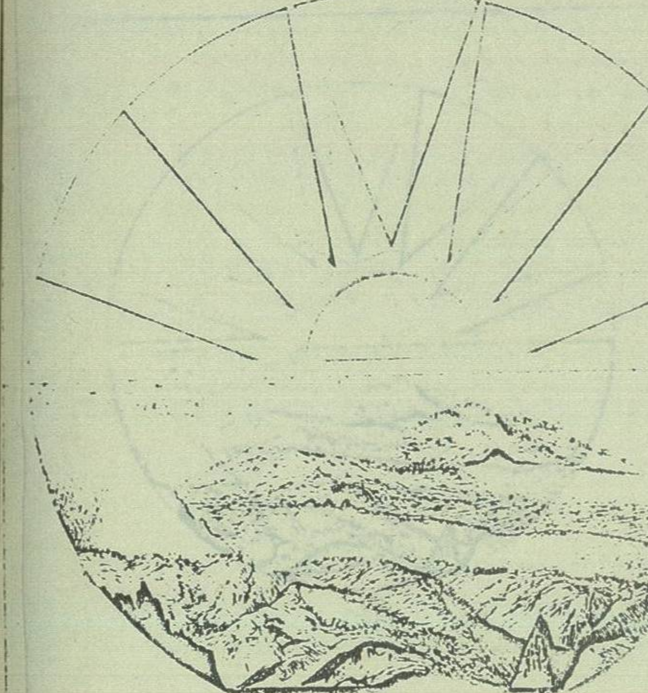

THE SOLAR ERA

Part 5—The Pollution of Our Solar Energy

Extreme consequences of air pollution could be: another ice age, melting polar ice caps, massive carcinogenic UV radiation. Government, industry, and the public must make the effort and pay the price to reverse the rising pollution down to a rational minimum.

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MAN HAS lived on the earth for many thousands of years and has proved to be a very successful species. He has proliferated throughout the planet, subjugated other species to his own use, and released on the earth new man-made processes which match the intensity and scope of natural ones. Now man finds reason to question his success, because the very power that he has exerted on the rest of nature threatens his own survival.

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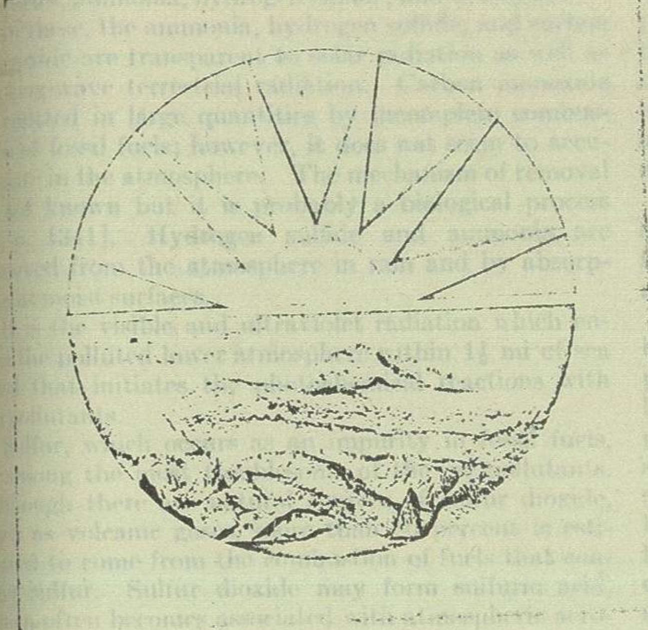
Based on a paper contributed by the ASME Solar Energy Applications Group.

Urbanization and industrialization are two of the most significant and dynamic phenomena of the twentieth century. Their consequences, both good and bad, are being experienced throughout society. More and more man is beginning to take a hard if somewhat bleary-eyed look at the urbanized environment in which he lives. Frequently his buildings are covered with grime, his rivers darkened and turgid with wastes, and his air thickened with strange corrosive particles.

Pollution is a predictable result of the tendency of humans to congregate. Man has continually polluted one of his basic needs—the atmosphere. Two major contributions to air pollution are from the smokestacks of industry and the exhaust pipes of automobiles.

The public usually considers the aesthetic, economic, and health effects of air pollution. The presence of smoke and smog dims the sun and sky, which offends the aesthetic sense. Injury to vegetation and livestock, corrosion and soiling of materials and structures, and depression of property values are examples of economic damage caused by air pollution. A more significant effect, though, is the effect upon human health. Circumstantial evidence suggests that air pollution is a contributory cause of the high cancer rate found in urban areas. Rasping coughs, smarting eyes, nausea, and irritability are among the lesser symptoms attributed to air pollution.



