Doctors to the Environment

In response to national concern and to faculty and student interest, Caltech launches a new interdisciplinary program in Environmental Engineering Science.

Environmental engineering scientists at Caltech welcome the attention the public is now giving their field. Problems on which they have worked for years have suddenly become front page news. Water reclamation and reuse, the origin and fate of atmospheric submicron particles, the effect of wastewater discharges on coastal waters—fields in which the members of the environmental faculty have pioneered—are the glamour topics of the seventies.

Members of the environmental faculty hope this awakening public interest is the start of a long-range national commitment to the preservation and protection of the environment.

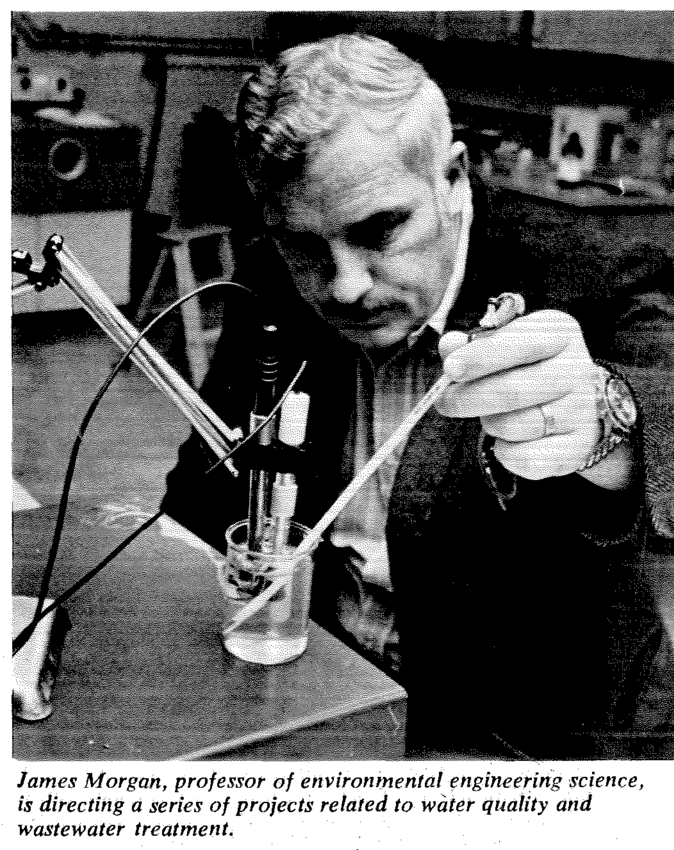
Environmental studies at Caltech go back many years. Key contributions were made by A. J. Haagen-Smit, professor of bio-organic chemistry, beginning 20 years ago when he demonstrated that the primary smog producers were automobiles and power plants—not backyard incinerators as many people had believed. Jack McKee, professor of environmental engineering, has worked for more than two decades on the reclamation of safe, usable water from sewage and industrial wastes. Ten years ago he established the environmental health engineering program at Caltech and helped bring in many of the faculty now playing a major role in environmental studies. A seminal role in the hydraulics field was played by Vito Vanoni, professor of hydraulics and a specialist in the field of sediment transport by natural waters.

In 1969, in response to the national concern and faculty and student interest, a new interdisciplinary program was established at Caltech which allows the Institute for the first time to confer advanced degrees in environmental engineering science. Norman Brooks, professor of environmental science and civil engineering, serves as program coordinator. Based on a solid foundation of research and coursework, EES is passing through an exciting period of innovation; a new applied science is emerging which brings together engineering and ecology. What classical disciplines are basic to this new field? What new topics should be developed? To what extent are studies in air and water pollution dependent on the same basic principles? These are some of the problems with which the faculty is currently wrestling.

Teaching students the physics and chemistry of "messy systems" like dirty air and water has forced the faculty to invent new approaches both in their research and in their classes. The analytical method of the pure sciences, depending for its effectiveness on the study of elementary processes, must be modified in dealing with pollution problems, and these modifications require considerable ingenuity.

