ENGINEERING

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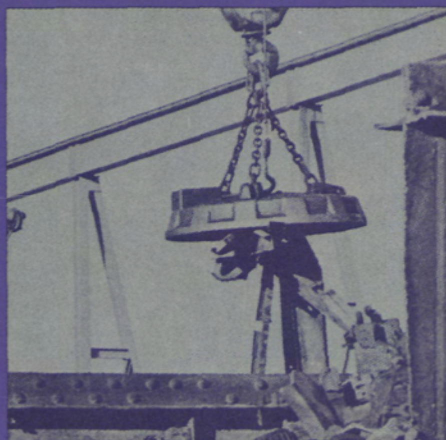

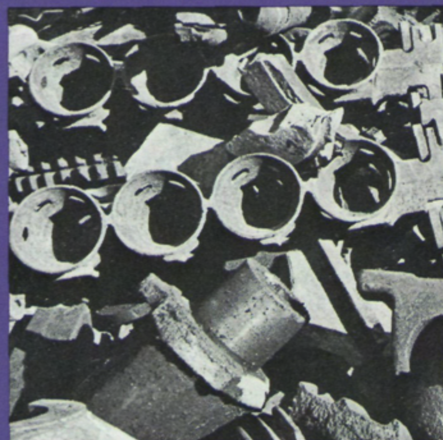

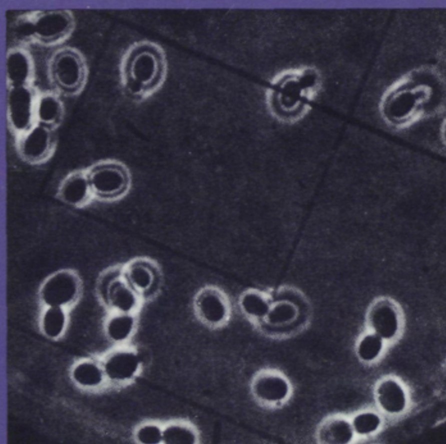

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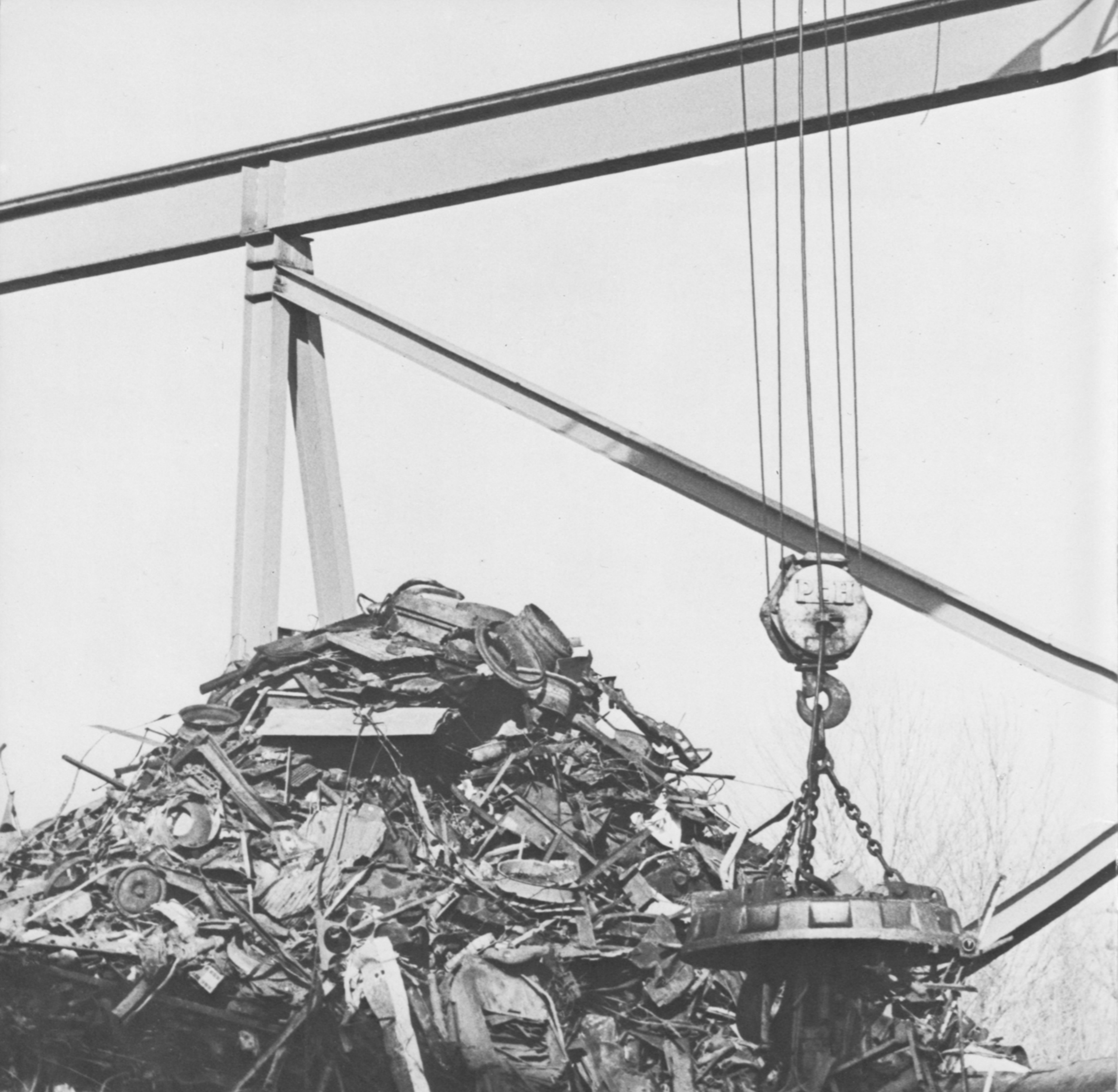
WASTES: NUISANCE OR RESOURCE?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IN THIS ISSUE

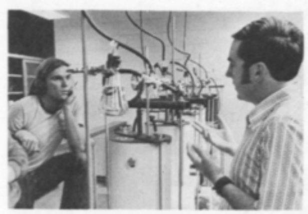
An industrialist and chemical engineer explores the economic as well as social reasons for in-plant utilization of waste materials rather than disposal. Herbert D. Doan, a member of the board of directors and former president of the Dow Chemical Company, is a Cornell graduate and serves on the Engineering College Council.

The production of microbial protein by growing it on organic wastes and the concept of the "urban farm" are among subjects discussed by Victor H. Edwards, assistant professor of chemical engineering at Cornell, in an interview with *Quarterly* editor Gladys J. McConkey.

Charles D. Gates, professor and acting chairman of Cornell's Department of Environmental Engineering, discusses the technological and economic feasibility of solid waste management systems and what needs to be done to encourage resource recovery.

Not only solid wastes themselves but the land on which they are buried represent resources that can be recovered and reused. The reclamation of landfill sites is discussed by Dwight A. Sangrey, an associate professor at the Cornell College of Engineering and a specialist in soils and geotechnical engineering.

The nation's critical energy requirements as they impinge on the need for preservation of the environment are discussed by Peter L. Auer, Cornell professor of aerospace engineering and director of the Laboratory of Plasma Studies. His remarks are excerpted from his summary address at the Cornell Workshop on Energy and the Environment, at which leading United States authorities considered the issues and formulated proposals for future energy supply and management.



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Opposite: Salvage of scrap metal is an operation of Wallace Steel, Inc., of Ithaca, New York.

USING WASTE MATERIALS

A Challenge for Engineers

by Herbert D. Doan

Businessmen have long recognized the value of efficient management of resources. But growing environmental awareness has provided a new perspective on the efficiency of industrial operations: less waste means more efficient production. For both economic and social reasons, industry is and must be deeply involved in better resources management.

Several observations summarize the situation today as I see it.

■ We Americans operate in a system of pluralism with many decision-making points. It can come as a jar to those who work in industry to discover that some of their ideas are thwarted by blockades on one or another ideological plane—social, political, or economic.

■ We are accustomed to fabulous scientific predictions and accomplishments. Yet it seems clear that most often progress occurs through an abundance of relatively small but measurable achievements. As I will try to show, this is what is happening in the area of waste retrieval.

■ We need an initiative that snowballs —not an illusion of commitment. And

if we believe in the incentive of profit opportunity, we need not be overwhelmed by the price tags: better use of raw materials is a route to lower costs.

■ Even though reclamation is now an $8 billion yearly business by estimate of the National Association of Secondary Material Industries, the application of our technology in this area is still at an early stage. We haven't caught up with existing technology, let alone come to terms with what could be devised.

■ Our national priorities are still in the process of development. The United States has no consistent and identifiable policies on conservation of resources.

Yet making better use of waste materials is an environmental mandate. We who have learned well how to reap must now study how to glean. In a sense, I suppose we are reinventing the wheel. Increasing attention to waste retrieval invokes a venerable teaching of conventional wisdom—that there is virtue in thrift. Our pileups today would make a Connecticut Yankee squirm. Our redeeming grace is the growing conviction that our resources are finite and that our own waste of those resources can bury us all.

There are mighty hurdles to overcome. Footdragging is still a lively pursuit for those who haven't sensed a profit opportunity or, worse still, have ignored the buildup of stiff regulations. There is a need for regulations, but short-sighted standards can slow us down. For example, a dairy that wanted to regrind its polyethylene milk bottles and convert them to drainage tile dis-

"... better use of raw materials is a route to lower costs."

covered that the tile was required to be of virgin material. Government, education, and industry still have not learned well how to work together effectively in planning and action.

THE UNIQUE ROLE OF THE CHEMICAL INDUSTRY

Since my area of knowledge is industrial, I will focus my attention on that aspect of waste management.

The chemical industry, which I know best, has a unique role to play in solving its own pollution problems and in helping in the solution of others. The rationale goes like this:

Pollutants arise chiefly from the chemical processes and waste disposal practices of our civilization. The chemical industry and, perhaps more importantly, the chemical engineer understand chemical processing. And they have an economic motivation to be efficient—reduced waste means higher productivity.

The Dow Chemical Company, whose operations I know best, has been able to demonstrate that this is more than theory. Some examples of recycling activities at Dow plants illustrate how increased production and reduced pollution can go together.

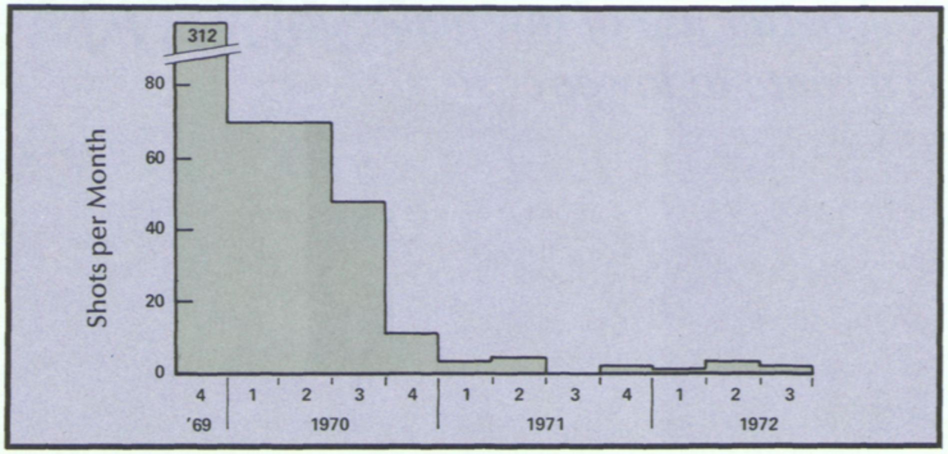
- A plant at Pittsburg, California, spent $80,000 on an odor-abatement problem at a production unit for chelating agents. Abatement involved recycling gas and liquid waste streams back into the process to be converted into saleable product. Most of the capital investment was recovered within a few months because of improved production efficiencies; the odor problem was reduced 90 percent.
- An ethylene diamine plant in Texas increased its yield efficiency 5 percent, resulting in a reduction of 10 pounds per minute of chemical oxygen demand in the total effluent. The product recovered amounts to 350,000 pounds per month. The increased efficiency is equivalent to $10,000 per month in reduced raw materials.
- At fourteen styrene/butadiene plants around the world, average raw material yields have been increased from 94.5 percent in 1966 to 98.3 percent in 1971. This was achieved through innovative process improvement in seven major areas of loss of material to the environment.

Through literally thousands of such recycling activities, aimed at waste prevention rather than waste treatment, Dow has been able to demonstrate a net profit from pollution control. Using 1966-1969 as a base period, Dow people calculate that by the end of 1974 the company will have achieved a total reduction of 80 to 90 percent in the amount of wastes discharged to the environment. I should add that the economic break-even probabilities diminish as zero pollution is approached. Although complete elimination of pollution is a company goal, it appears to me to be an impossible achievement.

CONTROL OF POLLUTION AT THE SOURCE

In planning for pollution control within an industrial plant, there are two ways to go: Either contaminants can be kept out of the plant effluents in the first place, or else they must be removed later at greater expense. I think any engineer will agree that if the retrieval route is taken, the cost of pollu-

Dramatic evidence of the effectiveness of analytical and monitoring equipment in reducing industrial spills is shown in this chart for the Midland Division of the Dow Chemical Company. "Shots per month" represent the average number of spills of more than fifty pounds of organic material that occurred per month during quarterly periods since late 1969. The equipment, installed in August 1969, has helped engineers develop methods of controlling very closely the quantities of organic waste in plant effluents.



tion control will be enormous. On the other hand, as the science of waste prevention is developed, the economic problems of pollution control will diminish. Earle Barnes, president of the Dow Chemical Company in the United States, calls this a basic economic law of pollution reduction and control.

Dow, for example, is expending enormous effort on pollution control at the source. Great strides have been made toward building plants with closed-cycle operations. A lot must be done to bring older operations to the high standards that have been set, but the advances of the past decade in the fundamentals of chemistry—particularly analytical chemistry—and chemical engineering have provided a reservoir of "know how" available for modifying chemical processes.

A key is the conservation of matter. In the chemical and related industries, the response can be in the form of total recycling or it can be in the utilization or elimination of byproducts. These must be the bases of efforts to eliminate wastes, whether they be in the form of liquids, solids, or air emissions. When new plants are engineered so as to use closed-cycle operations, and especially when impurities can be removed from raw materials before they enter a process, then higher quality and higher yields can be expected.

WHAT CAN BE DONE OUTSIDE THE PLANT

As they look outside the plant gates, industrialists see additional opportunities for pollution control that are within the limits of present technology. In most areas, United States residents pay five to ten cents per 1,000 gallons for sewage treatment that is grossly inadequate. For something like twenty cents per 1,000 gallons, the treatment could be improved, with use of existing technology, so that in quality the effluents from these plants would be just short of potable water. The cost increase would be just about one quarter of what Americans pay for cigarettes each year. We must be tough on ourselves to pay the bill.

I said that the technology exists. Let me give an idea of what can be done immediately. The City of Cleveland gave Dow a contract to run the city's Westerly Sewage Treatment Plant for three months. Dow was able to reduce the amount of solids going into the river from 27 tons per day to 9 tons per day, and the phosphorus content of the effluent from 1.2 to 0.2 tons per day—and achieved these results without the need for capital investment.