Perhaps the most terrifying effect of air pollution is never mentioned. What if the concentration of air pollution were to become so dense that the temperature of the earth was affected? Greater reflection of the incoming solar radiation could lead to another ice age. If carbon dioxide were carelessly allowed to build up in the atmosphere and absorb the long-wave terrestrial radiation, the consequence might be a temperature rise capable of melting the polar ice caps.

Chemical reactions are known that can remove the ozone in the upper atmosphere, and this process, if carried far enough, could result in most living things being roasted to death as more ultraviolet radiation reached the earth.

These examples are extremes which we hope will never happen, but they could well become reality if man continues to pollute the solar radiation. In all likelihood, air pollution can never be entirely eliminated, but it can and must be reduced from its present levels. The question is whether governmental institutions, industry, and the public are willing to make the effort and pay the price.

Effects of Solar Radiation

As solar radiation falls on the earth approximately 35 percent is screened out by the atmosphere in reflection or scattering back into space. Owing to the very strong absorption by O_2, N_2, O, N, and O_3 up to 3000 angstroms, the solar spectrum is very sharply terminated. The rest of the solar radiation is absorbed and used in heating the lower atmosphere, maintaining the earth temperature, and providing the energy for some atmospheric and biological processes. As the earth is in steady state with respect to space, it reradiates all this energy throughout a broad range of wavelengths with a flat maximum at 12 microns [1].[4] In this range of the spectrum, water vapor and carbon dioxide in the atmosphere absorb significant amounts of radiation, forming a roof above the surface of the earth which functions as does the roof of glass over a greenhouse. As a result, the earth is protected from the terrible extremes of heat and cold that the surface of an airless planet experiences.

It is solar energy which provides the driving energy of the water cycle: evaporating the water, lifting the vapor in clouds, then depositing it as rain or snow from where it will flow back to be evaporated again. Another contribution of solar energy is in the generation of winds that are an important part of the temperature-regulating system of the earth. Solar energy is also stored in the very high atmosphere as electrical energy which daily varies the magnetic field of the earth.

In the process of photosynthesis [1, p. 64] plants use radiant energy from the sun to convert carbon dioxide and water into carbohydrates, at the same time releasing oxygen into the atmosphere. When plant materials decompose or are eaten by animals, the process is reversed. Oxygen is used to convert carbohydrates into energy plus carbon dioxide and water. Annually, about 110 billion tons of carbon dioxide are evolved in photosynthesis. This is roughly 5 percent of the carbon dioxide in the atmosphere. Under normal conditions the amounts of carbon dioxide and oxygen in the atmosphere remain approximately in equilibrium from year to year. The actual amount of solar energy diverted into living systems is small in relation to the earth's total energy budget. Only about one-tenth of 1 percent of the energy received from the sun by the earth is fixed in photosynthesis. The production of fossil fuels also is based on the carbon cycle.

In the atmosphere one major photochemical reaction occurs: High-energy radiation from the sun reacts with oxygen. At heights above 50 mi oxygen exists almost exclusively in the monatomic form. Dropping to lower levels the conditions become favorable for the formation of triatomic oxygen or ozone [2]. The region of greatest ozone concentration is reported to be between 10 and 20 mi. The principal molecular air constituents—carbon dioxide, nitrogen, oxygen, and water—are all transparent to the visible and ultraviolet radiation down to at least 2000 Å. The ozone layer is a filter for this ultraviolet radiation, which, if not stopped, could ruin all vegetable and animal life.

As a matter of fact solar radiation has dictated the actions and habits of life on earth, since it provides the light by which we see and by means of photosynthesis the food we eat and the oxygen we breathe. Besides, sunshine has many beneficial effects for the health; one of the best known is the production of vitamin D which is essential for the absorption and metabolism of calcium.

Atmospheric Pollutants

The major air pollutants, most resulting from the combustion of fossil fuels, are carbon monoxide, sulfur and its oxides, nitrogen oxides, hydrocarbons and solid

[4] Numbers in brackets designate References at end of article.

particles, ammonia, hydrogen sulfide, and aldehydes.

Of these, the ammonia, hydrogen sulfide, and carbon monoxide are transparent to solar radiation as well as to long-wave terrestrial radiation. Carbon monoxide is emitted in large quantities by incomplete combustion of fossil fuels; however, it does not seem to accumulate in the atmosphere. The mechanism of removal is not known but it is probably a biological process [2, p. 1341]. Hydrogen sulfide and ammonia are removed from the atmosphere in rain and by absorption at moist surfaces.

It is the visible and ultraviolet radiation which enters the polluted lower atmosphere within 1½ mi of sea level that initiates the photochemical reactions with air pollutants.