The program includes new courses in air pollution engineering and ecology, fluid mechanics, and economics. One of the most successful in arousing student interest has been the undergraduate course "Engineering Problems of Man's Environment." Lectures by faculty specialists on air and water resources, weather modification, and other topics are supplemented by discussions on specific problems by small groups of faculty and students. The course is an introductory one for students considering advanced work in this field.

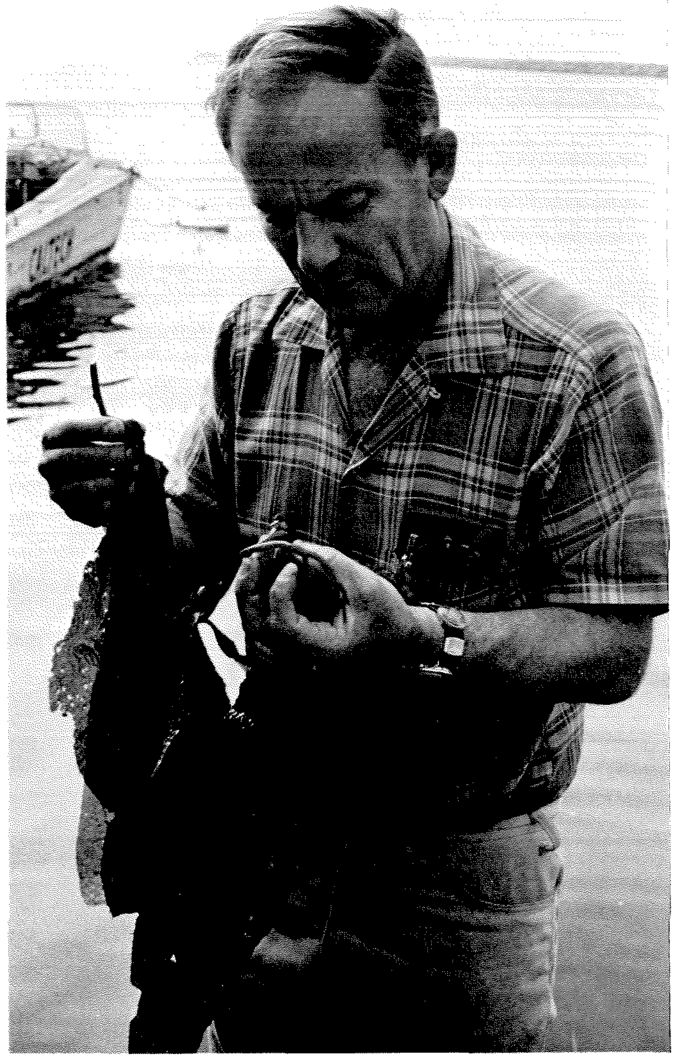
With engineers and scientists playing a leading role, it is not surprising to find an emphasis on technological solutions to problems caused by an aberrant technology.



James Morgan, professor of environmental engineering science, is directing a series of projects related to water quality and wastewater treatment.

Given the temper of the times, this type of approach is bound to lead to criticism. "There is a conspicuous absence of thought addressed to the ethics, or morality, which should propel such a program," one young woman wrote to Sheldon Friedlander, professor of chemical and environmental health engineering, regarding his proposals for an environmental forecasting program—a study of technological trends and their environmental implications.

Faculty members do recognize the importance of ethical considerations in setting environmental goals. Indeed, such considerations lead many of them to enter the environmental field in the first place. But they also believe that goal determination and implementation should be based on the most complete information possible. That, in large part, is why Caltech has responded to the environmental crisis with the formation of the Environmental Engineering Science Program.



Wheeler North, professor of environmental science, is supervising a project aimed at restoring the kelp beds that once grew off the California coast.