Incidentally, the detergent companies are being pressed to get phosphates out of their products because phosphates become nutrients that kill the lakes. But human wastes contribute about the same amount of phosphates as detergents do. The only real solution would seem to be to remove phosphates in sewage-treatment plants—and this can be done now, to the extent of a 90 percent reduction, with primary and secondary treatment.

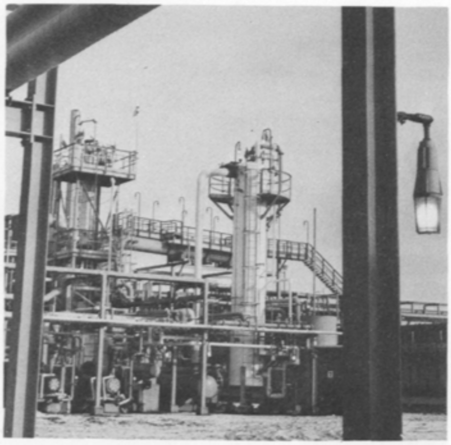
FINDING NEW USES FOR RECOVERED MATERIALS

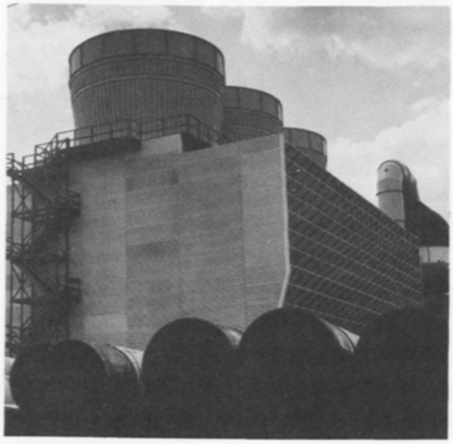
The next challenge, of course, is to find uses for the recovered materials. To the informed mind, almost any form of waste has potential. Georgia-Pacific Corporation has built a $3 million shipping facility in Oregon to export waste wood chips collected from Pacific northwest forest-product manufacturers. Many firms now burn their chips. On the east coast, an inventor is converting wood slashings and garbage to garden mulch. In the Philippines and Hawaii, sugar-cane residues fuel boilers to generate electricity.

Chemical Week predicts, in a recent issue, that some 2,000 oxygen analyzers will be installed in chemical plants, steel mills, and power-generation stations this year. Improved oxygen flow can mean reduced fuel bills and better control of unburned hydrocarbons.

In solid waste recovery, a variety of encouraging developments are under way. "Recycle the can" is the order of the day. This year aluminum firms expect to handle nearly a billion recycled cans, accounting for more than 36 million pounds of aluminum. People in the steel industry are working hard to demonstrate that tin cans can be recycled, and tin-free steel is on its way as an aid to the separation of materials. A number of firms are entering the business of separating mixed trash. New types of waste-collection vehicles are entering use, an important development in view of the estimate that municipalities now spend four times as much on collection as they do on disposal.

There is real cause for optimism in actions by municipal and state governmental units to turn waste into usable energy. One example is the plan by the city of Nashville, Tennessee, to build a $13.7 million incineration and air-conditioning complex. The complex will be capable of consuming more than 700 tons of municipal waste each





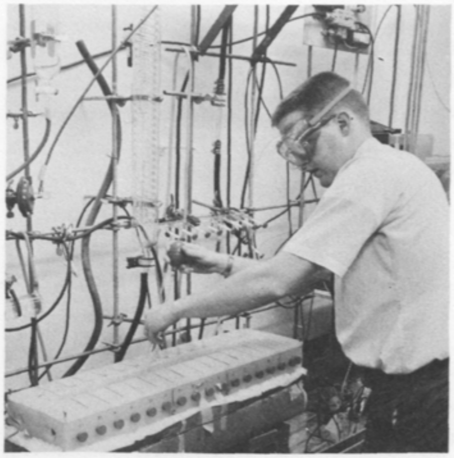
Left: Some recently built Dow Chemical Company recycling plants. At top, a chlor-alkali facility where engineers have implemented recycling to the extent that there are no outlets to the river. At center, one of twenty-eight cooling towers being installed to recycle cooling water. Below, a view of a demonstration plant for the removal of contaminants from brine, which is then recycled. Four adsorption towers contain carbon through which contaminated brine flows. The $1.3 million experimental plant is a joint project of Dow and the Federal Water Quality Administration.

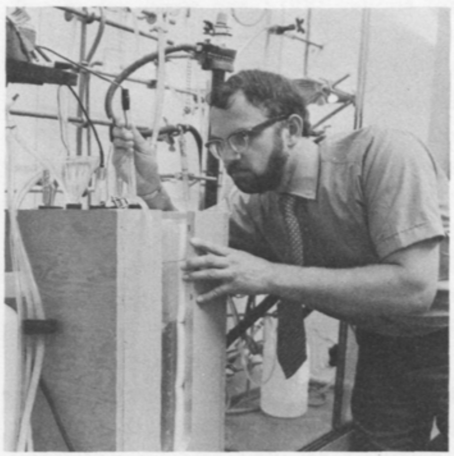
day and will use the energy to provide central heating and air conditioning for twenty-seven downtown office buildings. At a state level, Connecticut has hired the General Electric Company to develop and manage a system for disposing of garbage, trash, and other solid wastes. This program aims at maximum recovery of material and energy; some fifteen regional planning agencies and 169 cities and towns are involved in the planning and implementation. Connecticut is thinking in terms not only of solid-waste disposal, but also of the creation of new jobs and businesses through reuse of materials.

STUMBLING BLOCKS TO PROGRESS IN RECYCLING

These are the types of developments that have to come—soon and on a broad scale. What stands in the way? Most observers seem to agree that the biggest stumbling blocks are conflicting laws and insufficient economic incentive for users of recycled materials.

In a recent article in *Environment,* Robert R. Grinstead, a Dow researcher, identifies some problems that he feels must be resolved before better recycling becomes a reality. He concludes that:





Chemical engineers at Dow study methods for the treatment of waste brine streams. At top, a laboratory test is made of a proposed method for treating waste brines from herbicide production. Below, a mini-plant scale reactor is used to study the removal of organics from waste brine streams.

1. Urban officials need some concrete assistance and reassurance to encourage them to make an investment in a municipal recycling plant.

2. Some way must be found to establish a satisfactory economic link between producers and disposers. While the cost of manufacturing is included in the selling price (which the consumer shoulders), no similar means exists for discharging the cost of disposal.

3. Ways must be found to produce a significantly large amount of usable recycled materials, and markets for recycled materials must be encouraged. Under such conditions, urban "trash mines" might generate enough cash to pay for the cost of disposing of the trash.

RESEARCH ON SECONDARY MATERIALS INDUSTRIES

It is encouraging that market evaluations are now underway. The August, 1972 issue of *Environmental Science and Technology* reports on a thoroughgoing survey of the secondary materials industry by Battelle Memorial Institute. The article, by Howard Ness, also takes note of inequitable federal tax policies, discriminatory transportation rates, out-of-date local, state, and national procurement policies, and lack of leadership at the municipal and state levels. Ness cites conclusions of the National Commission on Materials Policy as presented in its interim report of April, 1972, and makes the comment:

> Even though recycling has gone on for years, it now must be developed and increased to become a "new way of life."

Herbert D. Doan (right) is a member of the Cornell Engineering College Council, an advisory group. He is shown at the October meeting in Ithaca with Charles W. Lake, Jr., chairman of the Council, who is president of the R. R. Donnelly and Sons Company.

Maximum consideration must be directed to these questions. How can recycling be increased? How can the amount of material recycled be more meaningful in terms of total raw material supply? To do this, priorities must be reexamined; attitudes and prejudices must be changed; and man can no longer be satisfied with the status quo.

NEW PROBLEMS FOR NEW ENGINEERS

It is apparent from earlier issues of *ENGINEERING: Cornell Quarterly* that the faculty of the College of Engineering has set out to design a new engineer: he knows his specialty but he has an interdisciplinary frame of reference. This is the very person we need to cope with the increasingly important problems of waste retrieval or prevention, for whether our new engineer goes into industry, government, or education, he will become involved with "outside" factors that will influence his problem-solving ability.

And for the new engineer—or the older one—I can't imagine a better challenge than to help sort out our waste problems and to move the system. There is enough evidence of progress to make me believe it can be done. Indeed, it must. And the well trained engineer with a broad view of his effect on the world will be in the vanguard of those who will seek not only to resolve specific problems at hand, but to encompass in their planning the entire cycle from raw materials to finished products and back to raw materials again: from dust to dust.

Herbert D. Doan, member of the board of directors and former president of the Dow Chemical Company, is a Cornell graduate in chemical engineering and a member of the Cornell Engineering College Council.

Doan joined the Dow Chemical Company, which his grandfather founded before the turn of the century, after his graduation from Cornell in 1949. He was a member of Dow's Technical Service and Development Department for several years, then served in the Research Department, and in 1956 organized and became the first manager of the Chemicals Department. Doan was elected a member of the Dow Board of Directors in 1953, executive vice president in 1960, president in 1962, and chairman of the Executive Committee in 1970. He retired as president, chief executive officer, and chairman of the Executive Committee in 1971, but remains on the Board.

At the present time he is active as a partner of Doan Associates, an organization he helped found. He is also on the Board of Directors of the Dow Corning Corporation of Midland, Michigan; American Research and Development of Boston, Massachusetts; the Chemical Bank and Trust Company of Midland; Interactive Systems, Inc., of Ann Arbor, Michigan; and Cayuga Associates of Ithaca, New York.

In addition to serving on the Cornell Engineering College Council, an advisory board to the College administration, Doan is active in other organizations in the area of higher education. He is president of the Michigan Foundation for Advanced Research, a member of the Advisory Board of the Graduate School of Business at Michigan State University, and a member of the Board of Fellows for Saginaw Valley College.

He makes his home in Midland and is active in community affairs in that area. He is a member of the American Institute of Chemical Engineers and the American Chemical Society.

FOOD FROM ORGANIC REFUSE

An Interview with Victor H. Edwards

Processes that can transform garbage, manure, chemical plant wastes, and other organic refuse into edible protein provide ingenious ways to simultaneously help dispose of solid wastes, preserve the environment, and yield valuable food products. These microbial processes and some of their present and potential applications are discussed by Victor H. Edwards, assistant professor of chemical engineering, in an interview conducted by Quarterly *editor Gladys J. McConkey. Professor Edwards foresees not only the development of large-scale waste management systems, but also possibilities for broad new plans for community living.*

What are the basic chemical and biological processes by which organic wastes can be transformed into food?

The ability of many fungi, bacteria, or other simple forms of life to grow on organic matter is the basis of these methods. Microorganisms can often digest materials which humans or other animals cannot. They grow on the organic wastes and can be harvested as single-cell protein. For some types of organic refuse, hydrolysis or other chemical treatment might be required prior to the fermentation process, and it might be necessary to add certain nutrients such as nitrogen or phosphorus.

What are the advantages of utilizing organic wastes for the production of edible protein?

Three obvious advantages are that the refuse is disposed of, useful products are obtained rather than resources wasted, and a valuable source of food is made available. There are other benefits. Microbial processes help prevent pollution: for example, with use of a conversion process, organic wastes from chemical processing plants can be removed from the effluent streams rather than emptied into waterways. Additional environmental benefits include the elimination of objectionable disposal sites and decreases in rodent population.

Do you feel that single-cell protein is or can be a significant food source?

In terms of present and impending food shortages on a global scale, new means of providing food, especially protein, are obviously extremely valuable. Yeast and bacteria contain as much as 80% protein (on a dry basis), as compared with alternative sources such as soybeans, which are about 50% protein. Edible microorganisms could provide a contingent food source during temporary periods of famine or they could serve as a continuing means of helping to feed a growing, hungry world population. Recent studies indicate that by the year 2000 the need for protein will exceed the earth's capability to produce the traditional protein sources—meat, milk, eggs, fish, grains, etc. Single-cell protein, mostly yeast, is already being used as animal feed and as a constituent of food for human consumption, and these usages could be greatly increased. Studies have shown, for example, that chickens can be satisfactorily raised with yeast as the sole source of protein. As human food, sin-

A chick raised on feed whose protein content consisted entirely of yeast cultivated on organic refuse is admired by Mary Elizabeth Edwards, daughter of Professor Edwards. Chicks were raised as a demonstration project in a freshman "mini course."

gle-cell protein could provide high-quality protein to supplement a vegetable diet.

As a food for humans, of course, single-cell protein must meet a number of criteria. People are generally reluctant to accept new foods unless they are palatable and, preferably, familiar, as well as economical. It would probably be desirable to use microbial protein as an additive to traditional foods rather than attempt to market it as an independent product. Blending single-cell protein with other vegetable materials and forming it into artificial grains or incorporating it into artificial meat or into flour, beverages, soups, or other foods should help make microbial protein more acceptable. The form chosen should be compatible with local customs and tastes. In societies that can afford to be discriminating in food choices, animal protein will probably continue to be preferred, but even under such circumstances single-cell protein products can make a valuable contribution as animal feed. There is also the possibility of extracting a protein concentrate from the cells. On a long-term, worldwide basis, it appears that there will be a market for all kinds of protein.

What kinds of wastes can be used as material for protein synthesis?

Three large categories are urban, industrial, and agricultural solid organic wastes. Urban wastes include, for example, garbage, waste paper, and sewage. Usable industrial wastes include chemical byproducts such as acetates, maleic acid, methanol, and formaldehyde. Agricultural wastes might be byproducts of a main crop, such as wheat straw, or parts of fruits and vegetables that are discarded at food processing plants, or manure. Animal wastes are becoming an increasing problem as more sophisticated technology is employed in agriculture. Egg and poultry factories are now common, and the use of cattle feedlots rather than pasturage is increasing. In the United States, solid waste from animals amounts to ten times that of the human population. The quantity of organic matter in garbage also greatly exceeds the amount of organic matter in domestic sewage.

What kinds of microorganisms can be grown on organic wastes?

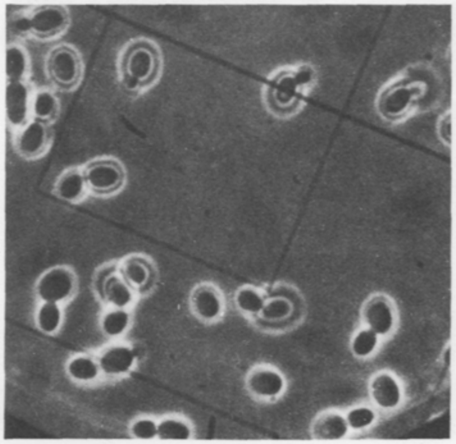
The most prevalent and familiar single-cell plants that can be produced by fermentation are various yeasts. These have a long history of use in the production and preservation of foods such as dairy products, beer, vinegar, and bread. Bacteria have also been used for centuries in the preparation of foods such as cheese and yoghurt. But man discovered fermentation processes by accident, and the use of microbes has evolved as an art rather than a science. There are literally thousands of microorganisms that could be investigated as food sources, and efforts can now be made to discover them and select them for specific usages. Some organisms grow on given substrates better or more rapidly than others, and some are easier to recover than others. Different organisms and methods of production could yield protein products with different characteristics; ways of obtaining desired mixtures of amino acids could be devised, for example. Microorganisms can be considered the last major potential food crop.

