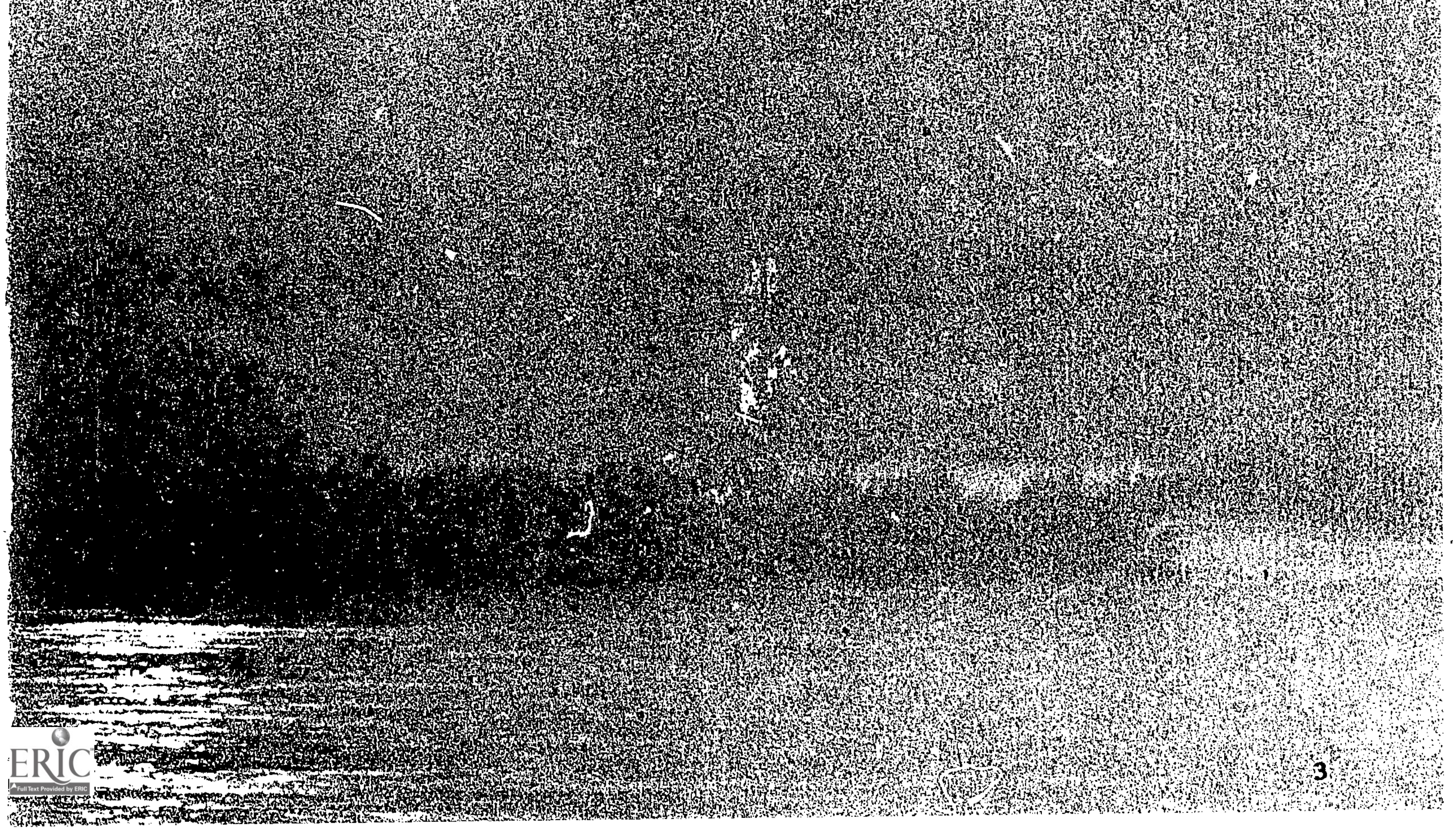
Photosynthesis—synthesizing by light—is one of nature's most important recycling processes. It uses solar energy to recover oxygen from carbon dioxide, thereby setting off a chain of chemical reactions which produce the basic food for all living things. Its unbelievably complex mysteries are not completely unraveled and will not be until scientists fully understand the effects of sunlight on chlorophyll, the pigment in green leaves and plants, and on chloroplasts, the microscopic machines in chlorophyll.

Each chloroplast contains chlorophyll molecules which absorb the orange-red (*long*) and the violet-blue (*short*) rays of sunlight, but reflect out the green (*middle*) rays. This is why leaves look green. If the molecules absorbed all the sun's rays, leaves would be black.

The absorbed rays spur the molecules into furious action. They collide, bounce, separate, reunite and gain or lose atoms or electrons with lightning speed. In the process, oxygen is produced, which is released to the atmosphere, and sugars are synthesized. Some of the sugar feeds the leaf itself; more flows as a nourishing stream of sap throughout the tree; some is converted into starches, proteins and oils—creating fruits, seeds, flowers and the like.

Nor is photosynthesis limited to tree leaves. Every green growing plant carries on the process, and must do so to survive. This is true of aquatic plants as well. Microscopic algae called diatoms carry on the bulk of aquatic photosynthesis. Tiny animals called zooplankton feed upon diatoms, which in turn are eaten by aquatic creatures as small as sardines and as big as whales.

Therefore, since man and animals eat green plants and other animals, the particular photochemical reaction, known as photosynthesis is the process we depend upon for survival. Other photochemical reactions, however, can have adverse effects which will be described later.



CAUSES

Nature emits air contaminants in far greater amounts than does man. Problems arise, however, when nature's self-cleansing capabilities are overwhelmed by man's excessive input from densely populated and industrialized areas.

According to the U. S. Public Health Service, the five man-made contaminants emitted in the largest quantities are:

Carbon monoxide,
Sulfur oxides,
Nitrogen oxides,
Hydrocarbons and
Particulates.

Most of these result from combustion—man's use of fire to provide heat, power, transportation, and to dispose of refuse.

Combustion is the rapid combination of oxygen with other substances, notably those containing carbon, and the consequent release of energy. Perfect combustion is achieved only through the proper mixture of pure oxygen and pure carbon. Its harmless byproducts are carbon dioxide and water vapor. However, under day-to-day conditions, the materials used in combustion are neither pure nor the process ideal and potential air pollutants are produced.

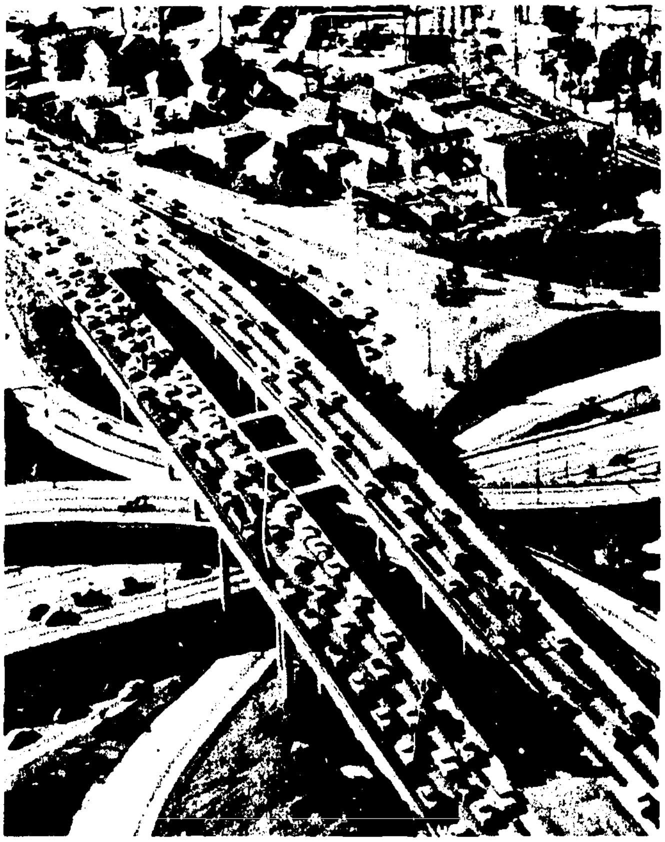
Let us consider the five major man-made contaminants in more detail:

CARBON MONOXIDE

Recent studies at the Argonne National Laboratory reveal that nature is the source of about 90 percent of this contaminant, mostly through photochemical oxidation of methane—a gas resulting largely from decomposition of organic matter in marshes, forests and the like.