A Sampling of Current Research in EES

James Morgan, professor of environmental engineering science, is currently directing a whole series of projects relating to water, including wastewater treatment and water quality. One aspect of Morgan's research is directed toward learning how to remove particles that are so small they won't normally settle out or be effectively filtered by most treatment processes. Morgan wants to learn enough about different polymer molecules to be able to predict which kinds are best for removing particles from water. He hopes eventually to find ways of "hooking" the tiny particles together so they can be removed.

Some of this research is being done in cooperation with a Jet Propulsion Laboratory group led by Alan Rembaum, a member of the JPL technical staff in the polymer research section, and also a lecturer in chemical engineering at Caltech. The group hopes to find new substances that can be put to work in removing particles from water.

The particles of interest to the Caltech and JPL researchers range in size from a few microns down to about 1/10 of a micron (a micron is equal to about 1/25,000 of an inch) and may be particles of clays or other minerals such as silica, bacteria, or even synthetic organic products.

What has been learned so far?

For one thing, there is a significant natural variation in the mineral properties of waters in different parts of the world, and these chemical variations lead to significant effects on the configuration of polyelectrolytes and on their ability to flocculate particles (hook them together electrochemically). For another, the group has learned a lot from graduate student Dennis Kasper's studies about the effect of the polymer's molecular size on its flocculation ability. But they hope to learn more about polymer architecture—and they still do not clearly understand how different sorts of polymers function in different waters.

Another problem Morgan and his colleagues hope to probe more deeply involves determining the effects of urban waste discharges into coastal receiving waters. There are dozens of compounds in both the waste products and receiving water, and the Caltech environmental chemists would like to develop a method for determining what are the significant chemical reactions that could take place in distribution of the wastes into receiving water. This problem is being attacked initially by programming a computer to simulate all the possible reactions in a model system. Eventually laboratory and field experiments will be conducted for those conditions that the computer finds most promising.

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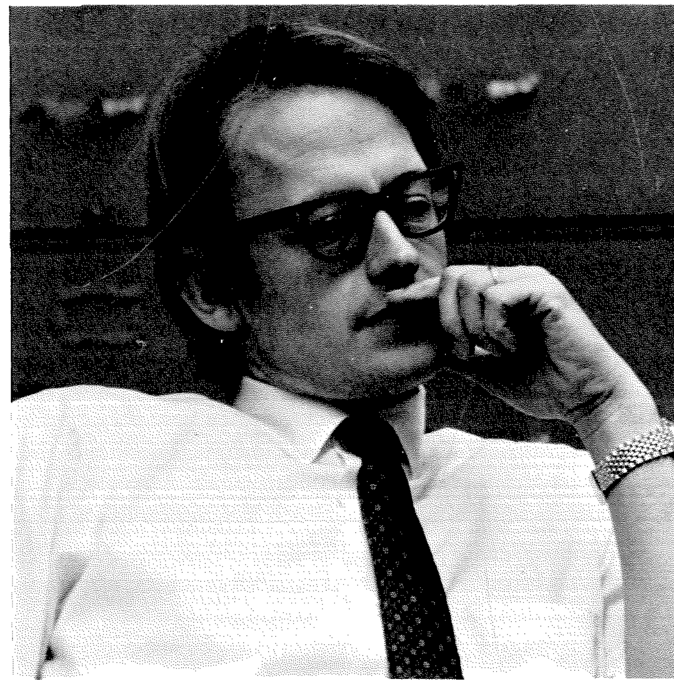


John List, assistant professor of environmental engineering science, is studying the behavior of jets in a density-stratified liquid, hopes to find better ways to design sewage outfalls so the effluent won't be washed back ashore.

The problem of ocean pollution is being studied in a quite different way by Wheeler North, professor of environmental science, who has been working at the Kerckhoff Marine Laboratory in Corona del Mar on a project aimed at restoring the giant kelp beds that once grew just off the California coast. These kelp beds, which contribute an estimated 100 million dollars a year to the regional economy, supply chemicals for more than 300 commercial products and provide a habitat for the fish that support the state's fresh fish and canning industry.