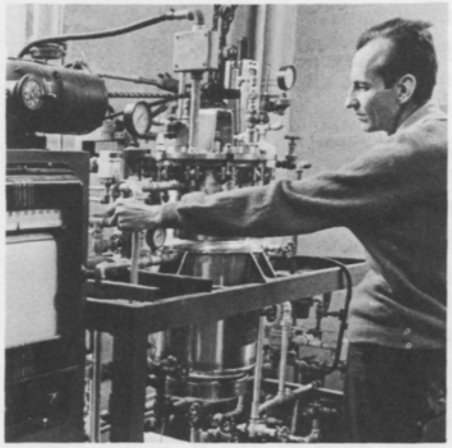
A variety of research projects related to the utilization of organic wastes is underway in the School of Chemical Engineering.

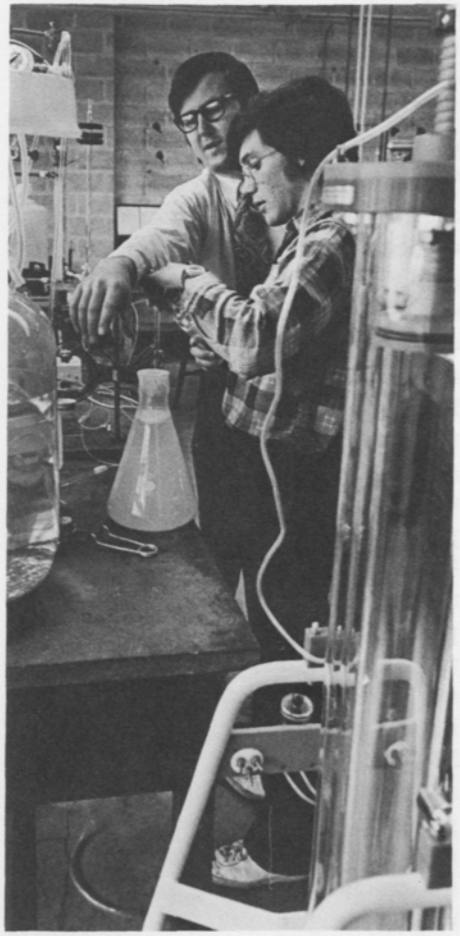
Right above: Candida utilis, *the yeast used in Professor Edwards' research on conversion of organic wastes, is shown in a micrograph taken by graduate student Jay Jackson.*

Below: Alex L. Tannahill, a technical associate, operates a 40-liter fermentation pilot plant used to study the production of yeast and to supply yeast for animal-feeding trials.

Right: Methods for the optimal design of chromatographic processes are being developed by Professor Edwards and graduate student John Helft. In the past few years, plants have been built in the United States and Sweden for the separation by gel chromatography of lactose and protein recovered from whey, a waste by-product of cheese manufacture.







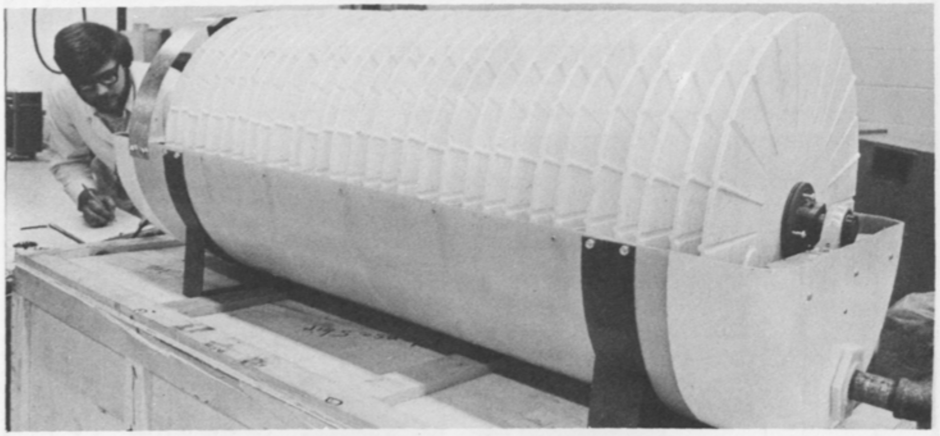
What research is being conducted at Cornell in the area of protein synthesis from waste products?

Research on microbial growth in chemical effluents has been proceeding in the School of Chemical Engineering for several years. Both Professor Robert K. Finn and I have directed these studies.

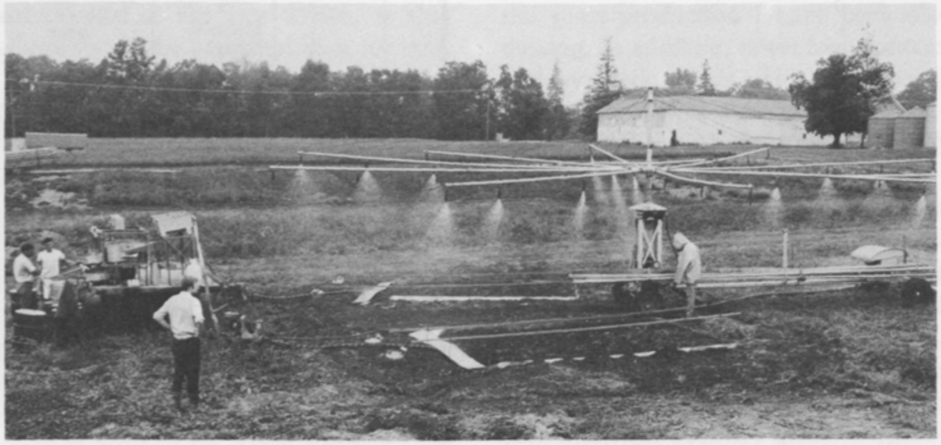
Among projects that we and our students have worked on are the growth of yeast *(Candida utilis)* on formaldehyde and sodium acetate, two of the many organic wastes of the chemical industry. The utilization of formaldehyde illustrates how microbial processes can be adapted to particular circumstances. Yeast will not grow on formaldehyde, and bacteria only poorly, but our research demonstrates that with prior conversion to sugars by alkaline condensation, yeast growth may be technically feasible. In the investigation of sodium acetate, the technical feasibility of using this chemical effluent as the primary carbon source for growth of yeast was demonstrated. Optimum conditions of temperature, pH, and concentration were determined, and batch and continuous culture techniques were studied.

Another project is an investigation of the growth of bacteria *(Pseudomonas fluorescens)* on sodium maleate, a constituent of the waste streams from some manufacturing processes. The study has included analysis of the composition of the bacterial cell product in terms of protein, lipid, RNA, and DNA content, and determination of the amino acid distribution of the protein—important information from the standpoint of nutrition.

My associates and I are also doing



Considerable research in the Department of Agricultural Engineering is also directed toward the utilization of organic wastes. Professors Raymond C. Loehr, Douglas A. Haith, and David C. Ludington are active in these projects.
Left: A rotating "bio-disc" is tested for feasibility as a means of treating agricultural wastes such as poultry waste in a liquid state. With this equipment, in which bacteria grow on the disc surface and purify the organic matter, an effluent with greatly reduced pollution characteristics is produced.



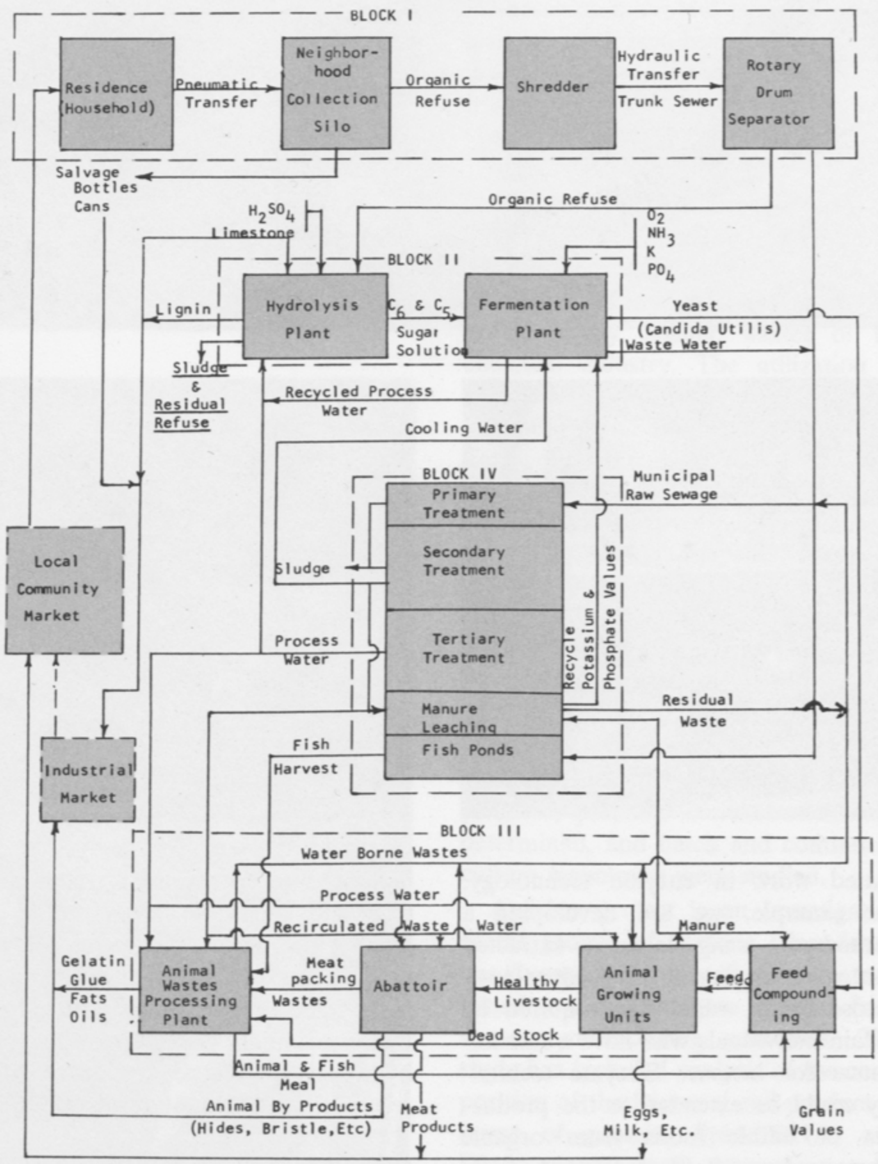
related work in enzyme technology. For example, we are developing a method of using lactases extracted from microorganisms to produce low-lactose foods, which are required by certain individuals who have a low tolerance for lactose. Enzyme technology could be extended to the production of edible foods from organic substances unsuitable for human consumption. For example, about 22 billion pounds of whey are produced annually in the United States as a waste byproduct from cheese manufacture, and recovery of usable protein and sugar in whey could be greatly simplified if research of this type is successful. Cellulose could be hydrolyzed enzymatically. And enzyme hydrolysis might prove better than acid hydrolysis for the conversion of urban refuse or agricultural residues.

How are students involved in classwork or research in these areas?

Graduate students participate in much of this research, of course. In one recent thesis study, a mathematical

Left above: The treatment of poultry waste is being studied in the Agricultural Waste Management Laboratory, where an oxidation ditch for 250 birds has been constructed. The Laboratory, one of the largest facilities of its kind in the nation, can be used to demonstrate treatment processes for all types of animal wastes.
Above: Treated and untreated animal wastes are disposed of on the land in experimental programs under the supervision of Cornell's Department of Agronomy in the New York State College of Agriculture and Life Sciences. Shown is a test site at Aurora, New York.

A DESIGN FOR A CITY FARM*



*From F. H. Meller, *Conversion of Organic Wastes into Yeast*, U.S. Public Health Service Publication No. 1909, 1969.

"There are literally thousands of microorganisms that could be investigated as food sources. . ."

model for the selection of optimum conditions for bacterial growth was developed, and a method for computer control of the process was outlined. Even undergraduates can become involved in this work. Last year in a freshman mini course on Cultivation of Cells in the Service of Man, the production of edible protein from organic wastes was discussed and the feasibility of such processes was demonstrated in a class project in which baby chicks were fed with yeast that had been cultivated on organic refuse.

You have been active in promoting the idea of the "city farm." Will you explain what this is?

Increasing industrialization of agriculture and urbanization are two important trends in technologically developed areas. One result of these trends is that large quantities of organic refuse —sewage, garbage, industrial wastes, and wastes from intensive animal-rearing units—are concentrated near their sources. The idea of the "city farm," which was originated by Floyd H. Meller in the late 1960s, is that there should be a general plan for integrating the complex processes involved in urban consumption, waste production, disposal, and utilization of wastes. The concept grew out of studies on the fermentation by yeast of acid hydrolysate from garbage, and studies such as ours at Cornell on the conversion of chemical wastes fit very well into the large-scale concept.

According to a city farm plan, wastes would be recycled in an internal system that would be as self-sufficient as possible. For example, animal feedlots would be located close to urban centers where land costs are high and food needs great. The animal wastes and urban solid wastes would be used to grow microorganisms which would then be used for animal feed. The feedlots, packing house, waste treatment plant, and feed-compounding units would all be located near each other and their functions would be coordinated. One can think of the city farm as a food production system in which organic wastes would be recycled through artificial food chains such as the yeast production I have been discussing. In addition, novel food sources and synthetic foods, which are being derived both chemically and biologically, could form links in the new food chains.

Implementation of such a scheme is complicated, of course. The accompanying flow chart showing details of suggested operations gives some idea of how a city farm could be organized. Operations in Block I of the figure are essentially those concerned with refuse collection and transfer; Block II operations are essentially for the conversion of organic refuse to yeast; Block III processes are associated with animal production and byproduct industries; and Block IV operations include the important steps of residual treatment of wastes produced in the entire urban farm complex. An interesting feature of the Block IV plan is the utilization of sewage for fish production. Other features could be integrated into such a plan. Canning plants could be included in the system, with their large amounts of refuse contributing to the organic recycling process.

". . . organic wastes would be recycled through artificial food chains."

Why is it termed an urban or city farm?

In a sense, it represents a return to tradition. The urban farm is analogous to the individually owned, self-sustaining farm once characteristic of agriculture in this country. In such rural farms, a variety of crops and animals were raised, and wastes were fed to the animals or returned to the soil. In many parts of the world today, such arrangements still pertain. In parts of Asia, for example, wastes from towns may be dumped into the rivers, and while such practices create problems including those of health and sanitation, they do represent a crude means of recycling: fish that grow in abundance on the organic material are used for food, for instance. In more technologically advanced societies today, agricultural practices are largely based on the single-crop concept, and the "built in" methods of utilizing wastes are gone.

The need to find new ways of utilizing instead of wasting these resources is widely recognized. People in many areas of agricultural and biological sciences are working on these problems. The attractiveness of the urban farm idea is that integration of the various processes and recycling are easier if the operational units are geographically close to each other, as they once were on the rural farms of America.

How well developed is the urban farm idea in terms of economics?