Man's input of some 10 percent is attributed to imperfect or incomplete combustion of gasoline, oil, coal and wood. The most familiar source is the automobile exhaust. *(Note: Auto exhaust odor is caused by other ingredients such as aldehydes, acids and ketones, not by carbon monoxide.)*

When carbon monoxide is released into open air and dispersed by wind, it is not troublesome since nature gradually converts it to carbon dioxide. However, during climatic inversions—when there is little or no wind and the air aloft is too warm for heated surface air to rise—carbon monoxide may temporarily accumulate in urban communities, thus creating problems. Also, when vehicles are left running in tunnels or enclosed areas, carbon monoxide can reach dangerous concentrations since, when inhaled, it acts on the blood stream to prevent absorption of life-giving oxygen.



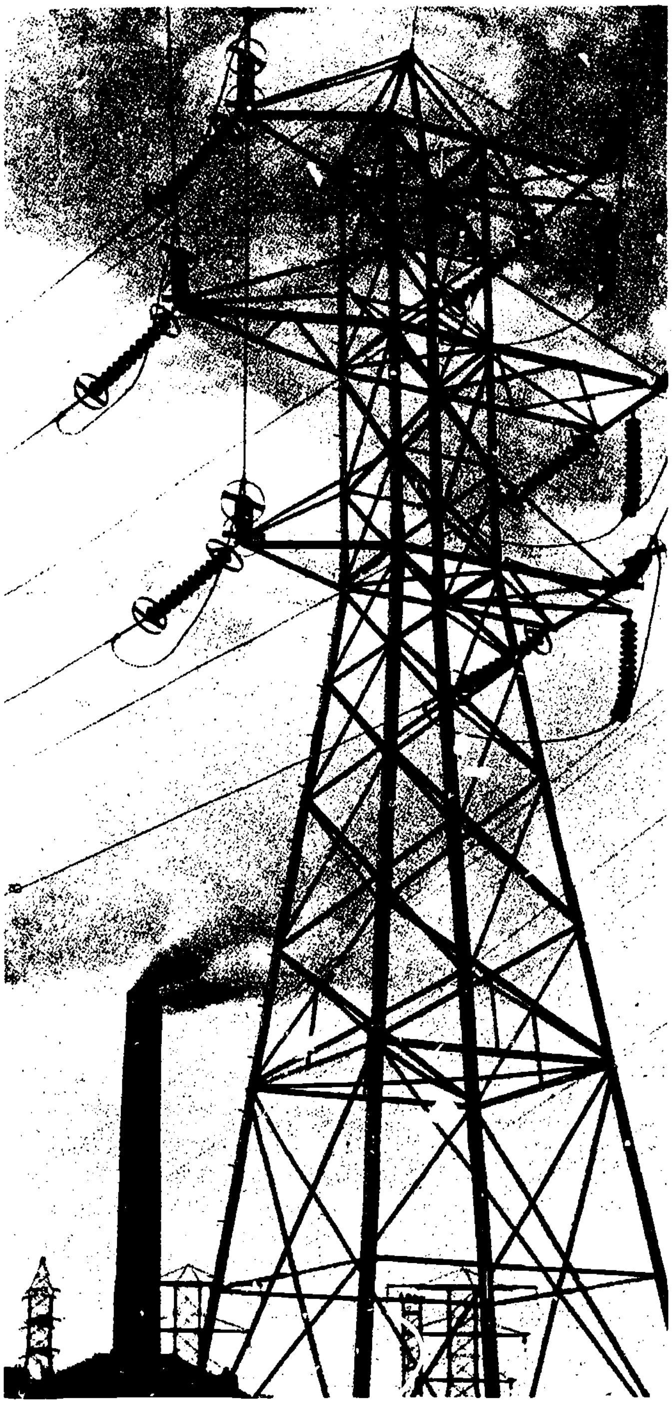
SULFUR OXIDES

According to the National Industrial Pollution Control Council, nature is responsible for about two-thirds of the sulfur emitted into the atmosphere. Major sources are volcanoes and fumaroles —holes in or near volcanoes.

Man's input is mostly in the form of sulfur dioxide, with minor amounts of sulfur trioxide, resulting from combustion of sulfur-containing fuels—coal or oil—by power plants. Smelting sulfide ores and some chemical operations, such as sulfuric acid manufacture, also produce modest amounts of sulfur oxides.

Both sulfur dioxide and sulfur trioxide are soluble in water and can be washed from the air by rainfall. This is part of nature's design, since sulfur is essential to plant nutrition. However, large amounts can be harmful if the soil is low in alkali.

Also, photochemical reactions can convert sulfur dioxide to sulfur trioxide which avidly combines with water vapor in the atmosphere to form acid mists. In the absence of rain over an extended period, such mists can accelerate the deterioration of paints, metals, building materials and textiles, especially some man-made fibers used in stockings, dresses and the like.



NITROGEN OXIDES

As stated earlier, nitrogen comprises nearly four-fifths of the atmosphere. Although it is relatively inert, under high temperatures and through various biological reactions it can combine with oxygen to form several different oxides of nitrogen. Natural causes include lightning, volcanic eruptions and decomposition of organic matter. This, too, is part of nature's design since nitrogen is essential to plant growth but cannot be utilized by green plants in its elemental atmospheric form.

Only two nitrogen oxides are of concern as air pollutants—nitric oxide and nitrogen dioxide. It has been estimated that their production through natural causes is perhaps 10 times greater than from man-made sources. While the latter includes some chemical manufacturing processes, the bulk of nitrogen oxide emissions is mostly in the form of nitric oxide resulting from high-temperature combustion in furnaces and in transportation vehicles.

Nearly half of man's input comes from so-called *stationary* sources, utility plants which provide electricity or steam and manufacturing operations which produce essential high-grade metals such as stainless steel, chromium and nickel.

Transportation accounts for a large portion of this man-made contaminant and gasoline engines are by far the largest source. Diesels and non-transportation uses of motor fuels contribute lesser amounts, while aircraft emissions, contrary to wide-spread belief, contain negligible quantities. Home heating units, municipal incinerators and even forest fires also produce nitric oxide. It is a problem because:

When released to the atmosphere in the presence of sunlight and certain organic vapors such as reactive hydrocarbons, nitric oxide combines with oxygen in the air to create nitrogen dioxide—a brownish gas. While much of this gas is washed from the air by rainfall, thus benefiting soil and plants, it does play a major role in photochemical smog—the hazy mixture of eye, nose and throat irritants—which is prevalent in many urban areas.

HYDROCARBONS

On a global scale, nature produces about five times as many airborne hydrocarbons as does man, mostly through decomposition of organic matter in forests and vegetation. The primary man-made sources are:

- Unburned or partially-burned fuels, and
- Evaporation of industrial solvents.

As the word implies, hydrocarbons contain only hydrogen and carbon. There are several classes of these compounds. Some contribute to photochemical smog far more than others. For instance: Unsaturated hydrocarbons, which contain fewer hydrogen atoms than the corresponding saturated molecule (e.g.: *Ethylene, in which each molecule contains two carbon and four hydrogen atoms as compared to the corresponding saturated compound,* ethane, *which has two carbon and six hydrogen atoms per molecule).*

Hydrocarbons are essential to the life cycle. Some have an odor, such as terpenes in a pine forest. As they occur in the atmosphere, nearly all of them are transparent gases or vapors and are involved in natural photochemical processes. In fact, the Great Smoky Mountains, part of the Appalachian system in North Carolina and Tennessee, were so named because of the characteristic haze generated by photochemical reactions involving terpenes released by pine trees. And, "Bahía de Humos y Fuegos" *(Bay of Smokes and Fires)* was the name given to what is now Los Angeles Harbor in 1542 by its Spanish discoverer, Juan Rodriguez Cabrillo. No doubt he attributed the haze to smoke from primitive Indian fires when, actually, it was a natural photochemical phenomenon.