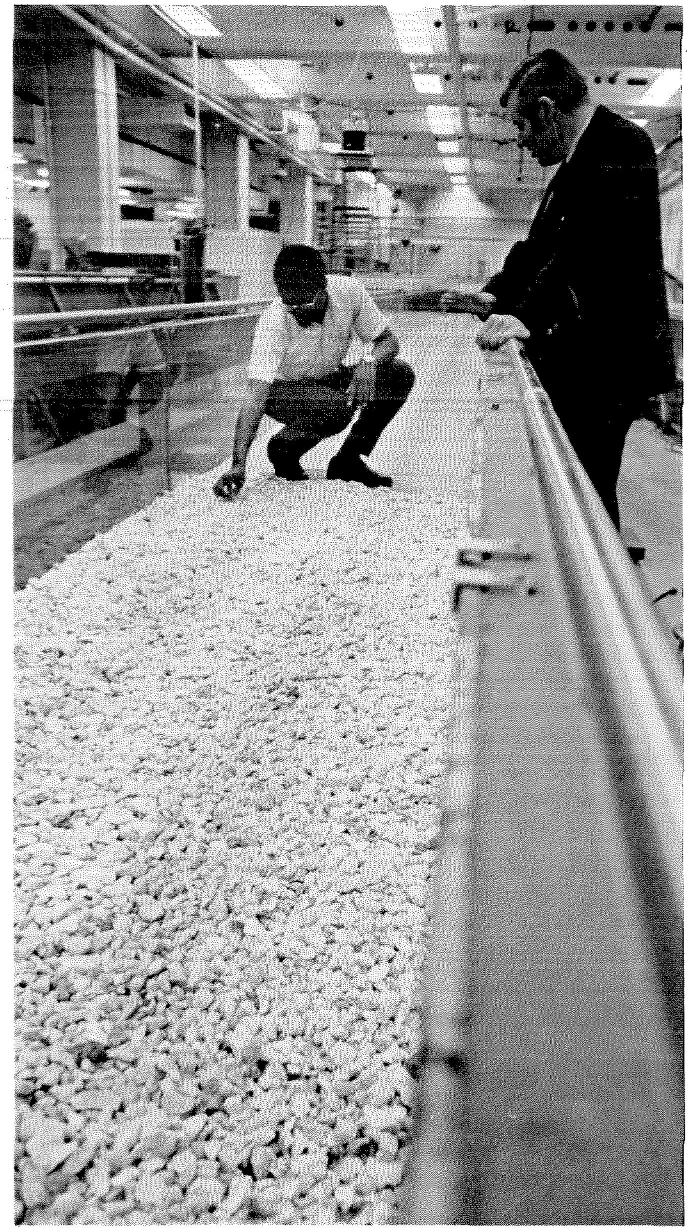
North embarked on his project after it was found in 1960 that 95 percent of the kelp beds had disappeared. His first efforts resulted in successful restoration of large kelp forests in the San Diego area, and he has since worked at devising ways to protect the kelp from grazing sea urchins and to plant new kelp in areas where it used to flourish. He has now developed seeding techniques that may prove successful for large-scale reforestation.

The first attempts to seed the ocean with reproductive spores proved to be laborious and not very fruitful. However, seeding was much more successful when North's group started planting baby kelp plants that had been cultured in the laboratory. When the plants were introduced into suitable areas, the rate of survival changed from about one in 1,000,000,000 to about one in 100,000.

North and two other researchers have been seeding ocean areas with the embryo plants for more than six months off La Jolla near San Diego, at Corona del Mar, and at Palos Verdes. The results at La Jolla and Corona del Mar were about equal, and pretty good, but at Palos Verdes the men were less successful; their young kelp plants were grazed thoroughly by two species of fish that consider them delicacies.