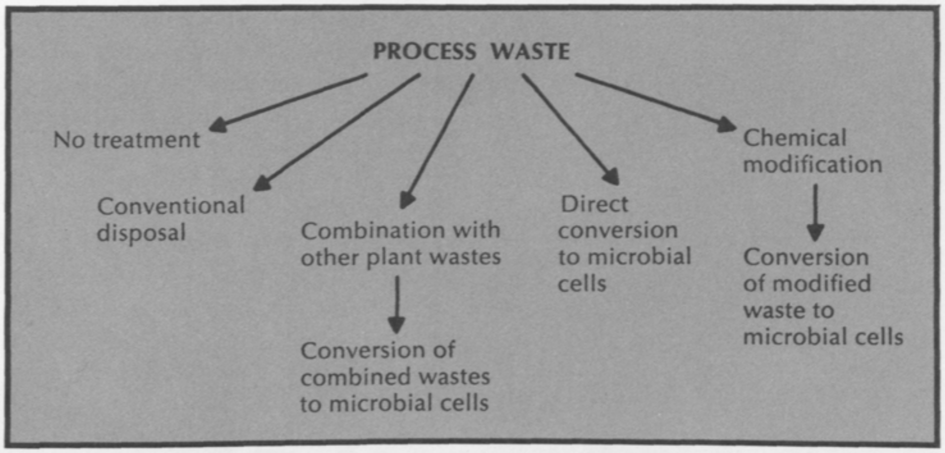
The economics of plans such as this are in a preliminary stage of development. An important aspect is the location of job-providing operational units close to the urban centers where the workers live and where farm products are consumed. Many ideas congenial to the urban farm concept are being tried out. For example, commercial fish culture based on the use of high-protein feeds, including yeast grown on organic wastes, is under development. Waste heat from nuclear power plants is being tried for the heating of waters used for growing shrimp. It is obvious that many economic as well as technological, social, and other concerns are involved in implementing broad plans such as this. Specialists in many fields would be needed to work in great cooperative efforts.

Is there much interest nationally in the urban farm idea?

The idea is catching on in many places all over the country. There is federal interest, as evidenced by research support from agencies such as the National Science Foundation, the Department of Health, Education and Welfare, the Environmental Protection Agency, and the Atomic Energy Commission. Last fall a symposium on Processing Agricultural and Municipal Wastes was held at a national meeting of the American Chemical Society; this spring at the national meeting of the American Institute of Chemical Engineers there will be a symposium on Engineering for an Urban Farm, for which I am serving as cochairman. The papers submitted for this symposium indicate that there is considerable interest in the subject and that ideas are being developed.

Do you feel that these ideas carry broad implications for urban development and life styles?

If the urban farm concept were implemented effectively, the development of a large number of moderately sized and well defined communities rather than huge, sprawling metropolises would be encouraged. This would, of course, have



Some alternatives in the disposal of an organic waste. The refinement of the treatment technique increases from left to right in the figure. Which route is the most economical depends on the particular waste and on such factors as the size of the operation. Under favorable circumstances, one of the three routes producing microbial food or fodder is more economical than conventional disposal. Other recycling alternatives include direct recovery of edible materials from the raw waste, and conversion to life forms other than microorganisms.

many implications—environmental, social, economic, political.

Actually, I am very much interested in an even broader idea for encouraging the development all over the world of balanced systems of production, consumption, and conservation. It is an idea, still quite theoretical, that I first presented last year at Cornell in a seminar conducted by Malcolm Slesser of the University of Strathclyde (in Glasgow) and sponsored by Cornell's Program on Science, Technology and Society. I think of it as the "Garden of Eden" concept.

Will you explain this "Garden of Eden" concept?

Nature has developed for each part of the world a multi-crop biological system that includes plants and animals. As man has developed agriculture, he has cleared land for separate crops, and has progressively employed more efficient but less natural methods for raising them. The single-crop method of agriculture favored today offers many advantages, but it also creates a number of problems. The production of wheat on huge farms, for instance, has been beneficial in providing grain for a hungry world, but it has entailed the use of herbicides, pesticides, and artificial fertilizers, all of which have ecologically detrimental side effects. It may now be time for the human race to take a new leap and begin a return, with the help of advanced technology, to a natural environmental state.

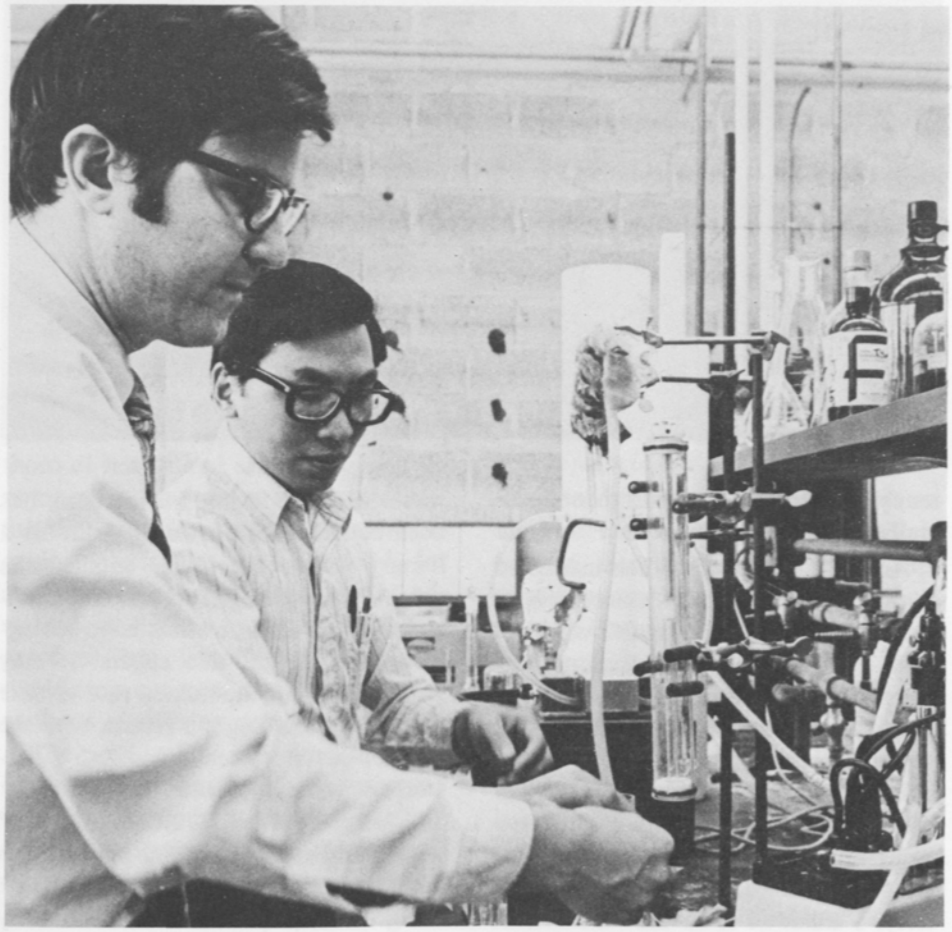
Essentially, the "Garden of Eden" idea is to base agricultural practices on the harvesting of fractions of mixed, indigenous crops with use of locally available resources and without depleting natural resources. We can envision, for instance, a huge machine with a wood-burning, pollution-free engine harvesting a mixed crop from part of the land in such a way that erosion is avoided. This machine might be followed by another that would replant. A harvesting machine might sort or grind up the produce for food processing and retain some of it for fuel, which would thus be derived ultimately from solar energy. Herbicides and pesticides would not be needed because animal life would not be driven out or inhibited. It would be necessary to return minerals to the soil, but total fertilizer requirements might be greatly reduced.

This concept is similar, on an expanded scale, to the urban farm idea. Its central feature is the planning of comprehensive, self-sustaining systems that would preserve resources and the environment. The attraction of the concept is that much of the earth could be returned to a state of nature without the sacrifice of desired life styles.

To put such a plan into operation would require very careful planning and sophisticated technology of all kinds. Of course, its application would vary greatly from region to region—each locality would have to develop special technologies. Some areas might continue to be used for single-crop agriculture where this seemed most beneficial, but then special conservation measures would be taken. If depletionary practices were permitted in certain areas, they would be done so as to preserve other resources: before land were strip mined, for example, the forest would be harvested and utilized completely, and after the mining had been accom-

Research in enzyme technology is a part of Professor Edwards' program. A current project with graduate student Kai Tam (shown in the photograph) is the development of a method of immobilizing trypsin, an enzyme capable of modifying protein through hydrolysis. More soluble proteins produced in this way could be used, for example, in soft drinks containing protein rather than carbohydrates. Immobilization of enzymes is accomplished by chemically binding them to inert carriers; the technique permits the reuse of an enzyme and also keeps it out of the end product.

Research on the insolubilization of the enzyme lactase to develop new low-lactose foods is being conducted in a joint project of Leopold Wierzbicki, a postdoctoral research associate, Professor Edwards, and Professor Frank Kosikowski of the Cornell Department of Food Science.



plished, the area would be refilled and replanted.

There are, of course, other approaches to solving our contemporary problems of feeding a rising population, meeting an impending energy-supply crisis, coping with environmental pollution, etc. Biological control methods can be encouraged as alternatives to the use of chemical pesticides. Methods for safe nuclear energy production can be developed. The overriding need is to stop wasting, spoiling, and using up our resources. Man has made great changes on the earth in a very short period of time. Humans are now beginning to realize that they must be concerned with the welfare of other species of life and with the conservation of all natural resources, even if only for the selfish reason of survival.

What approaches to the development of systems for organic waste utilization do you consider most feasible or productive at the present time?

More research on all aspects of the subject is needed. This includes economic as well as technological feasibility studies. Large-scale plans will require the efforts of specialists in many disciplines, and many years of developmental work. But in the meantime, basic studies in specific problems should be undertaken. For scientists and engineers at the present time, key problems are to identify feasible waste materials, investigate the characteristics and usefulness of various microorganisms, discover the best ways to accomplish the production of microbial protein, and design suitable production systems.

Research projects are now, perhaps

necessarily, somewhat piecemeal. Work on a specific chemical-plant effluent, for example, might be undertaken for the purpose of disposing of and utilizing waste products in an economically advantageous way. A lumber company might review the economics of the microbial or enzymatic digestion of cellulosic wastes, or it might promote research on the catalytic cracking of lignin and its derivatives to produce liquid or gaseous fuels that could supplement our fossil fuel supplies. There is an extremely wide range of possible applications of this sort.

In conducting such a study, one would investigate such matters as what organisms can grow on a given material and how rapidly; environmental factors that influence growth and nutritional value of the product; which strains of an organism yield the most desirable properties; and under what conditions the highest degree of conversion can be achieved. Many technological aspects must be examined. These might include such problems as what means can be employed for sterilization, if this is needed, or how the end product can best be separated out, or what the optimum conditions of flow rate, dilution, etc., are for the maximum conversion of the waste.

The design of comprehensive systems for the utilization of organic wastes will emerge as knowledge is accumulated. But regardless of what forms such systems may take, or how they may influence human life in the future, the underlying processes of converting organic wastes to food and energy are indispensable and should contribute to both an improved environment and a better-fed world.

Victor H. Edwards has been an assistant professor of chemical engineering at Cornell since 1967, when he received the Ph.D. degree from the University of California at Berkeley. As a graduate student he worked at Berkeley's Lawrence Radiation Laboratory, conducting research on sulfate-reducing bacteria, and since coming to Cornell he has continued to study microbial processes, especially as applied to industrial waste disposal and food production. He is also working in the field of enzyme engineering and spent a year at the National Science Foundation in 1971, developing and administering a new national research program in this area.

Professor Edwards has published extensively in his specialty subjects, and is an active participant in professional activities and conferences. Last year he spent several weeks in Japan lecturing on fermentation technology at Osaka University as part of a group training course sponsored by UNESCO, visiting laboratories and universities throughout the country, and participating in the fourth annual International Fermentation Symposium. This spring he will serve as cochairman of an American Institute of Chemical Engineers (AIChE) symposium on "Engineering for an Urban Farm," a subject discussed in these pages of the Quarterly.

Professor Edwards took his undergraduate education at Rice University, receiving the B.A. degree in chemical engineering in 1962. He had industrial experience during his student years in summer jobs with the Union Carbide Chemical Company, the Humble Oil and Refining Company, and the Shell Development Company. He also worked in the Forest Products Laboratory at the University of California while he was a graduate student.

He is a member of AIChE, the American Chemical Society, the Society for Industrial Microbiology, the Society of Fermentation Technology (Japan), Phi Lambda Upsilon, and Sigma Tau.

RECOVER, REUSE, RECYCLE

New Approaches to the Solid Waste Problem

by Charles D. Gates

The more than four billion tons of solid wastes generated in the United States each year have created a major and growing disposal problem across the nation. It is a problem that interfaces with other major national concerns such as environmental pollution, urban blight, and the need for conservation of resources. And it is a costly problem: municipal expenditures for the collection and disposal of solid wastes has been estimated at $4 billion a year, a total exceeded only by annual municipal costs for education and for highways.

The Congress, in the Resource Recovery Act of 1970, directed that the emphasis in the national solid waste management research program be changed from disposal toward recovery, reuse, and recycling. This legislation stated the need for the development of "solid waste management and resource recovery systems which preserve and enhance the quality of the air, water, and land resources." New legislation that is being drafted for presentation to the next Congress is said to emphasize the application of technology that is already available and to encourage the development of markets for recycled material. The new program will call for economic incentives such as tax credits and subsidies, intended to make the recovered materials more competitive with virgin materials. This program, it is hoped, will encourage private industry to design and build processes and plants to reclaim waste materials and to utilize them in manufactured goods.

SOLID WASTES: WHERE THEY COME FROM, WHERE THEY GO

The hundreds of millions of tons of raw materials, agricultural products, fuels, and minerals which man uses each year are not "consumed" but, in accordance with the principles of the conservation of matter, either become economically valuable products or are left over as residual materials or energy that must be disposed of. Eventually the products, too, become residuals and must be either wasted to the environment or recycled.

Agricultural, domestic, commercial, and industrial activities are all significant sources of the broad spectrum of materials and objects loosely defined as solid waste. Each day the average family in the United States discards approximately five pounds per person of materials that are no longer useful to the family. Industries contribute at a comparable but unknown rate. Large appliances, automobile hulks, demolition rubble, and animal manures add to the total.

The United States Environmental Protection Agency has estimated that the current annual production of solid waste from residential, commercial, institutional, and industrial sources is about 360 million tons, of which 190 million tons are collected and disposed of. The latter figure is expected to grow to 340 million tons by 1980. Both these figures are dwarfed by the approximately 4,000 million tons of agricultural and mineral wastes generated but not collected.

Solid wastes, defined as those that are neither air-borne nor water-borne, are commonly disposed of on the land. Subsequently, many of them are transported by the environment—either di-

"... recycling will be included ... in solid waste management programs only when it is both technically and economically feasible."

rectly or through ecosystems and food chains, and after varying amounts of dilution, decay, and transformation—to diverse human, plant, animal, and inanimate receptors. This transport of materials and energy degrades environmental quality, disrupts ecosystems, and adversely affects human health and welfare. In addition, the disposal of solid waste by incineration or landfilling represents a socially and economically unacceptable drain on many nonrenewable natural resources such as minerals.