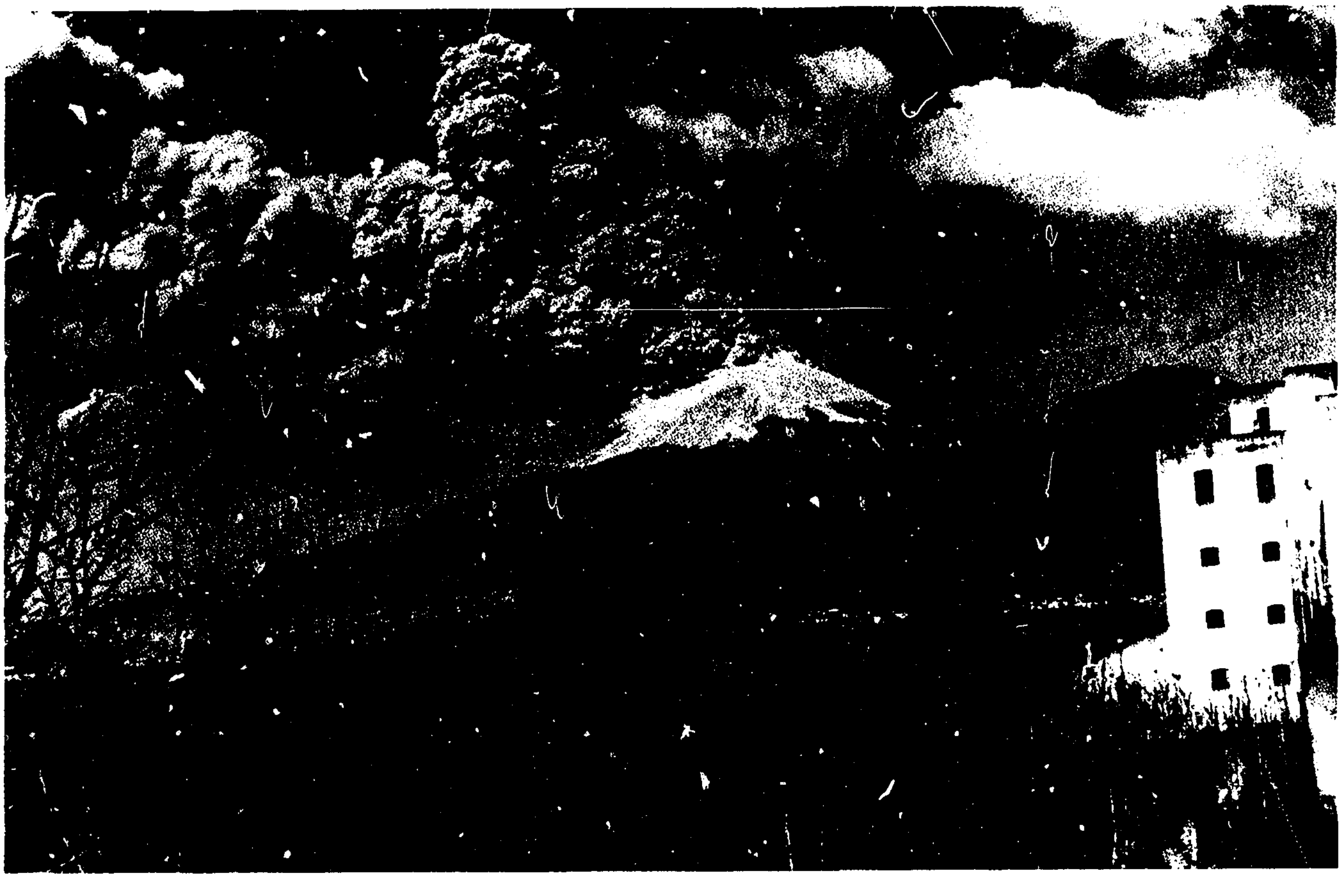
This is not to say that man does not contribute to conditions which cause photochemical smog. In urban and highly industrialized areas he certainly does, and scientists have been battling for years to solve this exceedingly complex problem. Perhaps this over-simplified description indicates just how complex it is:

As stated in the previous chapter, when nitric oxide is released into the presence of sunlight and certain hydrocarbon compounds, nature converts it to nitrogen dioxide, which readily absorbs ultraviolet light from the sun. This causes it to break down into nitric oxide and atomic oxygen—single oxygen atoms. (Normal air oxygen is molecular—two atoms bound together). Atomic oxygen may react with molecular oxygen to form ozone—three oxygen atoms bound together. Ozone can then react with nitric oxide to create molecular oxygen and more nitrogen dioxide.

In turn, atomic oxygen can react with some hydrocarbons to form chemical species called radicals. They may take part in further reactions to create more radicals which can react with molecular oxygen, other hydrocarbons or nitric oxide. In some instances, more nitrogen dioxide is generated; in others, nitric oxide disappears, causing ozone to accumulate and further react with hydrocarbons. Some of the resulting compounds are potent irritants to eyes, nose and throat. Others may form particulates which hamper sunlight reaching the earth.

If you are confused, it is perfectly natural, because the entire process is far from being fully understood and can vary tremendously, thus creating an equally varying potential for smog.

While these reactions are part of nature's air-cleansing process, their immediate effects are obviously much less desirable than natural green-plant photochemistry whereby oxygen is recovered from carbon dioxide.



PARTICULATES

Storms, winds and volcanoes put far more particles into the air than does man. A man-made percentage is nearly impossible to estimate, but particles result from grinding, spraying and combustion operations.

Although particulates are last in the U.S. Government's list of the five most prominent man-made air contaminants, they are perhaps highest in public concern due to their visibility. In this regard, one major misconception is that all white plumes issuing from stacks are pollutants. In many cases, they are only steam—often resulting from a pollution control process.

Particles range in size from something microscopic *(less than a millionth of an inch)* to coarse grit. They may react in endless ways—growing by condensation, adsorbing or absorbing vapors and gases, coagulating or dispersing, and absorbing and scattering light. Because of these variables, as well as their real or esthetic effect on individuals, their importance to air pollution cannot be overestimated.

CURES

In considering air pollution control, either preventive or remedial, it is important to keep man-made emissions in perspective. For, as has been established, natural causes of the five major air contaminants far exceed, in total amount, those from man-made sources and are one aspect of nature's life cycle.

The natural presence of such materials, then, provides background concentrations which must be taken into account. Where they are substantial, there is less leeway for man-made emissions if objectionable levels are to be avoided.

However, every step in controlling man-made emissions adds to the cost of consumer goods.

Therefore, it is far more reasonable to let nature do the job for which it is highly qualified wherever satisfactory results can be achieved.

PROCESS CHANGE

It is apparent that most man-made contaminants stem from his use of fire—to cook and heat, to generate electricity, to provide power for transportation and manufacturing.

As a result, extensive efforts have been under way for many years to control the combustion process so as to minimize potentially polluting by-products. For instance:

- To the extent they are available and in relation to economic factors, low-sulfur fuels are used to reduce the emission of sulfur oxides.
- Improvements in carburetion, engine design, recycling and catalytic devices will ultimately control emissions of carbon monoxide, hydrocarbons and nitrogen oxides.
- Sanitary landfills and municipal incinerators are rapidly supplanting yard and apartment house incinerators.

These illustrate the most desirable type of emissions control—*process change*—which can include:

- The choice of raw materials or their modification prior to use,
- The manner in which they are processed or used,
- The design of equipment, and
- Operating procedures.

However, because there are practical limits to what can be achieved by process change, emissions may need to be controlled by one or a combination of these three methods:

Dispersion . . .