The seeding process involves taking microscopic-size embryo plants, which look like a brown fuzz or scum on the culture dish, and scraping them off with a razor blade. They are then washed into a container with chilled seawater and are taken to sea, where a diver takes the container down and dribbles the plants along the bottom at appropriate places. They need a rocky bottom to grow on, and sedimentation is disastrous for them.

One of the main threats to the remaining kelp forests has been the invading hordes of hungry sea urchins, which make giant kelp plants a major part of their normal diet. In the past, the sea urchin population was kept under control by sea lions. But sea lions have been hunted to near-extinction along the southern California coast. Furthermore, while sewage dumped into the sea nourishes the kelp, it does the same thing for the sea urchins, and upsets the balance between the number of urchins and their food supply. And so, fed by the sewage, and uncontrolled by the sea lions, the urchins manage to stay alive even after their normal kelp diet is gone, and they are ready and waiting to devour new kelp plants as they



Josephat Okoye, one of the first students to earn a PhD in environmental engineering science, and Norman Brooks, professor of environmental science and civil engineering—and coordinator of the EES program—prepare a flume for use in studies of pollution patterns in stream beds.

emerge. The sea urchin problem has finally been largely solved by dumping lime on them.

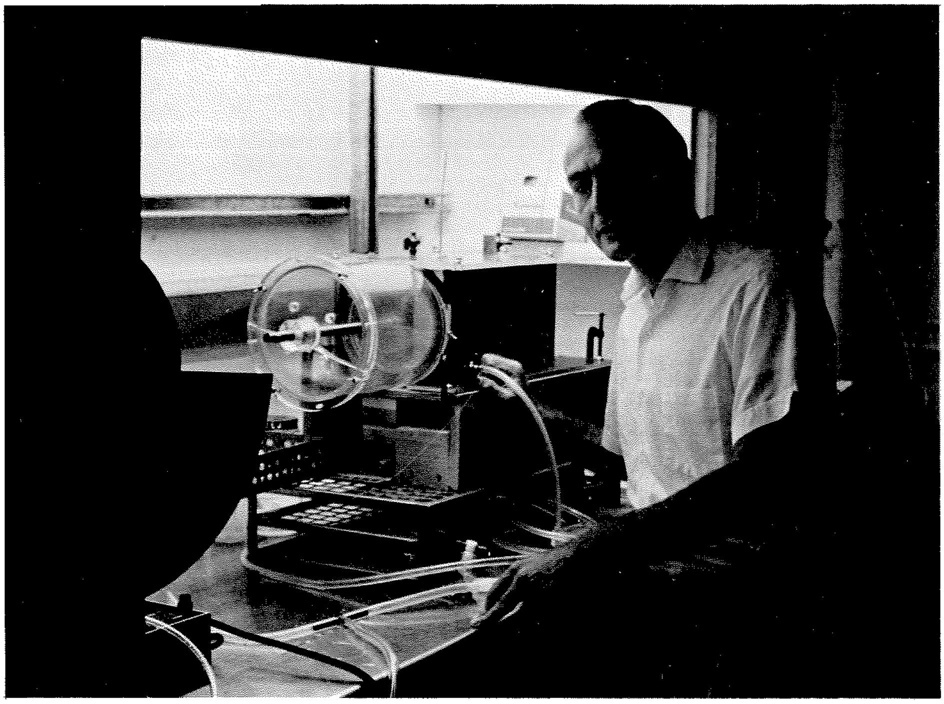
Current plans—under a grant from the National Science Foundation—are to expand production of embryo kelp plants so billions can be seeded in the open sea.

From the total environment point of view, the reutilization of some wastewater that is now being discharged into the ocean represents an exciting alternative. Jack McKee, professor of environmental engineering, has conducted research in this area for many years. A typical study was one carried out by a former student, A. B. Pincince, on oxygen balances in the upper layers of porous media during intermittent percolation of sewage. Research has also been conducted recently on the role of fungi in such operations and the efficacy of conversion of high concentrations of urea to nitrates by percolation through sand columns.