A NEW WASTE MANAGEMENT CONCEPT

The traditional approach to solid waste control has been to dispose of the refuse without worrying about such externalities as wasted resources or environmental and social costs. The current efforts to reorder waste management practices are being forced by a number of factors. For one thing, satisfactory landfill sites are becoming more difficult to locate. Also, there is an increasing concern about the air, land, and water pollution that may result from traditional disposal methods. Other factors are the progressive depletion of mineral resources and advances in the technology for recycling waste materials.

According to a new concept of solid waste management, all waste collection, transportation, processing, recycling, and disposal activities can be incorporated into an integrated system. For example, economists at Resources for the Future, a research organization, have developed a materials balance approach to the management of all residuals. This approach recognizes that the many elements—technological, social, economic, political, and institutional—that are inherent in the solid waste problem, and their complex interrelationships with the environmental quality problem, should be taken into account in any management scheme or system.

A comprehensive program of solid waste management would have multiple objectives. It would offer an integrated plan for the transport, processing, and disposal of the solid waste of a community. It would seek to minimize the production of solid waste and the cost of collecting it. It would provide for maximum recovery of recycleable materials and thereby help stem the depletion of material resources. And it would ensure minimum impact on environmental quality.

RECYCLING AS AN ELEMENT IN WASTE MANAGEMENT

Recycling of solid waste and recovery of materials should be viewed as one of the elements available for inclusion in comprehensive waste management systems. It should be recognized, however, that the fraction of waste material recovered in any particular management scheme will vary widely depending on factors inherent in the local situation. Complete recovery and recycling of all waste materials is neither technically nor economically feasible at this time. The urgency of the solid waste problem, together with existing economic and technological constraints, strongly suggest that the best approach at the present time is to focus on the recovery and reuse of specific materials.

The major reclaimable materials in

mixed municipal refuse are listed in Table 1. The approximate percentages were derived by averaging the data on samples from a number of sources. The term "mixed municipal refuse" is normally taken to mean the mixed solid materials generated in and collected from residences, commercial establishments, and institutions; most industrial wastes, larger demolition materials, and large objects such as junked cars are not included.

EXPLOITING THE SOLID WASTE STREAM

An estimate of the content of various metals in mixed municipal refuse in this country has been made by the Bureau of Mines. Using these values, and assuming a population of 200 million and a per capita waste production of five pounds per day, the total weight of metals potentially recoverable from the municipal solid waste stream can be calculated (see Table 2). The extent to which materials from the various solid waste sources are currently being recycled is illustrated graphically in Figure 1.

Table 1. MAJOR RECOVERABLE MATERIALS IN MIXED MUNICIPAL REFUSE

Material	Weight Percent (dry basis)
Paper	50
Other organic matter	28
Iron and steel	7
Nonferrous metals	2
Glass	9

RECOVERY AND RECLAMATION TECHNOLOGY

Recycling and reclamation of municipal solid waste is meaningful only in reference to individual waste materials such as glass, paper, and aluminum. The total technology available for recycling waste materials in mixed municipal refuse is best described as a spectrum of procedures extending from initial sorting and grinding (comminution) to the final industrial processes which make possible the incorporation of reclaimed materials into manufactured products.

Sorting and grinding are two processes that precede reclamation of individual materials in all the major recovery systems, yet the technology for each is seriously deficient. Mechanical sorting has been developed for some materials; no grinding equipment has been designed specifically for solid waste.

The recovery or reclaiming of waste materials is achieved by either salvage methods or conversion processes. Salvage refers to the recovery of the waste material in its original form or state. Salvageable items include, for example, glass, tin cans, and paper from mixed municipal refuse, and scrap metals from industrial solid waste. Conversion is achieved through the use of biological, chemical, or physical processes which convert or transform the material into a new product that can be recovered or reclaimed and reused.

Among the available conversion methods is composting, a familiar process that has been used for many years to produce a soil conditioner. It is

Table 2. METALS POTENTIALLY RECOVERABLE FROM MUNICIPAL SOLID WASTE

Metal	Weight Percent in Refuse (dry basis)	Potentially Recoverable (tons)	Percent of Annual U.S. Consumption
Aluminum	0.4	730,000	24
Copper	0.07	185,000	7
Zinc	0.07	185,000	12
Others		185,000	

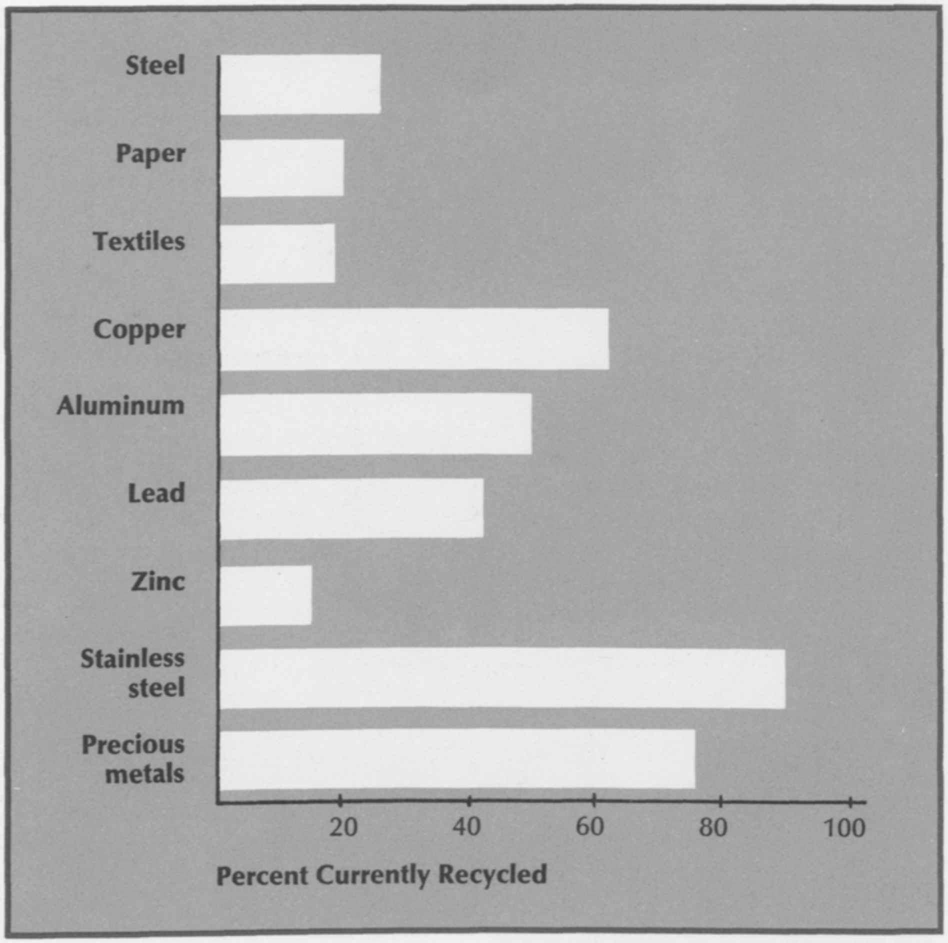


Figure 1. Recoverable waste materials currently being recycled. This graph is based on comparisons of the total amounts of individual solid waste materials technologically available for recovery and recycling with the amounts of each currently being recycled. Figures are derived from a recent study conducted by the Battelle Memorial Institute.

capable of salvaging and recycling the organic component of solid waste with minimum impact on the environment, but its economic value is not great enough to make it commercially feasible in the United States. Another conventional conversion process is incineration, which can have a useful function if the waste heat is recovered and utilized.

Several promising conversion processes are still under development. Pyrolysis, for example, is receiving considerable attention as a means of decomposing organic solid waste materials into recoverable gases, liquids, and solids. Biological fractionation processes, such as the hydrolysis of cellulose to glucose and subsequent yeast fermentation to produce alcohol, have great potential despite relatively high costs. Victor Edwards discusses aspects of conversion technology elsewhere in this issue of the *Quarterly*.

Efforts to examine and understand waste-processing systems are complicated by the recent and continuing proliferation of new processes and plants designed to recover, reclaim, recycle, or dispose of solid wastes. The possibility of using industrial technology to convert "garbage into gold" or recover "gold" from solid wastes continues to attract industry, entrepreneurs, and cities, but the processes are too diverse and complex and, in many cases, too well guarded to be readily understood and evaluated.

More interesting and promising are joint ventures, largely supported by federal funding, between cities and private organizations. Processes and plants are being developed by established firms such as Raytheon, Hercules, and Dow (see Herbert D. Doan's article in this issue of the *Quarterly*) and by newly incorporated specialty firms. These plants may prove to be the first capable of both recovery and disposal.

THE ECONOMICS OF WASTE MANAGEMENT

The recycling of individual solid waste materials found in mixed municipal refuse must be both technologically and economically feasible in order to justify it as an element in a solid waste management program. For example, the

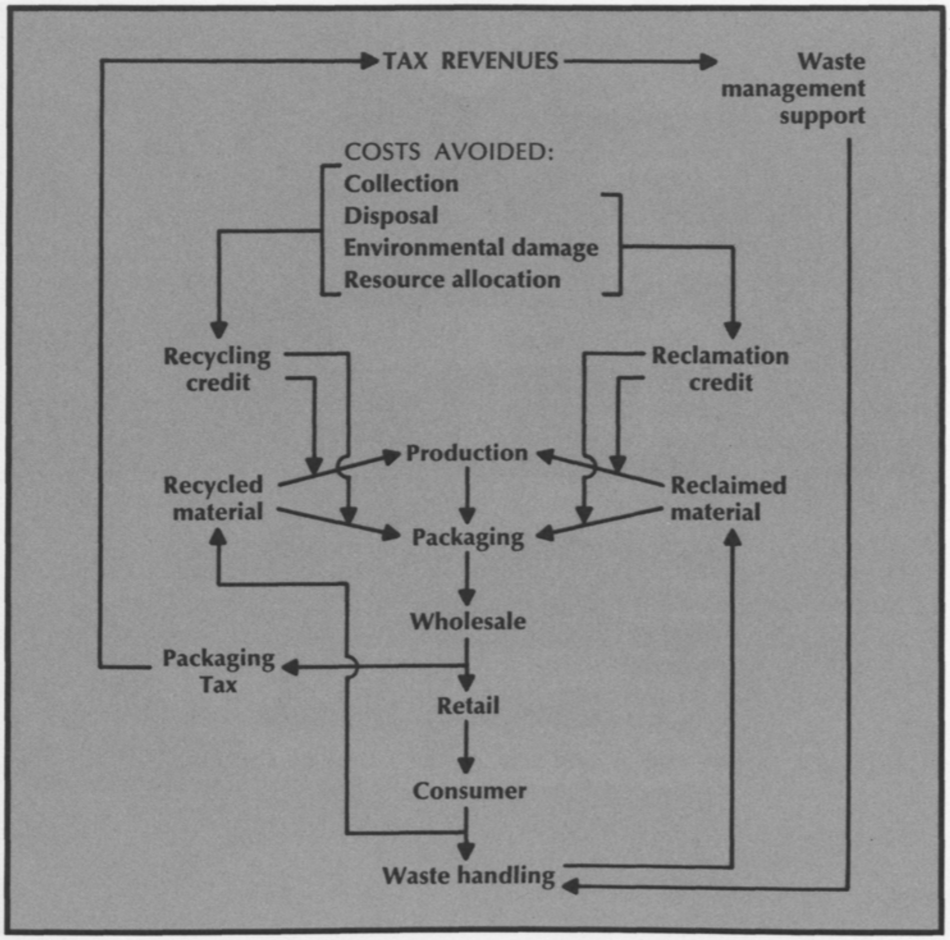


Figure 2. Operation of a proposed tax/credit system. This schematic is taken from the Cornell M.S. thesis of Fred Schwartz.

recovery and reuse of metallics, glass, and paper from municipal refuse is not economically feasible under contemporary market conditions. These wastes will be recovered and reused only as they become competitive with corresponding primary materials and as markets for them open up. Governmental actions that would improve the competitive position of secondary materials include changes in freight rates, customer specifications, depletion allowances, and zoning regulations, all of which may discriminate against reclaimed materials.

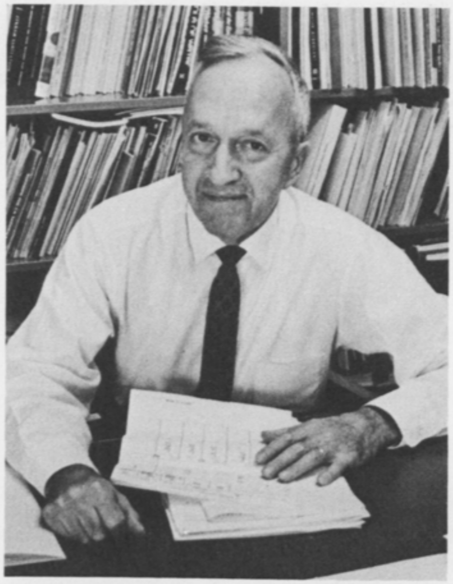
Many kinds of economic incentive and penalty programs have been suggested as mechanisms for enhancing the competitive position of reclaimed materials. In theory, the savings in disposal costs resulting from reclamation could be used as incentive payments to encourage more reclamation. Economic theory indicates that a publicly financed price-support program for reclaimed materials such as paper could stabilize prices and result in increased reclamation and a more dependable supply.

Subsidies are considered less effective, however, than changes that internalize costs. One widely proposed public action that would force internalization of external (social) costs is the taxation of solid waste producers by an amount that would be determined by the associated costs of environmental protection and environmental damage.

Some study along these lines has been carried out recently at Cornell. The potential of taxation as an element in the control of packaging wastes—a component which accounts for almost half of all municipal wastes—was explored in thesis research by Fred Schwartz, a graduate student who worked with me and Professor Richard Schramm of the Graduate School of Business and Public Administration. Schwartz proposed a cost-internalizing combination of a "packaging tax" on all packages intended for consumer use and a secondary materials credit. The combined assessment and deduction would be intended to make the tax payments equal to the environmental costs actually incurred. A schematic showing details of the proposed system is shown in Figure 2.

The tax would be levied at the wholesale level, but the cost, of course, would be passed along to the retailer and ultimately to the consumer. The tax would be based on package units, with the rate set to equal the prorated cost of collection, disposal, and environmental damage. Methodology for estimating the collection and disposal costs attributable to various forms of packaging was developed earlier in the research. Because environmental damage cannot be expressed in dollars, this was estimated as the expenditure necessary to avoid such detrimental effects as incinerator-caused air pollution, landfill-caused water pollution, unsightliness, and odors. Unit package costs computed on these bases ranged from 0.3 cents for glass to 2 cents for containerboard; corresponding costs per pound were 0.6 cents for glass and 1.3 cents for paperboard.

New approaches such as this are needed if reclamation is to succeed on a significant scale. Convincing arguments (the conservation of resources, protection of the environment, reduction in the amount of waste that must be disposed of) can be made in favor of recovery as opposed to disposal of solid waste materials, but the hard fact remains that recycling will be included as an element in solid waste management programs only when it is both technically and economically feasible. The recovery of the huge amounts of waste materials in mixed municipal refuse must wait the development and implementation of new technology and new economic incentives, as well as government actions.