. . . whereby emissions are diluted by the surrounding atmosphere. Tall stacks are generally used, their height being determined by the volume, the chemical/physical nature of the emission, topography and meteorological conditions.

Debate continues as to the acceptability of stacks for pollution control because they do not decrease the quantity of the emission. However, it is well established that, in many instances, properly engineered stacks do accomplish control objectives by decreasing the environmental impact of emissions.

Destruction . . .

. . . which generally consists of burning the emission, either with a smokeless flare, in a special incinerator, in the combustion chamber of a boiler or in an afterburner.

Destruction may also be carried out catalytically, that is—bringing the emission into contact with a substance which speeds up beneficial chemical change. In some instances, catalysis is used to control pollution while recapturing useful products.

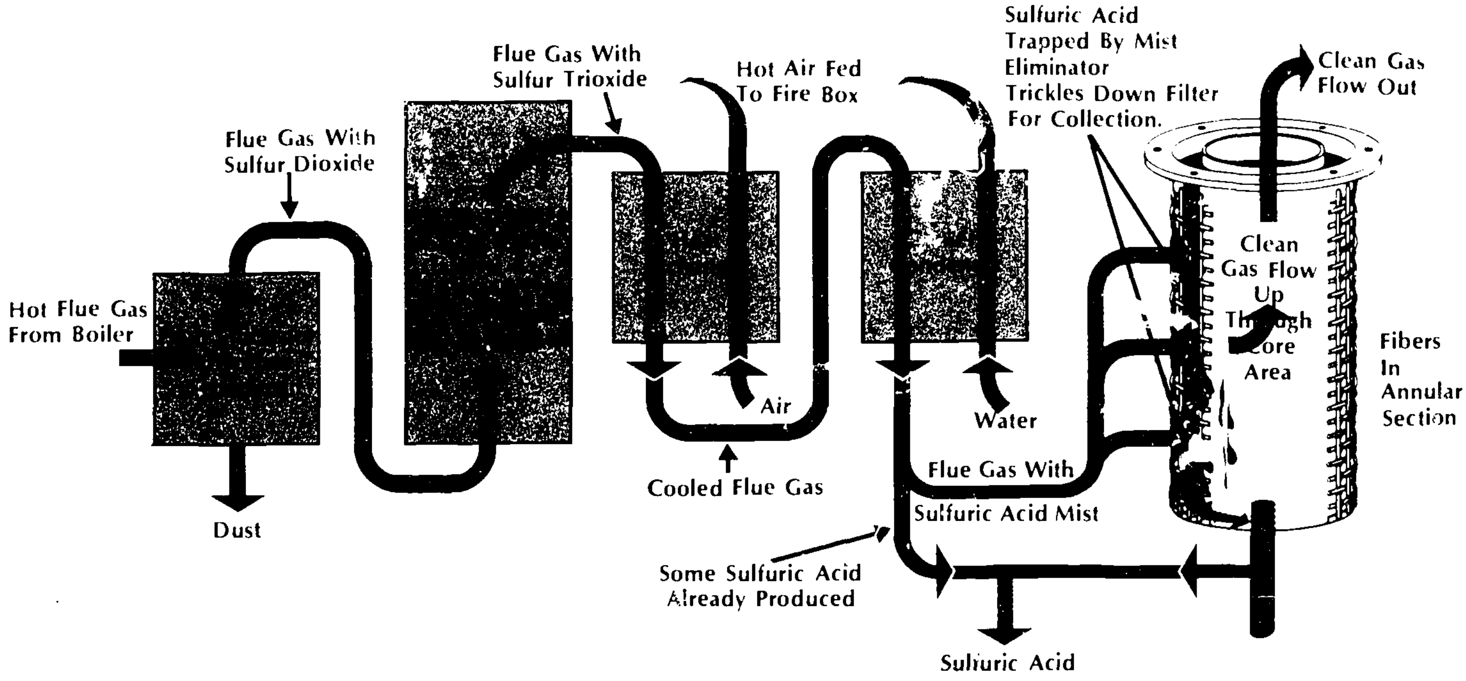
Collection . . .

. . . which is probably the most widely used method of air pollution control. There are a variety of techniques—employing the use of screens, filters, mechanical devices, electricity, water, chemicals and absorbing or adsorbing materials.

Let us explore how one or a combination of these three methods may be used to control pollution by the five major man-made contaminants.

CARBON MONOXIDE

The primary man-made cause of this contaminant is the internal combustion engine and its cure lies with more complete use of fuels, as does the control of hydrocarbon emissions from the same source. *Therefore, this will be subsequently covered under hydrocarbons.*



SULFUR OXIDES

Since these are predominantly caused by burning sulfur-bearing fuels, it would appear that use of low-sulfur fuels would provide for a cure. However, such a process change has its limitations:

- Sources of natural gas are rapidly diminishing.
- Propane gas *(derived from crude oil)* is costly for large-scale operations.
- Sulfur removal from crude oil is also expensive and would raise the price of heating and manufacturing.
- Low-sulfur coal is in short supply—inadequate for future needs.

Since atomic power plants are embroiled in controversy, their immediate capacity is far behind known energy requirements and may never meet them entirely.

Therefore, to meet energy needs in the immediate future, we need to rely on coal with a fairly high sulfur content. Most experts agree there is enough of it in the earth to last another 500 years.

Can sulfur be removed from coal before it is used? . . . or . . . Can a process change in burning reduce the effects of sulfur content?

The answer to both is yes . . . through *gasification* and *liquefaction*. However, improvement of these processes on a large scale, in order to meet the requirements of sulfur control laws, is still under way. None are low enough in cost to compete with existing procedures to remove sulfur from stack gases.

As a result, various methods which remove sulfur from flue gases—of which there is a bewildering array—will probably be employed for some time, with improvements being developed and tested in plant operations. Among them:

Limestone or dolomite . . .

. . . is relatively cheap and plentiful. Either is pulverized and injected into the furnace along with the fuel—pulverized coal. As the latter burns, the heat decomposes the minerals into carbon dioxide *(a harmless end-product of any combustion process)* and into:

- Calcium oxide, if limestone is used, or
- Calcium oxide and magnesium oxide, if dolomite is used.

Either of these, in turn, react with the sulfur content in the fuel to form solid matter—sulfites or sulfates—which can be removed for disposal by one of the *particle* cures described later.

This *dry* system, however, has certain drawbacks. The injected limestone or dolomite has a tendency to coat boiler tubes and, under certain conditions, to partially plug the boiler. Therefore, test operations are under way with a wet system wherein flue

SCHEMATIC OF A CATALYTIC OXIDATION PROCESS—
REMOVES SULFUR FROM STACK GASES—RECAPTURES SULFURIC ACID

gas from the boiler is *scrubbed* with water containing limestone particles or with water containing lime. Such scrubbing processes, also described later, show considerable promise and large scale applications are expected.

The recovered calcium sulfite or calcium sulfate is ordinarily disposed of as landfill. However, such landfill procedures are not simple and, because of the quantities involved, the potential *pile* up of these materials—should all power-generating systems use this method—is tremendous. In addition, such landfills can lead to water pollution problems due to leaching, particularly by magnesium salts resulting from the use of dolomite.

Catalytic Conversion . . .

. . . requires passing the flue gas over a special vanadium-containing catalyst where sulfur dioxide content is further oxidized to sulfur trioxide. Upon subsequent cooling, it reacts with moisture—added in a scrubber process—to form a sulfuric-acid mist which is trapped in a filter and recovered.

This method, an extension of conventional sulfuric-acid technology, duplicates under controlled conditions the chemical steps that would occur if the sulfur dioxide were released into the atmosphere where it would combine with rain or moisture. However, the process is expensive, with corresponding impact on consumer prices since, even though a saleable product is produced, its value is insufficient to offset the cost of recovery.

Molecular Sieves . . .

. . . belong to a class of compounds known as zeolites. They occur in nature and are unique in that they release moisture when heated and readsorb it when cool. In addition, they can selectively adsorb and release molecules other than water. Meanwhile, their crystalline structure remains unchanged.