The engineering aspects of environmental quality also embrace problems of solid-waste management, including recycling or recovery of useful materials. Working with personnel of the City of San Diego, McKee collaborated recently in a thorough evaluation of pyrolysis of municipal trash. It is hoped that this study can be expanded soon to the pilot-plant stage.

The fluid mechanics and hydrologic aspects of water quality are being studied by another group in the Keck Laboratories under the direction of Norman Brooks, professor of environmental science and civil engineering, and John List, assistant professor of environmental engineering science. This research is supported by the Federal Water Quality Administration, now part of the new federal Environmental Protection Agency.

Man's use of water involves taking it out of the natural water environs in one place, and returning it often as wastewater somewhere else. The way in which these operations are done has an important effect on water quality. Since many water bodies (ocean, estuaries, lakes, groundwater) are density-stratified because of temperature and salinity variations, the group has studied the mechanics of mixing in stratified fluids. For example, the research on buoyant jets and plumes by Loh-nien Fan, a recent PhD, and Brooks makes possible the design of large multiple-jet outfalls for sewage effluent disposal in the ocean in order to produce a diluted cloud of effluent completely trapped below the ocean thermocline. The design of the new 27,400-foot outfall under construction in Orange County, California, was based on these research results, and it is predicted that the sewage effluent cloud will be completely submerged for more than 11 months of every year. Only for brief periods in January and February does the stratification become too weak to prevent the sewage cloud from surfacing.



Sheldon Friedlander, professor of chemical and environmental health engineering, is studying various aspects of smog, including the behavior of aerosols in the human respiratory tract.

John List is now continuing theoretical and experimental work on the fundamental behavior of viscous momentum jets with or without buoyancy and swirl in a stratified environment. A deeper understanding of the mechanics will quickly lead to better designs of mixing structures of all kinds, including those for thermal discharges from power plants.

John Ditmars, a recent doctoral student in the group, studied the artificial destratification of water reservoirs to improve water quality and reoxygenate stagnant bottom waters. He developed a simulation model incorporating the selective withdrawal of water from the top of a reservoir, pumping through a pipe to the bottom, and jet-mixing it with the surroundings.

Two other students, Ed Prych and Joe Okoye, finished theses this year on transverse mixing of contaminants in river channels, with and without density differences. This work will be useful in predicting how fast a heated effluent introduced on one side of a river will mix fully across the river.

Visiting the Brooks-List group this year are Klas Cederwall from Chalmers Institute of Technology, Goteberg, Sweden; and Ralph Rumer from the State University of New York at Buffalo. Cederwall, a specialist on ocean waste disposal, has been working on mixing produced by line sources of a buoyant flow injected into a current. Rumer, who operates a rotating model of Lake Erie at his laboratory at SUNY Buffalo, is continuing his study of diffusion and current patterns in lakes.

Two other fields of hydraulic research are part of the over-all environmental effort. In the area of coastal engineering, Fredric Raichlen, associate professor of civil engineering, and doctoral student Joe Hammack have an active laboratory project on the generation and propagation of tsunamis, a matter of special concern to important coastal structures like power plants in case of significant fault movements in the California continental shelf. Other coastal problems Raichlen has studied recently include harbor oscillations and resonance, uplift on offshore platforms and docks by impact of large waves on the undersides of the structures, and oscillations of moored vessels in harbors.

A third area of research—sedimentation and stability of alluvial channels—is the interest of Vito Vanoni, professor of hydraulics, who is an expert in a wide range of problems relating to the erosion of sediment from the land, and its transport toward the ocean. As man has disturbed the land, and changed the river systems by a variety of man-made works, there have arisen severe problems of maintaining the sediment balance in rivers—on the one hand, the necessity of avoiding disastrous downward or sideward scour, and on the other, preventing filling and overflowing of river channels with excess sediment. For many years, Vanoni and his coworkers (including Norman Brooks) have contributed to the understanding of the mechanics of sediment-laden flows over alluvial beds. At present, graduate student Brent Taylor is doing laboratory flume research on the effect of water temperature on sediment transport and channel roughness.