Charles D. Gates, acting chairman of the Cornell Department of Environmental Engineering, is a specialist in water quality control and waste management. His current research is concerned with nitrification phenomena in natural waters and with the evaluation of waste disposal alternatives. His research and publications have dealt also with the effects of surface-active agents on water treatment processes, the disinfection of wastewaters, and deoxygenation phenomena in deep, stratified lakes.

Professor Gates has been a member of the Cornell faculty since 1947, and during his tenure at the university has served also as head of the sanitary engineering faculty and chairman of the former Department of Water Resources Engineering. He has initiated graduate training programs in the application of systems analysis to sanitary engineering and in water resource engineering, and he is currently director of the graduate training grant program in water quality control engineering.

As part of his activities in community water and wastewater planning and management, Professor Gates is currently serving as vice chairman of the Cayuga Lake Basin Planning Board. In 1971 he received a Presidential Commendation in recognition of his water pollution control activities.

He has recently worked or consulted with the New York State Department of Environmental Conservation, the Tennessee Valley Authority, and the New York State Canners and Freezers Association.

Professor Gates holds the B.A. degree from Williams College and the M.S. in sanitary engineering from Harvard University. Before coming to Cornell, he headed the Distillation Test Section of the Engineer Research and Development Laboratories in Virginia Beach, where he did research in desalination technology. Earlier he had worked as a civil engineer on flood control construction projects in Vermont and New Hampshire.

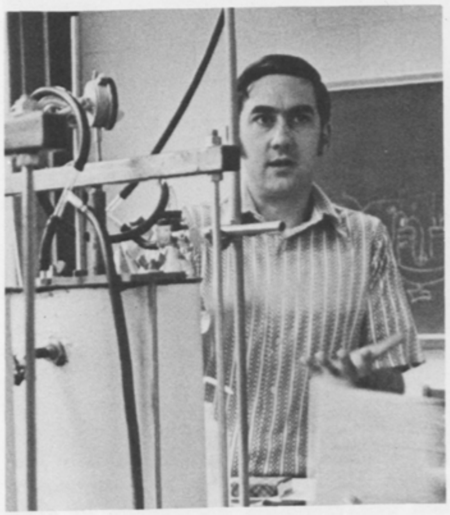
He is a member of the American Water Works Association, the Water Pollution Control Federation, the American Society for Engineering Education, Phi Beta Kappa, Chi Epsilon, and Sigma Xi.

ENGINEERING LANDFILL FOR REUSE OF SITES

by Dwight A. Sangrey

Historically, man's solution to solid waste has been to bury it. Undesired waste—municipal and agricultural refuse, industrial byproducts, strip mine or dredging spoil—was put on the least valuable land with no intention of ever using either again.

Now we see attention being focused on recovering the resources contained in solid waste. The potential worth of the aluminum, iron, glass, and other components is being explored. A less obvious consideration in the analysis of costs and benefits of resource recovery is the one resource common to all such schemes—the value of the land itself. In many cases, this is of little economic consequence; for example, a municipal landfill in a rural area would probably not have a high market value. But in other areas, particularly around large urban centers, the land value may be extremely high and may justify considerable attention to assure that the land is not lost as a resource. The key to such land conservation is research into the problems of solid waste disposal, and the application of sound technological understanding of the actual



placement and subsequent decomposition of these materials.

When properly engineered, the site of a landfill should be available for reuse within a reasonable time, perhaps several years. It is increasingly common to find such landfill areas used for recreational purposes—playgrounds, golf courses (because of settling of the land, the hazards may change from year to year), or even ski slopes.

SOLID WASTES AS LANDFILL

Another dimension of possibilities, however, involves use of the land to support buildings, highways, or other engineering works that impose very high loads on their foundations. Can solid waste landfill be designed in such a way that these structures would be adequately supported, either on the fill itself or by passing through the fill with ease and confidence?

In one respect the answer is clearly *yes.* A very common construction procedure is to create usable land in low swampy areas, or even in open water, through controlled artificial filling processes. (Of course, there may be important ecological implications to a project of this kind, and these certainly would be a factor in the overall design.) This fill is usually selected and placed so as to provide maximum site stability in the shortest possible time, and therefore certain fill materials are more desirable than others. Common solid wastes such as dredging or mining spoil, demolition debris, or construction excavation waste are frequently used; however, the question

". . . land value may be extremely high and may justify considerable attention to assure that the land is not lost as a resource."

really should be: To what degree can less desirable solid waste material be landfilled without diminishing the potential of the site for subsequent use?

A landfill site should have certain characteristics. It should be free of the nuisances of visible waste, rodents, and noxious gases. If it is to be used for any purpose other than the creation of a recreational area, the fill should be as incompressible as possible, noncorrosive to steel and concrete, and degraded to the degree that it is relatively stable biologically and chemically. All of this should be accomplished in the shortest possible time at the least possible cost.

BUILDING ON TOP OF THE TOWN DUMP

The principle of landfill reuse can be applied to the disposal of almost any kind of solid waste, but the familiar example of municipal sanitary landfill is probably a good one for the purpose of illustration.

What would go into this landfill and how might it be constructed? Any landfill has its own unique makeup of solid waste, which varies according to the living habits of the population served, the climate, the time of year, and a host of other factors. One thing that can be said of solid waste is that no two collections are likely to be identical; however, typical constituents of municipal solid waste have been identified (see Table 1). From the standpoint of engineering for reuse, some of these materials behave similarly, and can be grouped into a small number of categories:

- highly degradable organic material—garbage;
- less degradable fibrous organic material—mostly paper products;
- glass, stone, and other stable natural and man-made material;
- metallic waste—mostly iron;
- minor constituents of many kinds, which may play a major role in the subsequent performance of the fill.

Because they are compressible and degradable, materials in the first two groups are of most concern if the landfill is to be used to support some type of structure.

ENGINEERING A GOOD SANITARY LANDFILL

In a well engineered sanitary landfill, these solid wastes are placed in layers, compacted, and covered by natural earth. Among the best of modern techniques, and probably a required one if optimum use is to be made of the site, is the grinding or shredding of the refuse. This produces a much more homogeneous product, which can be placed and compacted or mixed with other materials.

Once compacted and covered, the landfill area becomes an active place, indeed, as the chemical and biological processes of degradation begin. Understanding and controlling these processes is the key to engineering a landfill. In addition to the variability of the fill composition, there is an equally complex assortment of factors that influence the chemical and biological regime. In general, one can say that the materials most changed by degradation are the organic ones. If there is available oxygen and moisture, organic materials will eventually decompose to carbon dioxide, water, and a stable residue without creating much of a problem. Unfortunately, almost all landfill organics decompose anaerobically, without sufficient oxygen, producing methane and other flammable or noxious gases, as well as liquid byproducts which may be extremely corrosive. These liquid wastes, along with other fluids produced by the landfill, make up a "leachate" which can pollute the ground or surface waters in the area of a landfill.

All of these factors must be considered in engineering a landfill for reuse. As a building foundation, a landfill containing organic material is very compressible—the raw organic material is compressible in itself and additional settlement occurs as decomposition proceeds. If a landfill site is to be used to support a building with settlement limitations, one obvious solution to the compressibility problem is to wait until the organic material has largely decomposed before beginning to build. This may require several decades if the decomposition is anaerobic.

As an alternative, a system can be designed to bring oxygen into the fill to produce aerobic conditions and thus dramatically increase the rates of decomposition. Research being done in Cornell's School of Civil and Environmental Engineering has demonstrated that passing air, or water saturated with oxygen, through decomposing solid waste can increase the rate of settlement in a municipal landfill by as much as 300 or 400 percent. Such techniques would not only allow much earlier reuse of a landfill area, but would also provide a final product—the inert stabilized refuse—with much better load-supporting characteristics.

Table 1. EAST COAST MUNICIPAL REFUSE COMPOSITION*

PHYSICAL CONSTITUENTS	WEIGHT PERCENT
Cardboard	7
Newspaper	14
Miscellaneous paper	25
Plastic film	2
Leather, molded plastics, rubber	2
Garbage	12
Grass and dirt	10
Textiles	3
Wood	7
Glass, ceramics, stones	10
Metallics	8
	100

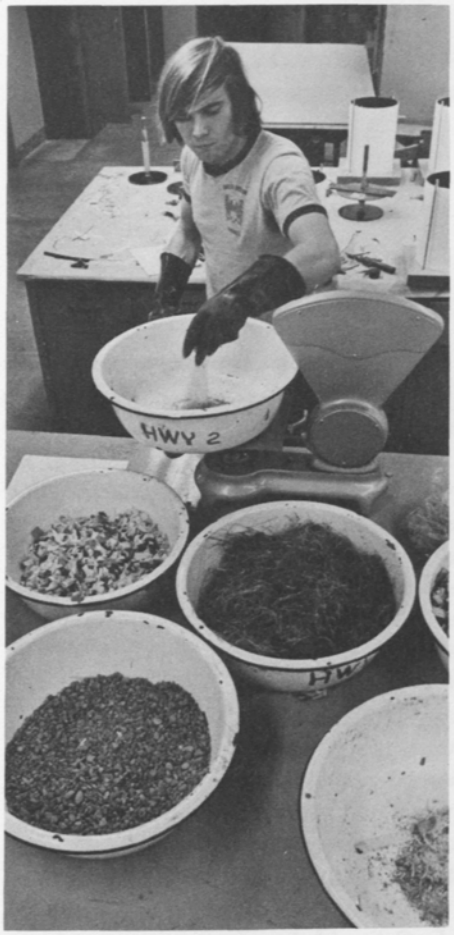
ROUGH CHEMICAL COMPOSITION	WEIGHT PERCENT
Moisture	28.0
Carbon	25.0
Hydrogen	3.3
Oxygen	21.1
Nitrogen	0.5
Sulfur	0.1
Glass, ceramics, etc.	9.3
Metals	7.2
Ash, other inserts	5.5
	100.0

*From E. R. Kaiser, U.S. Public Health Services Publication No. 1729, p. 93, 1967.

There are advantages to rapid aerobic decomposition, even if loads are not to be supported directly on the landfill. Eliminating or minimizing the production of methane, sulfides, and other gases is an example. Besides being a nuisance, these products may cause a severe safety problem by collecting in or under structures on a landfill. To make a landfill producing these gases usable, expensive systems to vent gases must be installed and special techniques to seal any buildings must be employed.

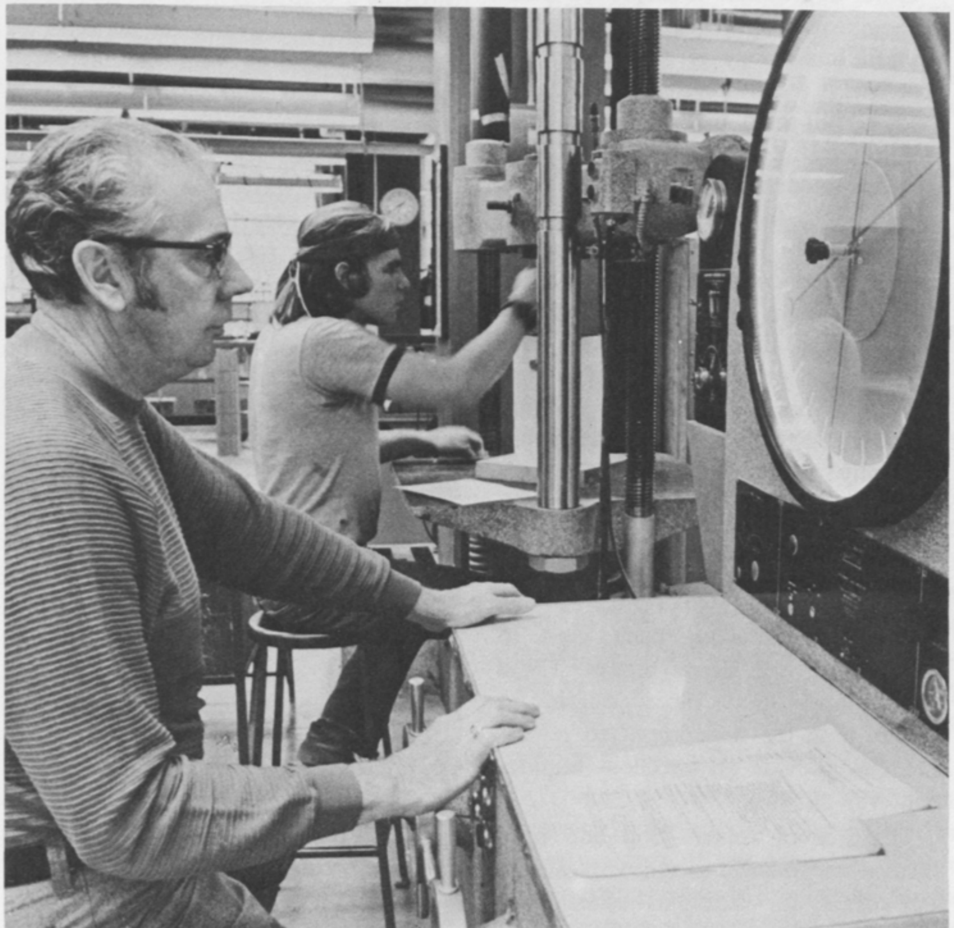
LEACHATE PRODUCTION AND CONTROL

Another major problem influenced by the landfill design is leachate production and control. A typical landfill not engineered for rapid reuse of the land can, nevertheless, be designed to minimize the amount of flowing water. This is accomplished by placing the refuse above the natural ground water and providing a seal of relatively impermeable soil on top of the fill to minimize rainfall infiltration. In spite



Left: A model mix of municipal solid refuse is prepared by John Cushing, a Master of Science degree candidate. Each of the major constituents must be collected separately, and they are carefully mixed in correct proportion.

Below: The mixed refuse is then placed in cells and compacted to simulate procedures which could be followed in a sanitary landfill. Bill Sawbridge, left, technician in the School of Civil and Environmental Engineering, works with students in this research.



of these precautions, in most relatively humid areas the landfill does produce a polluting leachate of liquids resulting from decomposition plus any infiltration.

When pollution abatement is desirable, leachate can be trapped and collected by installing drains, diversion seals, etc. The material can then be treated, often at substantial cost, just like any other liquid waste.

In a landfill engineered for reuse, a logical feature is a positive leachate control system integrated into the overall design. Some of the research currently underway at Cornell is concerned with recycling this leachate back through the refuse as part of the system for landfill reuse. If the leachate is given some minor treatment prior to being recycled, it can then be used to improve compaction efficiency and bring about a desirable change of the environment inside the landfill; for example, it can act as an oxygen carrier or can serve to decrease the concentration of chemicals that inhibit biological activity.

Other approaches to improved landfill engineering are being developed as modern technology is applied to the problem. A technique that is now being used in full-scale operations provides aeration by means of a pipe network installed underneath the landfill. Air is pumped into the network and up into the refuse. In the presence of ample oxygen, the decomposition can be aerobic rather than anaerobic, and therefore proceed more rapidly and with reduced gas problems. The pipe network can be used also for positive leachate control: the pumps can be periodically reversed in order to draw out any leachate percolating through the fill.