Chemical research during the last several years has developed methods to not only synthesize zeolites but to tailor-make their crystalline structures so they will adsorb only certain molecules. Once such a mass of material has adsorbed all it will hold, it can be purged for repeated reuse.

Molecular Sieves have been employed for many years in various gas and other purification procedures. Now, a highly-specialized sieve—a *crystalline metal alumino-silicate*—to call it by the correct name—has been devised to remove sulfur from the vent gas of a sulfuric acid manufacturing plant and, through purging, turn it into a marketable product. Success of the pilot project thus far indicates that Molecular Sieves may eventually be used on a large scale to remove sulfur from stack gases.

Another sulfur recovery process is described in the postscript to this booklet.

NITROGEN OXIDES

As stated earlier, high temperature combustion is the major man-made source of the two pollutants in this category—nitric oxide and nitrogen dioxide. The prime means of their control is preventive, that is—avoiding their formation rather than trying to recapture or neutralize them after-the-fact. This involves carrying on combustion at the lowest possible temperatures and the lowest excess oxygen consistent with complete oxidation.

However, this is not always compatible with regard to utility and industrial furnaces, so-called *stationary* sources, or to gasoline engines, since heat reduction is reflected in loss of power. As a result, other procedures are necessary to reduce emissions to *acceptable levels* so that nature can complete the job. The technology to do this is known. However, the primary obstacles are:

- Establishing standards for all categories;
- Time and money to complete the monumental task of replacing or modifying the vast number of furnaces and engines which were not designed to meet such standards.

Stationary Sources

Utility plants now under construction are being designed to reduce nitrogen oxide emissions to standards which have been established by the Environmental Protection Agency (EPA). Flue gas recirculation and staged combustion are the methods being applied. They may be used independently or in conjunction, depending on need. However, many existing facilities will continue to be used until the money, space and other related factors make it possible to modify or replace them.

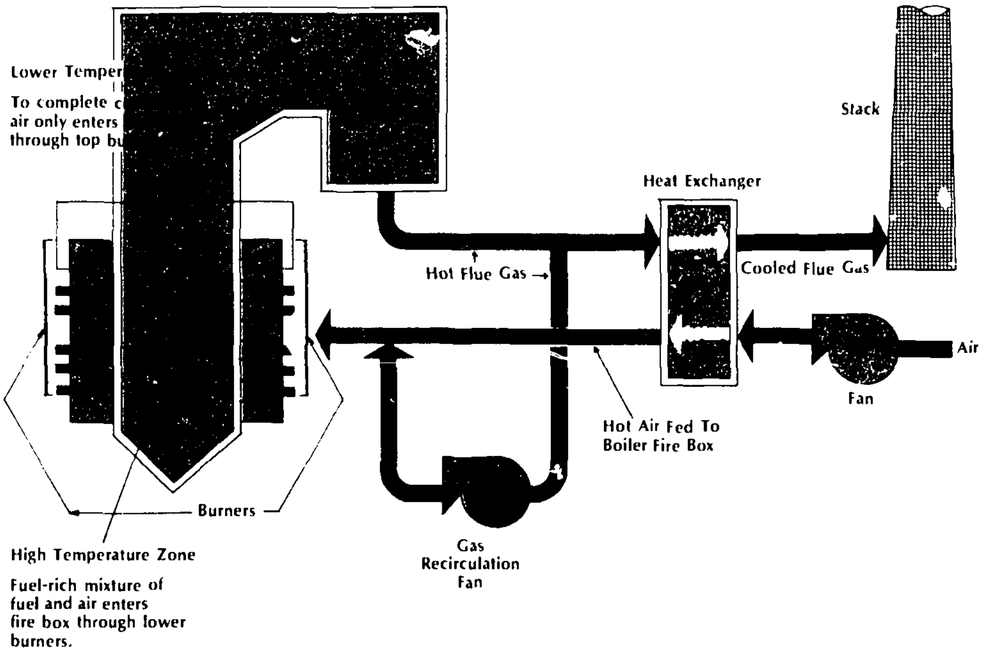
As yet, EPA has not established standards for industrial furnaces—those in refineries, cement and lime kilns, glass manufacturing and metallurgical operations. Most of these are smaller than their utility cousins and represent a special class since they must function at extremely high temperatures.

Control technology for home-heating units and municipal incinerators is known and EPA is expected to ultimately establish standards. However, due to the vast number of installations, conversion or replacement will take many years.

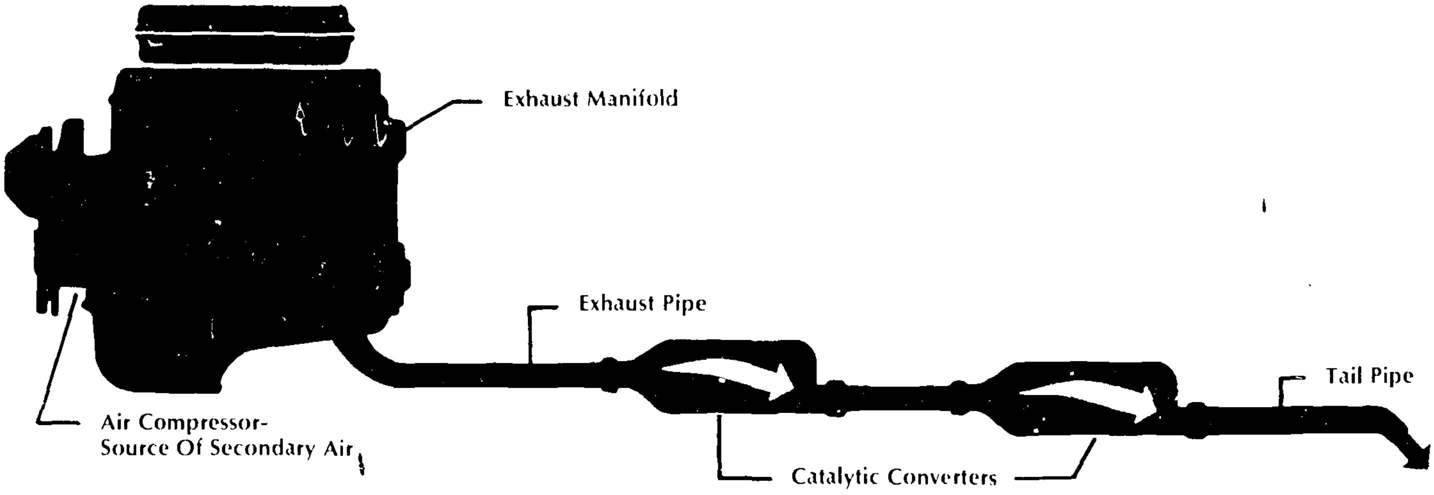
Automobiles

Federal standards for nitrogen oxide emissions from gasoline engines were established through the Clean Air Act Amendments of 1970. They are due to become effective in 1976, except in California, where state regulations will apply in 1975.

Methods of controlling such emissions are directly related to the control of carbon monoxide and hydrocarbon emissions.



SCHEMATIC OF COMBINED "STAGED COMBUSTION" AND "FLUE GAS RECIRCULATION" TO CONTROL NITROGEN OXIDE FORMATION IN STEAM BOILERS



HYDROCARBONS

As stated earlier, the primary man-made sources of hydrocarbon emissions are:

Evaporation . . .

. . . which is generally under control. At one time large amounts of hydrocarbons escaped from storage tank vents, during transfer to and from vehicles, through safety devices in manufacturing plants and from automobiles. Today:

- Floating roofs on storage tanks are widely used, eliminating the need for vents.
- Closed systems prevent vapors from escaping during transfer operations.
- Plant safety procedures effectively burn such solvents if they must be vented during manufacture or use and,
- In late-model cars, fuel vapors are captured in charcoal-filled canisters to be burned when the engine is running.

Combustion . . .