Dirty air, like polluted water, is a very complicated system composed of particles and contaminant molecules in a highly non-equilibrium state. Sheldon Friedlander, professor of chemical and environmental health engineering, has been looking for ways to characterize such systems, and has been concentrating on the particulate component and the conversion of gases to particles. Such particles limit visibility, carry harmful chemical components like lead and carcinogens into the lung, and may even affect climate on a global and regional scale.

One of Friedlander's current goals is the preparation of an element-by-element material balance for the Los Angeles Basin aerosol. How much of the existing particulate material is background aerosol and how much originates from man's activities in the Basin? How much particulate material is formed by chemical reactions in the atmosphere? Together with G. M. Hidy, a senior research fellow in environmental engineering, Friedlander has estimated some of these figures and finds that about 30 percent of the aerosol is produced by atmospheric reactions involving gaseous emissions, perhaps 40 percent is introduced directly into air by man, and the rest is natural background. Also working on this problem with Friedlander is Michael Miller, a recent PhD in physical chemistry from Northwestern, who has started experiments on the conversion of smog gases to particulate matter.

The key to understanding the effect of very small particles on health and visibility is their size distribution. About ten years ago, Friedlander proposed that under certain conditions the small particles in a smoke approach a size distribution independent of the original distribution. This means that rather simple and inexpensive measurements can be made to determine the size spectrum. Computer calculations at Caltech and elsewhere have given strong support to this hypothesis; recent calculations by chemical engineering graduate student Francis Lai and experiments carried out at the University of Minnesota have added further support for Friedlander's hypothesis when particles are smaller than the mean free path of the air.

In a related study supervised by Friedlander, graduate student Karl Bell is following the behavior of aerosols in a simulated portion of the human respiratory tract. The lung has about 21 generations of branches; it is well known to engineers that particles in an air flow tend to accumulate at branch points. Such deposition "hot spots" may serve as sites at which lung disorders are initiated. Bell's studies with small polystyrene latex particles confirm the hot-spot concept, but he has found that existing theoretical techniques are not adequate to explain the details of his experimental results.

John Seinfeld, associate professor of chemical engineering, has collaborated closely with Friedlander and is doing computer simulations of the dynamics of smog formation over an urban area. The primary goal of Seinfeld's research is to simulate the formation of photochemical smog in the Los Angeles Basin so that the effect of various proposed control strategies on atmospheric pollutant concentrations can be evaluated.

John Seinfeld, associate professor of chemical engineering, is working out possible air pollution-control strategies with a computer that simulates the atmosphere of the Los Angeles Basin.

The study involves two major tasks: first, learning how to predict what occurs as a result of the chemical reactions in the atmosphere; and second, learning how the great masses of air over the Los Angeles Basin move and distribute airborne contaminants.

The over-all computer simulation will predict—for a given set of weather conditions—the atmospheric concentrations of oxides of nitrogen, hydrocarbons, and ozone as a function of the time of day and location in the Basin.

The ultimate objective of Seinfeld's work is to determine optimal air pollution control strategies or, in other words, to formulate a basis for choosing the best set of control laws for a particular region.

Another area of air pollution research, nitrogen oxide control, is under the supervision of William Corcoran, professor of chemical engineering. Oxides of nitrogen emitted by automobiles and from the stacks of electrical generating stations are primary air pollutants in urban areas. Studies are being carried out in a small industrial burner in Corcoran's laboratory to determine how to minimize nitrogen oxide formation. These studies are supplemented by investigations of reactions involving oxides of nitrogen in the parts-per-million concentrations present in the atmosphere.