Sulfur, which occurs as an impurity in fossil fuels, is among the most troublesome of the air pollutants. Although there are natural sources of sulfur dioxide, such as volcanic gases, more than 80 percent is estimated to come from the combustion of fuels that contain sulfur. Sulfur dioxide may form sulfuric acid, which often becomes associated with atmospheric aerosols, or it may react further to form ammonium sulfate. A typical lifetime in the atmosphere is one week [3]. Sulfur exhibits moderate absorption in the ultraviolet end of the spectral range. This radiation does not represent sufficient energy to disrupt a bond in the molecule, and it must be assumed that initially only activated molecules are created. These energized molecules may either revert to their original state, dissipating the absorbed energy, or they may react with surrounding molecules. In the atmosphere, where oxygen concentration is higher in comparison to sulfur dioxide, ozone and sulfur trioxide are the products. It is possible, however, that sulfur compounds are accumulating in a layer of sulfate particles in the stratosphere. The mechanism of formation, its effects, and its relation to man-made emissions are not clear. These fine particles could have an effect on radiation from the upper atmosphere, thereby affecting mean global temperatures [4].

Nitrogen oxides occur naturally in the atmosphere as nitrous oxide, NO, and nitrogen dioxide, NO_2. The production of nitrogen oxides in combustion is highly sensitive to temperature. It is particularly likely to result from the explosive intermittent combustion taking place in the internal-combustion engine. Nitrous oxide is the most plentiful at 0.25 ppm and is relatively inert. Nitrogen dioxide is a strong absorber of ultraviolet radiation and triggers off photochemical reactions that produce smog [3]. Therefore, in the atmosphere, where the oxygen–nitrogen dioxide ratio is very large, ozone is produced.

Another, perhaps minor, source of ozone formation by photochemical reactions is from aldehydes which are produced in vast quantities as industrial and domestic wastes, and from incomplete combustion in automobile engines, incinerators, etc. [5].

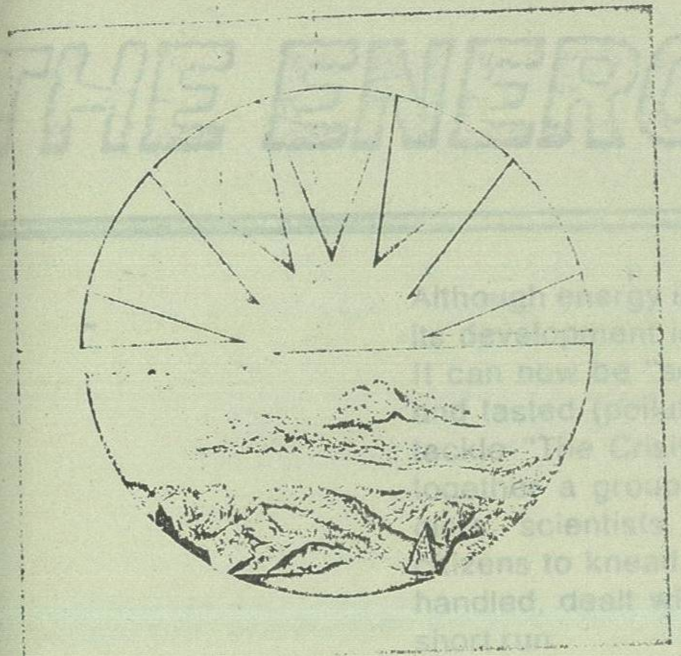
Hydrocarbons are emitted naturally into the atmosphere from forests and vegetation and in the form of methane from the bacterial decomposition of organic matter. Human activities account for only about 15 percent of the emissions, but these contributions are concentrated in urban areas. The reactions of hydrocarbons with nitrogen oxides in the presence of ultraviolet radiation produce the photochemical smog that appears so often over Los Angeles, Detroit, and other cities [3].

All these reactions are minor in their effect on the amount of solar radiation incident on the earth's surface, but they are associated with high air temperatures and reduced intensity of ultraviolet radiation [6].

Fine particles, carbon dioxide, and water vapor will be introduced into the stratosphere by supersonic transport, and the stratosphere is the region which it would be the most dangerous to pollute. A doubling of fine particles and a 10 percent increase in water vapor could significantly raise the temperature of the stratosphere and increase cloudiness. More solar radiation would be reflected back into space with the overall effect of lowering the earth's mean temperature. It has been determined that atmospheric temperature rose generally between 1860 and 1940. Between 1940 and 1960, although slight warming occurred in the northern part of Europe and in North America, there was a slight lowering of temperature for the world as a whole. The average annual temperature dropped one-half a degree.