. . . which must be carefully controlled in order to avoid emitting unburned or partially-burned fuels. To achieve this, two methods are now in use:

- Positive Crankcase Ventilation (PCV)—which recycles vapors and gases to the engine for burning with the fuel.
- Air injection into the manifold—which induces more complete combustion prior to the exhaust.

An additional method, which U.S. automotive manufacturers seem to prefer, is:

Catalytic Conversion . . .

. . . which calls for passing exhaust gases through two muffler-like chambers in the exhaust system.

The first chamber would be filled with an inert honeycomb structure which is plated with a thin film of a noble metal, such as platinum or palladium, or a base metal catalyst containing such elements as cobalt or manganese. These materials would accelerate the complete-burning of fuels through high temperature so as to decrease carbon monoxide and hydrocarbon emissions.

However, since high temperature increases nitric oxide production, a second chamber, containing a different catalyst, is required to dissociate it into elemental nitrogen and oxygen prior to emission through the tailpipe.

Technology in this second stage is far less advanced. However, as this booklet was written, it appeared the second-stage catalyst would comprise rare earths, perhaps of the lanthanum type. The state-of-the-art in this phase is still undergoing extensive research.

Other methods receiving intensive consideration include:

- Improved carburetion—to control the fuel-air ratio and thus achieve more complete burning while reducing peak temperatures in cylinder combustion chambers.
- Vortex combustion chambers—a means of burning the fuel-air mixture an unusually long time inside the engine so that potential pollutants are used up.

Additional control methods may include redesigned or completely new types of engines and improved or different fuels.

Ultimately, a combination of the processes now in use or being investigated will solve the nitrogen oxide/hydrocarbon/carbon monoxide emissions problem. The cost, however, will be reflected in the consumer price of fuel and automobiles.

PARTICULATES

Rainfall and earth's gravity are the prime mechanisms for removing particles from the air. Their efficiency, however, varies considerably in relation to the size of the particles and to the processes of coagulation and absorption of vapor. Particles are also removed when they impinge on buildings, trees or other objects.

Such natural removal is usually sufficient in isolated regions but not for densely populated and industrialized areas. As a result, several processes and devices are in use and are being improved. Each adds to the cost of consumer goods, since they either require large capital investments, or are expensive to operate. The four methods are:

Cyclones. . .

. . . that turn suspended particles in smoke or gas into a man-made whirlwind inside a container which throws out the larger particles so they can be collected.

While there are many variations, most cyclones are cone-shaped with a tube center. Dust-laden smoke or gas is forced in tangentially at the top which makes it spiral downward. Larger particles are blown against the side and fall to the bottom where they can be removed. Cleaner air flows upward through the center tube.

Cyclones are relatively inexpensive to buy and to operate, but they are efficient only for larger particles.

Wet Scrubbers . . .

. . . that capture particles too small to be collected in a cyclone.

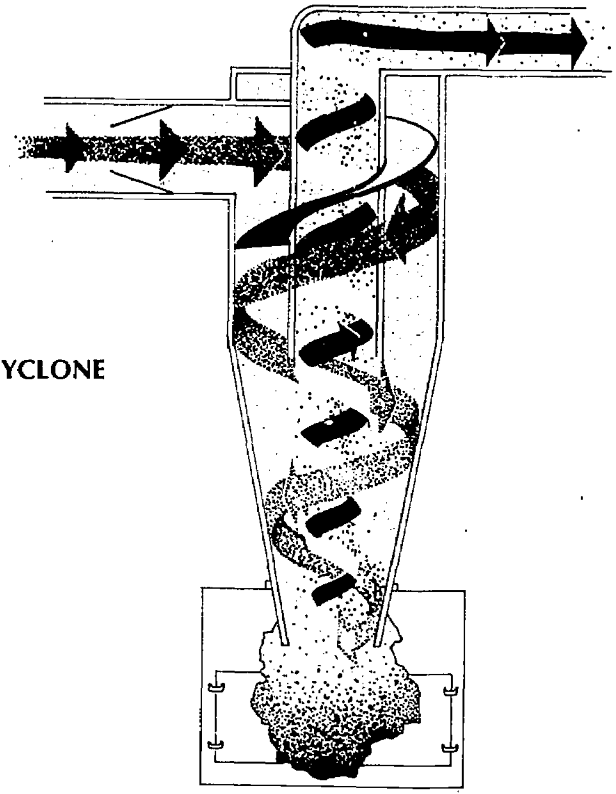
The smoke or gas is fed into a chamber or a stack where, depending on need, water or a specially-formulated scrubbing liquid runs down the sides, flows over a series of baffles like a waterfall, or is sprayed like a shower. This duplicates rainfall and washes particles out of the smoke or gas.

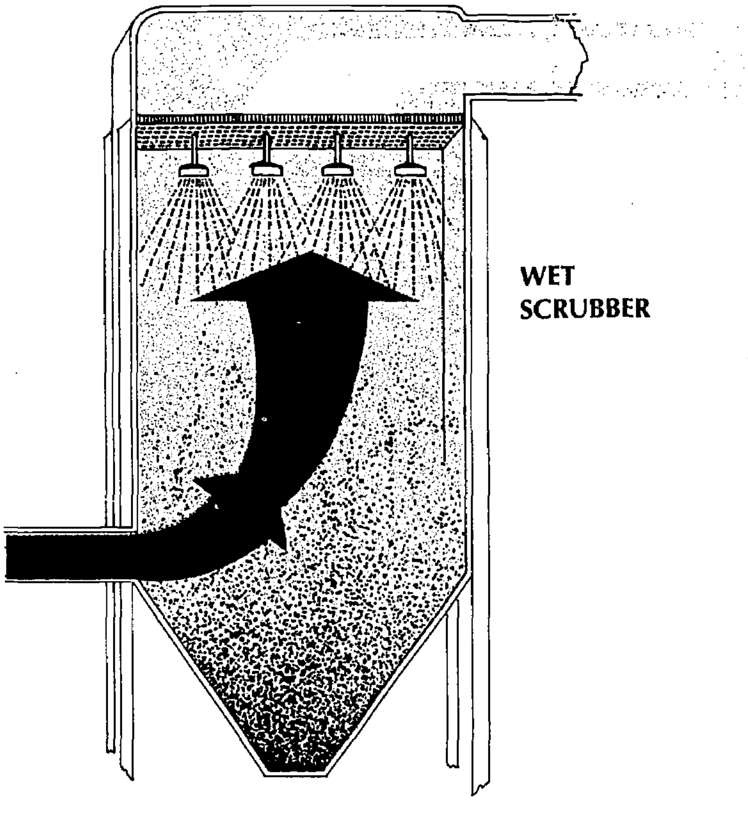
There are also high-energy wet scrubbers which turbulently mix the gas and the scrubbing liquid. These are highly efficient, but cost considerably more to operate due to their high energy demands.

Electrostatic Precipitators . . .

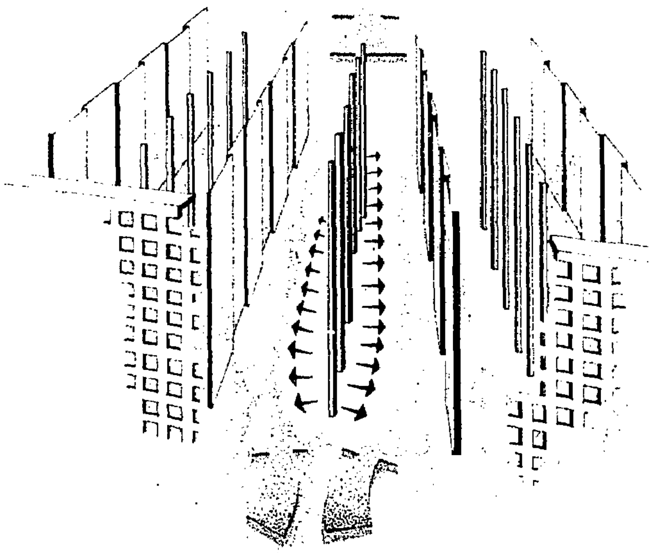
. . . that work on the principle of static electricity and are widely used.