The compaction of municipal refuse under extremely high pressures—the Tezuka Process—has been used to form refuse into dense blocks. These are obviously much more desirable in landfill than the noncompacted refuse, and can provide an excellent foundation.

Mixtures of refuse—soil and rock excavation material mixed with municipal refuse, for example—offer possibilities for improved landfill performance. Techniques for using mixtures of domestic and agricultural wastes are being developed in a joint research project at Cornell in the School of Civil and Environmental Engineering and the Department of Agricultural Engineering.

COST FACTORS IN LAND RECLAMATION

How much does this cost? Ultimately, the decision to engineer a landfill for reuse must be economically advantageous. A direct cost analysis could provide a comparison of the additional cost of such schemes as aeration or leachate recycling with the increased value that the land would have as a result of becoming more quickly available for reuse. The costs of collection of municipal waste and of its disposal in a landfill vary tremendously, but a typical figure for service by present methods for a population of several hundred thousand might be five dollars per ton, of which 80% would be used for collection and 20% for disposal. The implementation of some of the techniques under study at Cornell would add an estimated fifty cents to one dollar per ton. For a landfill thirty feet deep, this operational improvement would increase the cost of the land by $10,000 to $15,000 an acre.

This may be prohibitive in all but urban and near-urban areas. It is not an excessive cost, however, and if the less direct benefits of resource recovery and environmental improvement are included in an assessment, landfills engineered for reuse are certainly justified in such areas of high land cost.

Dwight A. Sangrey, a specialist in soil engineering, is an associate professor of civil and environmental engineering. He joined the College faculty in 1970 after spending three years at Queen's University at Kingston, Ontario, as an assistant professor.

Professor Sangrey also studied at Cornell, earning the Ph.D. in civil engineering in 1967. He holds the B.S. degree from Lafayette College and the M.S. from the University of Massachusetts, both in civil engineering.

A registered professional engineer, he has had industrial experience with the Shell Oil Company as a field and project engineer specializing in offshore marine structures and foundations, and with H. L. Griswold Associates as a general consultant. He is a member of the American Society for Testing and Materials, and received a research award from that organization in 1969. He is a member also of the American Society of Civil Engineers, the American Society for Engineering Education, the International Society for Soil Mechanics and Foundation Engineering, and the Highway Research Board.

In his second year of teaching at Cornell Professor Sangrey received the Excellence in Teaching Award that is given annually by the Cornell Society of Engineers and Tau Beta Pi, the honorary engineering society.

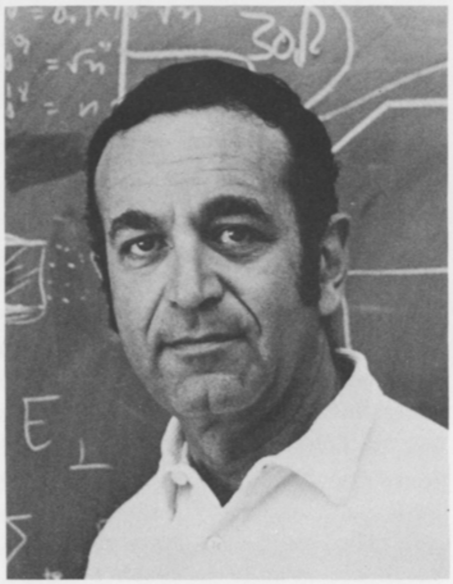
COMMENTARY

An Overview of Energy and the Environment

The critical interface between energy requirements and environmental concerns was examined early last year at a three-day Cornell Workshop on Energy and the Environment organized by the University and sponsored by the National Science Foundation. Among the more than forty leading authorities who participated was Peter L. Auer, Cornell professor of aerospace engineering and director of the Laboratory of Plasma Studies, who presented an interpretive summary address. Excerpts from this address are presented here.

Professor Auer pointed out in his remarks that the adoption of the National Environmental Protection Act of 1969, which created the Council on Environmental Quality, and the creation at about the same time of the Environmental Protection Agency, have already changed the conduct of business within the energy sector. The Cornell Workshop was planned to afford a balanced, rational view of the issues involved and thereby help in the formulation of a long-term national policy on energy.

A Summary Report of the Cornell Workshop on Energy and the Environment *includes statements from each of four panels that concentrated on different aspects of the subject, including technical ones not covered here. This report was published as a background document for the National Fuels and Energy Policy Study (Serial Number 92-23) and is available from the Government Printing Office.*



Professor Auer is spending his sabbatic leave this year conducting research on fusion power and plasma physics at Oxford University and at the Atomic Energy Research Establishment, Harwell, England. He joined the Cornell faculty in 1966 after twelve years' research experience in government and industry, and has directed the interdisciplinary Laboratory of Plasma Studies since its inception in 1969.

Energy plays a vital role in industrialized societies. It provides heat, light, and power for mechanical work. This nation, in particular, is a prodigious user of energy—at current rates it is consuming some 35 percent of the entire world's production. Our economy and life style are intimately tied to a comparatively lavish diet of energy.

There has been a growing awareness, however, that all is not well in the energy sector of the economy. Within the past few years a number of danger signals have appeared, all pointing to the fact that the abundant cheap sources of energy, taken mostly for granted in the past, are rapidly becoming less and less available. The supply of energy has not been able to keep up with the increase in demand.

Recently a new element entered the energy arena—the rapidly growing national concern for environmental quality. Little connection has been made as yet between energy shortages and environmental considerations, but we are becoming deeply concerned about these related problems. We are concerned that unabated growth in energy production and utilization might cause irreparable harm to the environment; and we are aware that measures to protect the environment may intensify the problems faced by the energy industry.

Basically, most of the difficulties in energy supply that have been experienced so far can be traced to the fact that the system is trying to operate near full capacity. This is not meant to imply that we have already approached some fundamental limitation; nothing could be further from the truth. What appears to have happened is that growth in demand has outstripped our plans for meeting it. Planning is also needed in the area of environmental quality preservation. Many of the environmental insults traceable to our reliance on energy may be either totally eliminated or appreciably controlled by modifying current practices, improving existing technologies, or developing as yet untried technologies which appear promising.

The problems confronting us today can only worsen and have potentially catastrophic results if growth in energy demand continues at its past exponential rates and appropriate remedial steps are not taken on the right time scale.

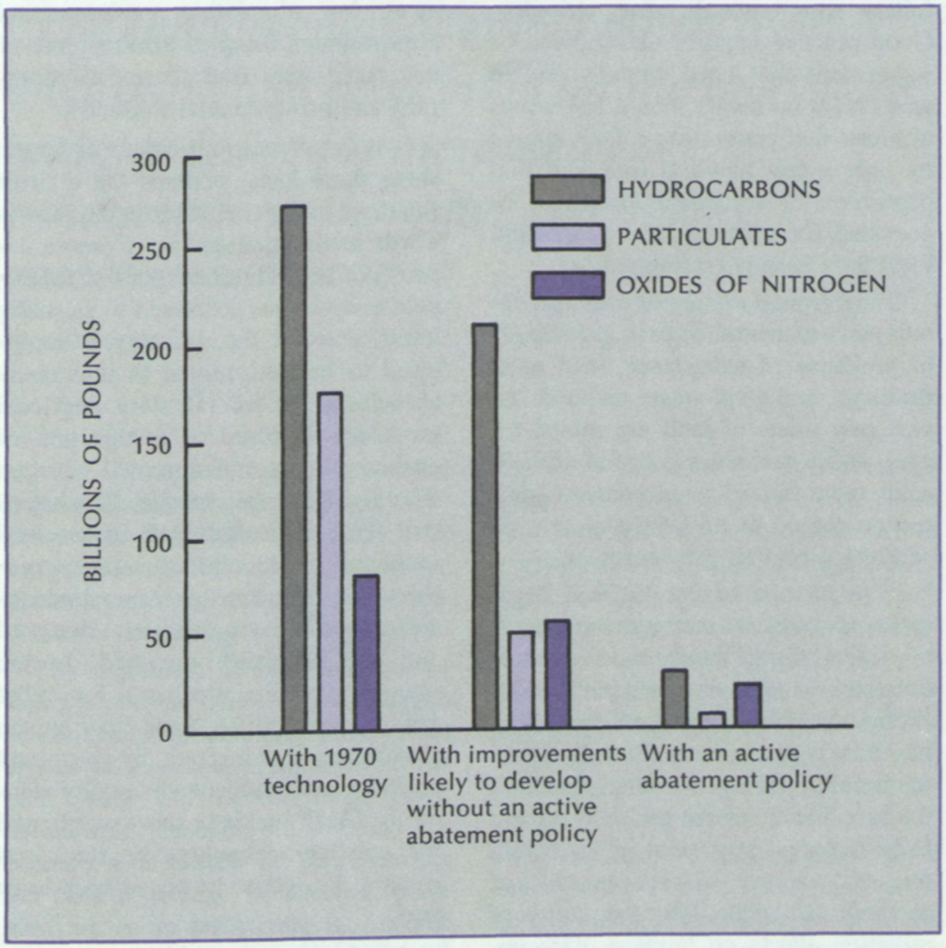
IS THERE A RATIONAL BASIS FOR PLANNING?

The fundamental dilemma posed by issues involving environmental protection on the one hand and the desire for increased energy production on the other can be largely resolved—at a cost. The question is to what extent we should attempt to balance benefit against cost. In fact, let us ask whether this is a promising start toward rational planning.

The notion that environment versus energy controversies can be settled on a purely quantitative basis by means of benefit-cost analyses is easily challengeable. What price do we attach to esthetic values? The objection to overhead transmission lines, for example, is largely esthetic. Placing large portions underground would remove the objection, but the cost would be ten to thirty times greater with present technology.

Another complicating factor is that the energy needs of a given community can have severe impact on the environment of regions far removed. Pollution and environmental damage are exportable commodities. Therefore, whose costs and whose benefits are we to balance? Even if we try to consider our entire national population and apply rules under the best of democratic principles, the problem is not necessarily contained. The Alaska pipeline controversy involves fears of oil spillage from tankers steaming between Valdez and our west coast ports; the endangered shorelines are Canadian as well as American. The use of tall smoke stacks to disperse SO_2 and reduce ground-level concentrations has been tried in England with happy results, but the prevailing wind blows from west to east and the Swedes may not be as happy with the outcome.

Environmental impact may transcend not only geographical boundaries, but also time. Certain acts committed by our generation may have delayed consequences. Depleting natural resources or inducing genetic



Projected pollution levels in the year 2000 under alternative abatement policies. These figures are based on a Workshop presentation of research conducted by Resources for the Future. In this graph, the figures are those projected under the assumptions of high population and economic growth. A general conclusion drawn in the study is that a direct attack on pollution is, at least in this century, a more promising strategy for obtaining a cleaner environment than reduction in population or economic growth.

damage by man-made radiation are but two examples. These are sources of hidden costs, so to speak; we do not bear them, but those who follow will. As we entered the nuclear age of energy production, for example, we began to accumulate radioactive wastes which for safety must be kept stored, in some cases, for centuries or even for thousands of years.

In any attempt to assign costs, it is important to distinguish between environmental damage or consequences that are permanent and those that are not. The unsightly overhead transmission lines, for example, may be removed eventually and placed underground once this becomes economically acceptable. Of far greater importance is the quality of our air, but even though this has worsened in the course of time, it has not been irreparably harmed.

Similar remarks may be made with regard to water quality, although our understanding of possible irreversible changes in complex aquatic ecological systems is still imperfect and one suspects that the time scale of adequate water quality restoration may be long. Of course, energy production and utilization is only one of many contributors to water pollution, while it is the principal source of air pollution.

Matters are qualitatively different where land is concerned. In modern times each generation has left its indelible mark on the land; whether or not this is to the benefit of succeeding generations is a matter of opinion. There are already clear indications that as natural gas and liquid hydrocarbon deposits become used up, an increasing dependence will be placed on our far more abundant coal resources, but attempts to utilize them have already led to controversy.

Coal is mined either on the surface or underground. Surface mining leaves scars on the land which make it unuseable unless adequate care is taken to reconstitute it. It has been shown elsewhere, primarily in Germany, that procedures exist whereby successful reclamation of strip-mined land can be achieved provided that proper precautions are taken and reclamation steps follow soon enough after stripping. Good practice requires that top soil be segregated; that open wounds remain as such for no longer than a few weeks at most; that restoration follow mining by only a few hundred feet; and that protection of reclaimed land area be provided for up to several years until local flora is fully established.

Underground mining of coal also entails environmental impact, principally in problems of subsidence, acid mine drainage, and solid waste disposal. As vast new tracts of land are mined for coal, policy makers will have to decide what measures of environmental protection should be adopted and at what additional cost to the consumer.

Any attempt to use rational arguments to arrive at energy-environmental trade-offs will require a credible data base as well as better public education. At the present time, for example, little is known quantitatively about the hazards of air pollutants, in spite of the fact that these are generally agreed to be the greatest present public health danger, whereas a vast amount of research has gone into the study of radiation effects on humans. This imbalance in knowledge must be redressed by expanding research on chemical pollutants.

HOW IS POLICY MADE?

Steps taken so far to improve environmental quality have sometimes been ruled by expediency and political considerations, and the results in some cases may not be in the public interest. Another consideration is that although the imposition of standards, such as automobile emission limits, can be a very effective carrot-and-stick instrument for stimulating environmental improvement, hasty or arbitrary use of this tactic may lead to undesired results and prove counterproductive.

It is possible to speculate at length along these lines; perhaps the difficult situation facing the electric utilities is worth mentioning briefly. Reserve capacity of several utilities serving metropolitan areas has decreased to alarming levels. Part of the difficulty is recognized to be institutional in that many agencies at the federal, state, and local levels are involved in certification of nuclear plants, and approval of plant sites is difficult to expedite. It is hoped that these difficulties will be resolved soon and that at the same time, measures will be taken to ensure that nuclear reactors are properly designed and can be safely operated. In the interim, though, prospects for relief are clouded, since fossil-fired steam plants are endangered by proposed emission and ambient air quality standards. Clean fuel is in short supply and the existing technology of stack gas cleanup has yet to be tested on a large scale.

Another cautionary note may be added. If restrictive discharge legislation (for example, Senate Bill 2770) becomes law, it may well prompt utilities to abandon once-through cooling of steam plants and switch to cooling towers or ponds. If this is done precipitously, certain localities may suffer from adverse climatic changes brought on by fogging and icing conditions. Any rush to adopt new technologies in imperfect states of development because of political or any other pressures can be potentially harmful. Finally, the preference of utilities to place generat-

"The fundamental dilemma posed by... environmental protection on the one hand and the desire for increased energy production on the other can be largely resolved—at a cost."

ing plants near load centers may have to be forsaken as acceptable sites become less and less available. This brings us back full circle to the earlier discussion on the economics and esthetics of long-range transmission.