There is also the possibility that newly introduced stratospheric pollutants may affect the concentration of ozone in this region. The likelihood of this happening is very slight, but if a decrease in ozone were initiated by some chemical reaction, more high-energy ultraviolet radiation would be able to reach the earth's surface. If this were to happen, people would experience burns caused by radiant energy many times greater than the radiation that causes sunburn on the clearest, hottest summer day.

Perhaps the most serious air pollution problem is the increase of carbon dioxide which is being added to the atmosphere. The injection of large quantities of carbon dioxide into the atmosphere in the past few decades has been extremely sudden in relation to important natural time scales. If the oceans were perfectly mixed at all times, carbon dioxide added to the atmosphere would distribute itself about five-sixths in the water and one-sixth in the air. In actuality the distribution is about equal. Since 1860 the concentration of carbon dioxide in the atmosphere has increased from 290 ppm to about 320 ppm. There is a possibility that this increase will lead to a worldwide rise in temperature. Carbon dioxide has strong absorption bands, particularly in the infrared region where most of the thermal energy radiating from the earth is concentrated at wavelengths of from 12 to 18 microns. Syukuro Manabe and R. T. Wetherald calculated that a rise in atmospheric carbon dioxide from 320 to 600 ppm would increase the average surface temperature by 4.25 deg assuming average cloudiness, and 5.25 deg assuming no clouds [3, p. 183]. This increase would cause the polar ice caps and glaciers to melt, raising the level of the sea and submerging great coastal cities such as New York and Vancouver.



Health and Other Consequences

Observations conducted in Tokyo demonstrated that ultraviolet radiation was significantly decreased by city smog [7]. The radiation was measured in the center of the city and in the suburbs. It was found that the intensity of the total radiation recorded in the center of the city was 70 or 80 percent of that recorded in the suburbs. However, the center only received 40 to 50 percent of the ultraviolet radiation that the suburbs received. It can be concluded that the attenuation of the total and of the ultraviolet radiation is an important problem for city inhabitants. Ultraviolet radiation produces a stimulus which allows the epidermis layer of skin of the human to make vitamin D. It has been proved that vitamin D prevents the disease known as rickets. The biological effects of several of the products of the reactions, including ozone and complex organic molecules, are often injurious. Ozone has highly detrimental effects on vegetation, but so far they have been localized. No worldwide effects have been discovered as yet [8].

Although it is improbable and not expected to happen in the future, the ozone absorption band could shift, due to air pollutants, with the result that ultraviolet radiation with wavelengths shorter than 2900 Å could penetrate the atmosphere. The predictable consequences on human health would be an increase in the rate of skin cancer and the generation of highly dangerous malignant melanomes which arise from the pigment cells. Even the little ultraviolet radiation which is not presently absorbed by the atmosphere can cause severe sunburn.

In the last 200 years, the industrialized nations have used two-fifths of the world's present supply of coal. At that rate, there will be no coal reserves by the twenty-third century. However much these periods may be stretched by unforeseen discoveries and improved technology, the end of the fossil-fuel era will inevitably come [8, p. 186]. Man will have to find another form of energy, possibly direct harnessing of solar radiation [9], [3, p. 178]. But what if at the same time he is polluting it?

Polluted air also means less sunlight. Cities today average from 15 to 20 percent less sunshine annually than the surrounding countryside. However, the consequences of such a loss, as far as human life is concerned, cannot yet be clearly seen.

On the other hand, a worldwide increase in cloudiness will certainly have important repercussions on the growth of plants and crops, and perhaps too, by way of a reduction in photosynthesis, on animal and human life.

Conclusion

It is possible that if the present intensity of atmospheric pollution were to continue for several centuries man would disturb the harmony of this planet and degenerate its climates, vegetation, and life. However, this prediction cannot really be based on observations made to date.

Some atmospheric pollutants, such as carbon monoxide, water vapor, and solid particles, could affect the amount of solar radiation reaching the earth, but it is not clear whether it would be more scattering back into space or more absorption, or whether the consequence would be a decrease or an increase in the mean temperature of the earth.

Other pollutants such as nitrogen oxides and sulfur oxides would alter the quality rather than the quantity of solar radiation by initiating processes capable of removing ozone from, or adding it to, the atmosphere, thus changing the present natural filter to ultraviolet radiation.

Whichever assumption may be right, we do not want to experience the ultimate test. This underlines the drastic lack of accurate worldwide and long-term solar-radiation measurement, without which no hypothesis concerning the future and the security of our environment can be formulated. It would be a shame if our solar energy were badly polluted by the time our fossil fuels run out.

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