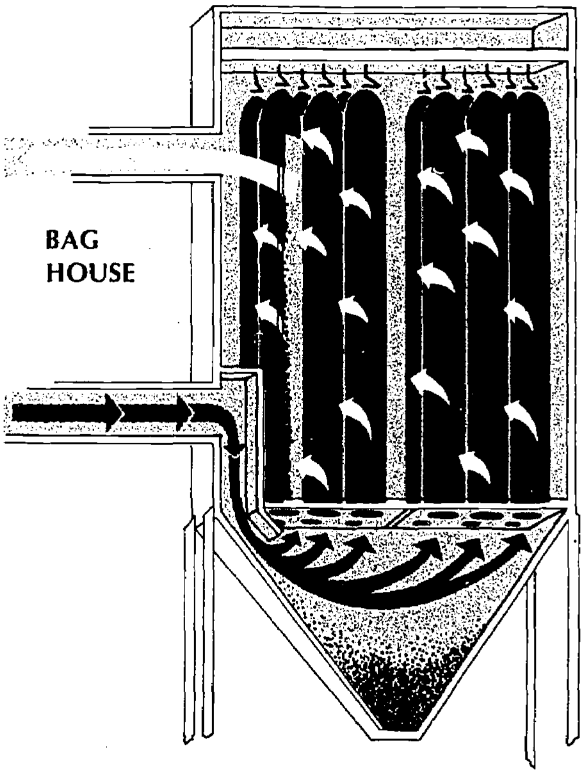
A strong electrical charge is placed on the particles which are attracted to plates with an opposite electrical charge placed inside a chamber. This method is highly efficient and can achieve 99 per-


CYCLONE


WET SCRUBBER

ELECTROSTATIC PRECIPITATOR





BAG HOUSE

cent removal of particles in most situations. Generally, the plates are cleaned with a *rapping* device which causes the particles to fall off for collection.

Compared to high-energy wet scrubbers, electrostatic precipitators are more expensive to install, but less costly to operate.

The only instances where they are not efficient is with certain particles which create electrically-conductive films that short-circuit the high voltages required, or those which are so insulating that the first thin layer prevents the electrically-charged plates from attracting further dust.

Filters . . .

. . . that may be used to clean the air in both wet and dry systems.

However, like those used in automobiles, home-heating units and coffee makers, filters must be designed for the specific need, taking into consideration the high volumes involved in large installations, the velocity of the gas, its temperature, chemical reactions and clogging.

One widely-used filtering technique is the *Bag House*. It can be compared to a series of giant vacuum cleaners which filter particles from the smoke or gas. This method is very efficient and may be used alone or following one of the previously-described *dry* systems.

It is necessary, however, to provide up to one square foot of filter area for every cubic foot per minute of gas flow to be treated. Therefore, the price of installation is generally high while operating costs vary, depending on the type of bag required, the nature of the captured material and the frequency of replacement.

RESIDUE

Every method of air pollution prevention collects something which must be disposed of. Sometimes it is useful, such as sulfur removed from smokestack gases. In some instances, ashes can be converted into building materials. More often, however, the leftovers have no value and are generally used as landfill or, in the case of wet scrubbing processes, are either treated before release into a sewer system or pumped into holding ponds where the captured material settles, permitting the water to either evaporate or overflow into a sewer or stream.

OTHER PROBLEMS

ODORS

. . . result from natural as well as man-made causes. Among the latter: Fertilizing, tanning, brewing; manufacturing chemicals, textiles and pharmaceuticals; ore smelting, petroleum refining and food processing; sewers, dumps, lagoons and settling ponds.

Odors are extremely prominent as a source of public resentment and, although most are not health hazards, nuisance laws to control them have been passed by a number of states.

While considerable progress has been made to measure odors mechanically, the final and most reliable device is the nose. As a result, all in-depth odor research is conducted by odor panels—groups of individuals whose responses to smells help to evaluate odor thresholds—the point of concentration where they can either be detected or become offensive.

Although many odors result from liquid solutions, they are gaseous in nature and variations of several processes described earlier can be employed to control them. Depending on the nature of each individual odor problem, they include one or a combination of the following:

Combustion . . .

. . . whereby the odorous gas is burned in a special incinerator or destroyed by a specific catalyst,

Ventilation . . .

. . . which dilutes the gas with air,

Absorption . . .

. . . wherein the gas is assimilated by a liquid, which may then be treated,

Adsorption . . .

. . . whereby the odor-containing molecules are gathered by a particular substance *(such as activated charcoal),*

Masking . . .

. . . which smothers a bad smell with a stronger, better smell, and,

Counteraction . . .

. . . which employs the discovery that many odors have a counter odor and that when proper ratios of each are brought together, they tend to neutralize each other.

The brevity of the above may cause some to assume that the elimination of offensive industrial or municipal odors is simple.

However, nothing could be farther from the truth. Each problem must be approached on an individual basis involving numerous facets such as *type, volume, degree of concentration, topography, prevailing winds and tolerance threshold.*

In turn, every step in odor control—along with all forms of pollution prevention—adds to the cost of the product and must be based on the fine line between social and economic benefits.

LEAD . . .

. . . in gasoline can cause heated debate among the most respected experts even though evidence of its deleterious effects is inconclusive. Most discussion concerns:

- Its possible influence on human health,
- The problems it creates in controlling other emissions, and
- Its possible impact on ecology and climate.

EPA announced regulations calling for one grade *of lead-free gasoline to be generally available* throughout the country by July 1974. *(This may be delayed due to the one-year postponement of Federal auto-emission standards.)* The purpose is to provide a fuel compatible with catalytic converters since, as presently designed, lead would interfere with their efficiency. Meanwhile, several chemical companies have exhaust-system lead traps in various stages of development.

DIESEL POWERED...

. . . vehicles have been the target of considerable criticism because of smoke and odor. While some older buses and trucks may still be in use, newer engines are built to meet Federal standards which went into effect January 1, 1970. They employ relatively high fuel injection pressures and produce little smoke or odor when properly maintained and operated. Also, barium additives in diesel fuel can dramatically reduce smoke.

Diesel engines produce only about one-tenth as much carbon monoxide as do gasoline engines. Hence, it is not considered a problem since diesels power less than one percent of the vehicle population.

However, diesel hydrocarbon emissions are about the same as gasoline engines and nitric oxide production is slightly higher. These can be controlled in the same manner as those resulting from gasoline engines.

CONCLUSION

To anyone who has read this booklet thus far it is obvious that clean air, as well as the food we eat and the water we drink is the result of an endless process of chemical change. True, some of it is bad. However, most of it is good, as exemplified by our continuing enjoyment of life.

The mere fact that photochemistry, the first link in the chemical chain that binds us together as individuals, also induces unwanted effects in our modern atmosphere means that air pollution problems can and will be solved through the application of chemical technology. This, however, involves three key *powers—money, mind and man.*

In three separate surveys during the past few years, the Manufacturing Chemists Association has attempted to determine the extent to which these powers have been and will be committed to air pollution control in the chemical manufacturing industry. In 1962, 125 member companies participated in the survey; in 1967, 129 and in 1972, 137. The results showed that:

In Moneypower . . .

. . . more than half a billion dollars have been invested in air pollution control equipment, with the sum due to more than double by 1976 to a total of more than a billion dollars.

This compares with $212 million invested up to 1962 and $288 million by 1967.

In addition, annual operating and maintenance costs for air pollution control have reached $77 million. In 1962, it was $24 million and in 1967, $42 million.

In Mindpower . . .