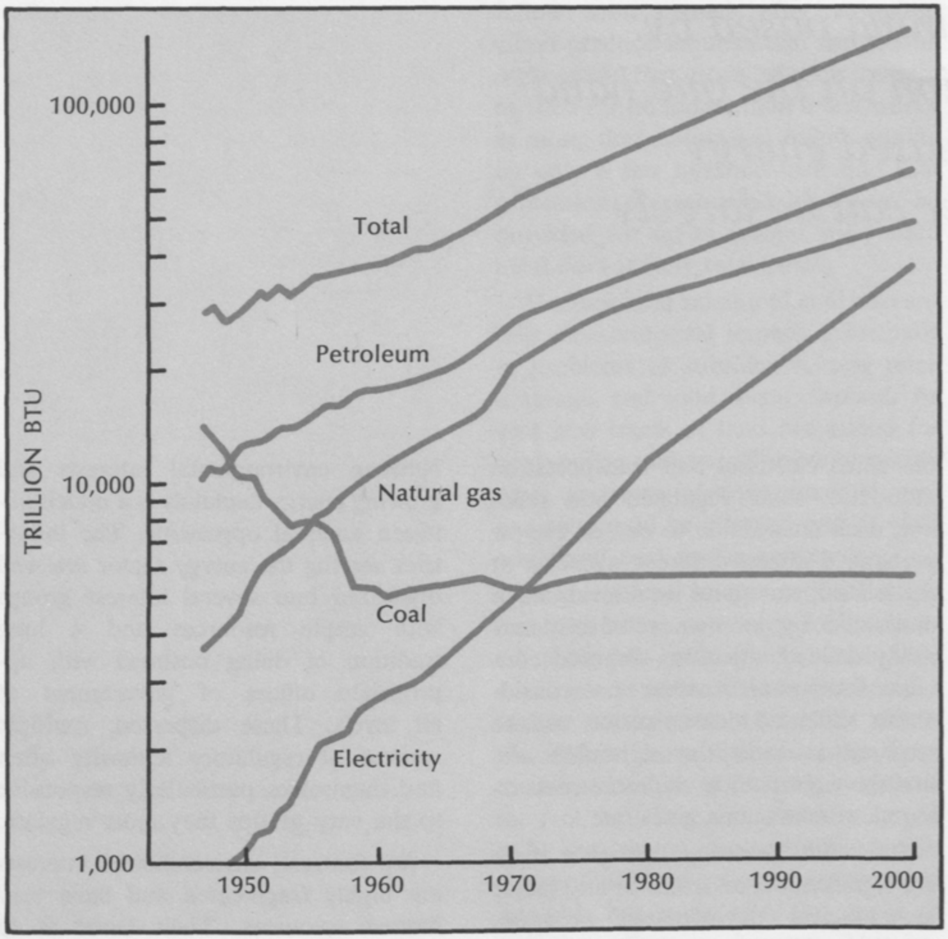
The nightmare of the environmentalists is that the horrible mathematical consequences of doubling rates in intervals of anywhere from eight to fifteen years will steadily take place decade after decade until we suddenly become asphyxiated or sink beneath our piles of garbage. By contrast, those who are more traditional in outlook argue that technological advances and the natural economic forces of the marketplace will serve to abate and ameliorate. Thus, we are promised that environmentally acceptable energy production will be provided by improved technology and that increased prices due to added cost or dwindling supplies will serve to damp the fires of growth.

One moment's reflection on the composition of the energy industry—consisting of coal mine operators, oil producers, gas producers, uranium mine operators, electric utilities, and the allied electrical and transportation industries, some regulated and some not, each answerable to one or two or perhaps a dozen different agencies at the federal, state, and local levels, each motivated by its own relatively narrowly defined objectives—should convince the casual observer that considerable skill and determination will be required to avert the nightmare and find the right path to the more reassuring view before time gives out.

It should be recognized that there are significant time scales in any major technological development program, that before it may start there must be an adequate research and development base on which to build, that after it is completed there is a time lag between planning and completion of plant construction, and that there is even a lag between finding new deposits of resources and bringing them to market. We may well ask at this juncture whether the institutional mechanisms available at present are adequate to the complex issues facing us as we try to chart a course between Scylla and Charybdis.

To some it appears that the conflict between environmental interests and growing energy demands is a match between unequal opponents. The industries serving the energy sector are well organized into several interest groups with ample resources and a long tradition of doing business with appropriate offices of government at all levels. These dispersed, multiple sources of regulatory authority often find themselves particularly responsive to the very groups they must regulate.

By contrast, environmental interests are highly fragmented and have very limited resources. Their tactic is to enlist public support through the use of the media, organization of citizen action groups, intervention in administrative proceedings, and selected use of the judicial process. The result has often been delay and apparent obstruction, yet the environmentalists will argue that this is necessary and in the long run productive. Thus, for example, delays in the construction of the Trans-Alaska Pipeline will assure that it is better designed and less likely to cause ecological havoc; similarly, the outcry on the potential failure of emergency core cooling systems has



Trends in energy consumption in the United States as considered by the panel on Growth Rate of Energy Demand at the Cornell Workshop on Energy and the Environment. The exponential changes are plotted in terms of British Thermal Units (BTU). Data for the years up to 1970 are from Bureau of Mines publications, and estimates for the years 1975 to 1985 were derived from a National Petroleum Council study. Projections beyond 1985 were made by extrapolation.

The panel indicated that the purpose of these projections was to provide a basis for discussion of possible changes and alternative plans for the future. It pointed out that many assumptions used in the forecasts are questionable: they have not taken into account, for example, effects of changing supply levels and price variations, of environmental constraints, or of unforeseen technological and social innovation. The data up to 1985 are considered fairly reliable, however, because many of the planning decisions relating to energy supply in those years have already been made, and because environmental standards and new technology are unlikely to exert a significant effect for at least a decade.

forced the AEC to make a careful review to assure that major nuclear disasters are truly as unlikely as had been predicted.

Even if the system of confrontations works in the manner expected by its practitioners, one would hope that the unnecessary delays and temporary hardships imposed on society could be eliminated through better organization, objective reasoning, and consensus planning that serves the collective interest of the public at large. Can this be accomplished under existing institutions? This question was explored in depth by one of the Workshop panels, and specific proposals were advanced. These include the creation of an overall National Energy Agency and of an ombudsman office to represent public opinion on environmental concerns. Especially emphasized was the need for substantial and immediate increases in federal support of research on energy-related problems.

ARE THERE LIMITS TO GROWTH?

Perhaps a significant question to ask at this point is: Can we support anticipated growth in energy demand without further deterioration of the environment? The past trend is well known: with the exception of coal, the consumption of which had been decreasing until the 1960s, all forms of energy, and especially electricity, have shown long-term trends of exponential growth in consumption, and we may anticipate that pressures creating greater demand for energy will intensify. Of course, as limited resources become exhausted, the growth pattern must by necessity attenuate sharply. In principle, though, our resources are not limited. Both the sun and the promise of nuclear power by means of a breeder technology or controlled fusion represent virtually inexhaustible means for supplying energy.

Roughly three-fourths of today's energy consumption in the United States is supplied by oil and natural gas, both of which are being used up faster than we can replace them from domestic sources. There is every indication that nuclear energy will play an increasingly prominent role. However, the state of the art and resources of the nuclear energy industry are such that it would be difficult to supply much more than one-half of the electrical generating capacity anticipated for the year 2000 by nuclear means. Consequently, it is more than likely that three-fourths of our total energy need will still have to be met by fossil fuel sources through the end of the century, unless unforeseen developments occur in the interim. The production of synthetic gas and oil from coal appears to be the technologically preferred solution. Our coal reserves could be adequate for possibly one to two hundred years if coal assumes a major burden of energy supply, along with nuclear fuels and breeder technology.

Unfortunately, the technology of coal conversion to environmentally acceptable fuel is largely in an embryonic state. Optimistic estimates predict that clean fuels prepared from coal will begin to contribute noticeably to energy requirements by 1985. It appears that for most of the remainder of this century we face the difficult task of expanding the availability of natural gas and oil by vigorous domestic exploration, improved recovery techniques, expensive transport from such distant sources as Alaska, and the politically complicated shift to more imports.

The essential point is that growth in supply of energy need not be limited because of some fundamental properties inherent in its production and utilization, but only because the complex series of decisions and actions required for orderly progress cannot be made on a timely basis within the framework of society as it exists. This is the essence of the view which holds that growth must be checked and moderated in order to find time for corrections to materialize. Unless actions designed to correct an imbalance in supply and reduce an adverse environmental impact are taken at the proper time and pursued with sufficient determination, there is little recourse but to moderate growth.

PRIORITIES AND RESEARCH NEEDS

Although environmental insult due to energy production and consumption is everywhere, some forms are more visible than others. A spectacular oil spill receives wide coverage from the news media and the public's attention becomes focused on miles of fouled beaches and countless oil-stained birds. There is great indignation and damage is said to be in the millions. By comparison, air pollution is estimated to cause damage to property and agriculture amounting to $10-$20 billion annually. While the oil spill is a local effect and directly harms a relatively small portion of the population, air pollution affects the entire population in varying degrees. In attacking the

". . . an increasing dependence will be placed on our far more abundant coal resources."

seemingly overwhelming environmental impact caused by society's demand for energy, some sense of priorities is desirable.

A recurring theme at the Cornell Workshop was the need for research in many areas. Air pollution was judged the single most injurious source of damage and potential health hazard; its principal source is the combustion of fossil fuels. Research and development on the clean burning of coal to eliminate sulfur oxides and other undesirable byproducts should have the highest priority.

Thermal pollution of rivers, lakes, and oceans that can result from waste heat disposal by stationary steam power plants and light water nuclear reactors is another problem that received attention. There is much to learn about the technology of the processes for heat dispersal, and research in this area must continue.

The need for coal conversion technology, which has already been discussed to some extent, was considered urgent. But even if all of our energy requirements were transferred to coal, we could readily exhaust our known proved reserves within a century. This implies that we must find ways to utilize our nuclear fuel resources to the fullest extent possible, and the development of breeders and controlled fusion reactors must be expedited.

New technologies must be encouraged. For example, prodigious quantities of energy represented by the solar flux of radiation are theoretically available. The problem, of course, is to find ways to concentrate this energy, store it, and utilize it effectively. What we need right now is some basic research on collector design and fabrication. Another possible large source of energy is geothermal power. In select regions of the country it offers immediate relief, and if the concept of using hot rocks thousands of feet beneath the earth's surface to supply energy is in fact feasible, geothermal power could have even wider application.

Research concerned with nontechnological issues is urgently required as well. For example, the inadequate state of understanding of environmental damage due to chemical contamination of the atmosphere and thermal discharge in water has been stressed.

Every time an environmental impact statement is filed or a regulatory pronouncement is issued, difficult decisions and trade-offs must be made on the basis of incomplete information. Nevertheless, one would like to guarantee that the decision is as sound as possible. To do this, we need greater insight into how to balance, for example, the threat of automakers that certain regulations will lead to so many job layoffs in Detroit against the prediction of public health officials that so many additional respiratory ailments will result unless ambient concentrations of certain chemicals are reduced beneath some level. How real are the threats and predictions and how are they related to each other?

To say that more research is needed is an understatement. Much more is required. We—a society composed of many innocent bystanders and potential victims, along with protagonists whose intentions inevitably are subject to question, plus the final arbiter—must all grow wiser together.

Faculty Publications

The following publications and conference papers by faculty members and graduate students of the Cornell College of Engineering were published or presented during May, June, and July 1972. Earlier publications inadvertently omitted from previous listings are included here with the date in parentheses. The names of Cornell personnel are in italics.

■ AGRICULTURAL ENGINEERING

Furry, R. B., Layer, J. W., and *Jorgensen, M. C.* 1972. Postharvest storage of cabbage. In *29th annual progress report, New York Farm Electrification Council*, pp. 55-69.

Gunkel, W. W. 1972. So your sprayer does a better job longer. *World Farming* 14(6):8–10.

Gunkel, W. W., Lorbeer, J. W., Kaufman, J., and Smith, H. A., Jr. 1972. New developments in artificial drying—a method for control of botrytis neck rot in bulk stored onions. In *29th annual progress report, New York Farm Electrification Council*, pp. 43–44.

Huang, T., and *Gunkel, W. W.* 1972. Theoretical and Experimental Studies of the Heating Front in a Deep Bed Hygroscopic Product. Paper read at Annual Meeting of the American Society of Agricultural Engineers, 27–30 June 1972, in Hot Springs, Arkansas.

Loehr, R. C., and *Ostrander, C. E.* 1972. *The oxidation ditch.* Agricultural Waste Management Series no. 2, Physical Sciences, Information Bulletin no. 30. Ithaca, New York: New York State College of Agriculture and Life Sciences, Cornell University.

Matthes, R. K., and *Cooke, J. R.* 1972. Solutions for Diffusion Coefficients Using La-Place Transforms. Paper read at Annual Meeting of the American Society of Agricultural Engineers, 27–30 June 1972, in Hot Springs, Arkansas.

McLendon, B. D., and *Furry, R. B.* 1972. Simulation of Integrating Sphere Evaluation of Diffuse Reflectance of Intact Biological Specimens. Paper read at Annual Meeting of the American Society of Agricultural Engineers, 27–30 June 1972, in Hot Springs, Arkansas.

Millier, W. F., and *Rehkugler, G. E.* 1972. A simulation—the effect of harvest starting date, harvesting rate and weather on the value of forage for dairy cows. *Transactions of the American Society of Agricultural Engineers* 15(3):409–13.

Prakasam, T. B. S., and *Loehr, R. C.* 1972. Microbial nitrification and denitrification in concentrated wastes. *Water Research* 6:859–69.

Scott, N. R., and *van Tienhoven, A.* 1972. Body Temperature Response of Poultry to Biogenic Amines Injected into Cerebral Ventricles. Paper read at Annual Meeting of the American Society of Agricultural Engineers, 27–30 June 1972, in Hot Springs, Arkansas.

Simpson, J. B., and *Rehkugler, G. E.* 1972. Forces and Apple Damage During Cushioned Impact. Paper read at Annual Meeting of the American Society of Agricultural Engineers, 27–30 June 1972, in Hot Springs, Arkansas.

■ APPLIED AND ENGINEERING PHYSICS

Bzura, J. J., Fessenden, T. J., *Fleischmann, H. H., Phelps, D. A., Smith, A. C.*, and *Woodall, D. M.* 1972. Trapping of high-current relativistic electron beams in a magnetic mirror trap. *Physical Review Letters* 29: 256–9.

Kurkijärvi, J., and *Webb, W. W.* 1972. Thermal Fluctuation Noise in a Superconducting Flux Detector. Paper read at 1972 Applied Superconductivity Conference, 1–3 May 1972, in Annapolis, Maryland.

Nelkin, M. 1972. Collective Motion in Simple Liquids. Paper read at conference on Molecular Dynamics of Liquids, 2–13 July 1972, in Menton, France.

Sack, H. S., and Hayes, R. R. 1972. Dielectric susceptibility of CN^- in RbCl from 1 to 26 GHz. *Physical Review B* 6:599-606.

■ CHEMICAL ENGINEERING

Anderson, J. L. 1972. Viscous Momentum Transport in Porous Membranes. Paper read at 72nd National Meeting of the American Institute of Chemical Engineers, 21–24 May 1972, in St. Louis, Missouri.

Edwards, V. H. 1972. Future directions in enzyme engineering. *Biotechnology and Bioengineering* symposium series no. 3:343–53.

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