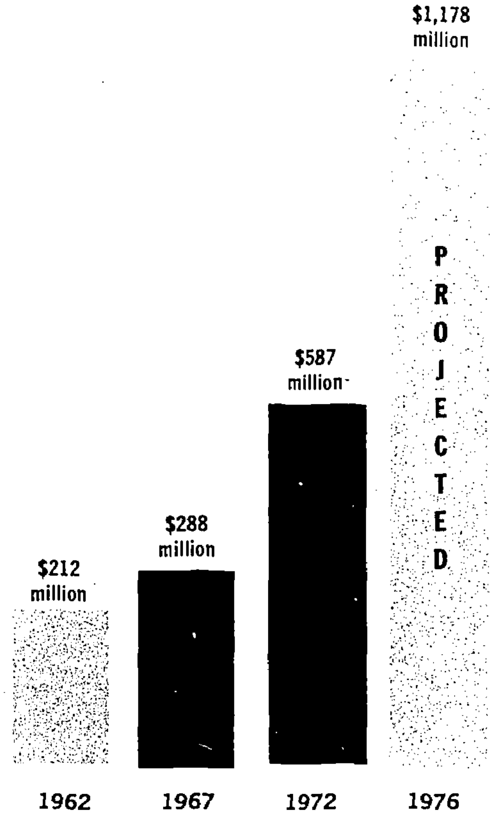
. . . research expenditures for air pollution control have reached $18.6 million a year.

This more than doubles the 1967 figure of $9.1 million. In 1962, it was $2.8 million.

In Manpower . . .

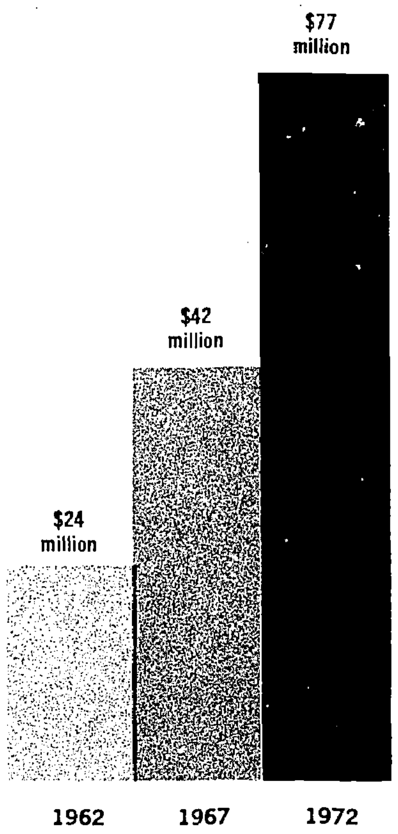
. . . the equivalent of 2,255 full-time personnel is devoted to air pollution control activity, as compared to 1,624 in 1967 and 1,340 in 1962.

ACTUAL AND PROJECTED CAPITAL INVESTMENT FOR AIR POLLUTION CONTROL

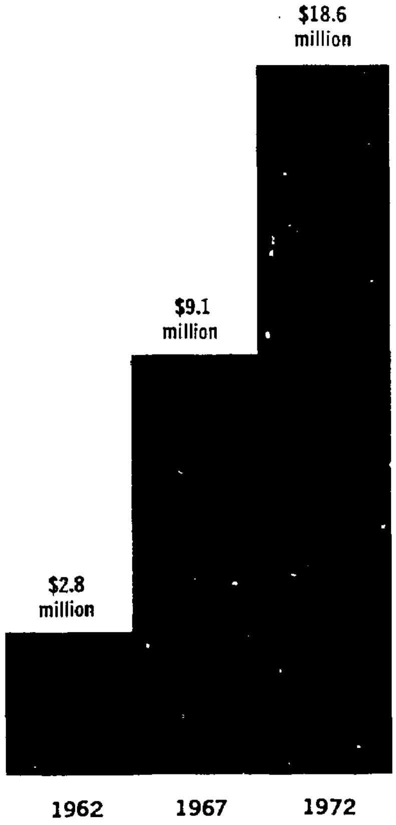


Number of reporting companies:
1962—125 1967—129 1972—137
Source: Manufacturing Chemists Association

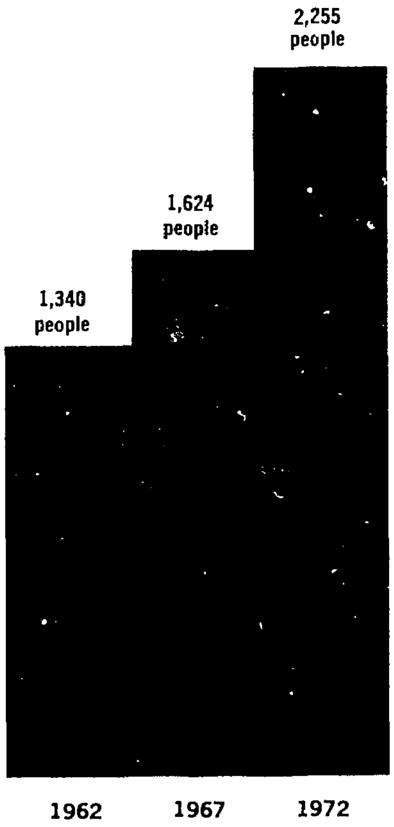
OPERATION AND MAINTENANCE COSTS FOR AIR POLLUTION CONTROL EQUIPMENT



RESEARCH EXPENDITURES FOR AIR POLLUTION CONTROL



MANPOWER ASSIGNED TO AIR POLLUTION CONTROL



POSTSCRIPT

The preceding statistics for the chemical manufacturing industry, impressive as they are, represent only a fraction of the total money, mind and manpower that will be required to control air pollution so that nature's self-cleansing ability is not overwhelmed. Ultimately, every citizen will be called upon to bear his share of the cost in terms of taxes, goods and services.

Consequently, the Federal Clean Air Act takes into consideration both the urgent need and the economic factors involved. Some standards for emissions have been established by the Environmental Protection Agency, others are in various stages of being set. In the process, there have been and will be pro and con arguments. But, agreement is unanimous that the goal of clean air must be attained. To this end, scientific genius and chemical technology will be further challenged. That we can be confident of results is perhaps typified by a recent case history:

As 1972 began, an innovative effort—one of many within the chemical industry—was under way to effectively remove sulfur dioxide from the smokestacks of two large electric power plants and turn it into a marketable product. It is unique since it is the first effort to be undertaken on a regional basis, the first involving both oil-fired and coal-fired utility furnaces and is another method for recovering sulfur from flue gas. Participants in the venture are: The Boston Edison Company, the U.S. Environmental Protection Agency, the Chemical Construction Corporation and an MCA member company. This is how it works:

Flue gas from Boston Edison's oil-fired boiler at Everett, Massachusetts is scrubbed with a slurry of magnesium oxide in water. The magnesium oxide, a non-combustible, reactive granular material, absorbs and reacts with at least 90 percent of the sulfur dioxide in the flue gas before the washed gas is sent up the smokestack. The product of this reaction is magnesium sulfite, which is recovered from the system as a granular crystalline material.

The crystalline magnesium sulfite is transported by bulk trailer to a regeneration facility adjacent to the chemical company's sulfuric-acid plant in Rumford, Rhode Island. There, the crystals are heated to release sulfur dioxide which is converted to saleable sulfuric acid, a valuable industrial commodity. The calcining step also converts the crystals back to magnesium oxide, which is transported back to Everett for re-use in the scrubber at the power plant.

This demonstration project is now under way. Construction for a similar project at a coal-fired boiler of Potomac Electric Power Company, not far from Washington, D.C., is now proceeding. In this plant, a preliminary scrubbing step is being provided for removal of fly-ash particles.

The economics of these demonstration plants is recognized to be poor. Full-scale application of this technology, however, is expected to provide an economical means of accomplishing the goal of low-sulfur emissions from powerhouse stacks, since there is no solid waste to be disposed of and the product is sulfuric acid of normal commercial strength and quality.

As the Boston operation began, the chemical company's President called the process "a major breakthrough in industry's efforts to curb air pollution in an economically practical manner." And, in March 1972, W. Reid Thompson, Chairman of the Board and President of the Potomac Electric Power Company, emphasized the significance of chemical recovery of sulfur products since there is a serious disposal problem of the waste byproducts from throwaway scrubbing operations. "Most important of all," Mr. Thompson stated, "the area benefits by cleaner air."

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