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WHAT PRICE WIND POWER?

by Dennis G. Shepherd

The coming shortage of energy is recognized by nearly everyone, although there are differences of opinion about how serious the problem is, how soon it will have a critical impact, and what should be done to meet it. Some maintain that sound conservation practices and a change of life style would be sufficient to overcome, or at least greatly delay, its onset. But the consensus is that we will have to develop alternative sources in the near future. Conservation should and will be practiced, if only for economic reasons as fuel and power costs rise, but engineers are making great efforts to utilize new sources of energy and develop new means of providing thermal, mechanical, and electrical power.

PROBLEMS OF LOW-GRADE SOURCES AND ECONOMICS

The alternatives to the nonrenewable energy sources—fossil and nuclear fuels—are numerous and varied, as shown in the table. (This list is by no means complete: it does not include nuclear fusion, nor does it cover the myriad technological devices, such as MHD, fuel cells, and thermionic converters, that are being developed to utilize conventional energy sources in more efficient ways.) But although they are so diversified, all of these alternatives have one factor in common: a low specific energy density. We have already been smart enough to utilize the earth's high-grade energy sources in spite of the difficulties involved, such as problems associated with very high temperature and high stress. Now we have to be possibly even more clever to adapt the lower-grade sources to economically viable applications.

And therein lies the rub: the vital factor in the whole energy problem is the economic one. In most cases, the basic technological problems involved in developing energy alternatives have been solved or appear certain to be overcome, given time and the effort and expertise that we know from experience are available. For the energy sources listed in the table, the technology presents no difficulties and uncertainties comparable to those confronted in, say, the development of nuclear reactors or the landing on the moon. This is not to imply, of course, that great efforts would not be necessary to develop the alternative systems from their present state, which may be only on the scale of a laboratory test or even a feasibility study, to a large-scale, routine, operational basis.

Solar power provides a good example. The use of solar energy, both for straightforward heating and for direct conversion to electricity, has been technologically feasible for some time, but its operational use is largely controlled by economic factors. Solar energy for heating is rapidly becoming more common; the thrust of development is now toward making it more practical through reduction of overall capital cost. On the other hand, the direct conversion of solar radiation to electricity has so far been made feasible only in the special case of electrical systems for space vehicles, where cost is a secondary consideration.

A factor that must be kept in mind is that the cost of conventional fuels can only increase in the future as their availability decreases, and that although initial costs of all equipment are also likely to go higher, the economic gap between the conventional and the so-called free sources of energy is narrowing. Furthermore, the fossil fuel situation could change abruptly at any time, with a consequent shift in the relative costs of alternative energy supplies. It is necessary to continually review the economic picture, for what is too costly today may be profitable tomorrow.
THE USE OF WIND POWER: WHY AGAIN NOW?

An example of an alternative energy source that offers the possibility of significant contribution to the future energy-supply structure is the ancient one of wind power. The use of wind to substitute for human and animal effort is possibly three thousand years old. The eminent science historian Joseph Needham has suggested that wind power might have developed in the Far East from the prayer mills of the Tibetan monks in very ancient, if inexactely known, times, and it was certainly familiar to the ancient Babylonians. Windmills were important enough in medieval England to be inventoried in the Domesday Book. Their use in Europe reached a zenith by the seventeenth century, especially in the Netherlands, where they were extensively used not only for milling grain and pumping water, but for a great variety of manufacturing processes such as sawing lumber, grinding cement and paint pigments, and making paper.

Although the windmill was largely supplanted by the steam engine, the steam turbine, and the internal combustion engine, all of which were able to generate electric power as well as act as general prime movers, there continued to be modest development of wind power in the first half of this century, notably in Denmark, Germany, and Great Britain. In this country there were large numbers of small windmills throughout rural areas up to the early 1930s, when the Rural Electrification Acts allowed electric transmission lines to be brought to tens of thousands of scattered farms and the farmer was only too happy to push the button instead of waiting for the wind to blow. The largest wind turbine yet constructed in the world, the 1,250-kilowatt “windmill on Grandpa’s Knob” in Vermont, was built and successfully operated in fairly recent times, during the years 1940–1945. Blade failure from vibration fatigue led finally to abandonment of the project, not as a technical failure, but on economic grounds.

Why, then, is there effort to resuscitate wind power today? Beyond the forced stimulus of energy shortage, there is optimism that the greatly improved materials now available, the new depth of knowledge in aerodynamics, and the recent advances in vibration analysis and automatic control will contribute to technical improvements that will make wind power a significant resource. The immensely attractive advantages of wind power are that the energy is free and unlimited and there is no atmospheric, water, or thermal pollution. The only liabilities appear to be possible noise and impairment of landscape.

THE ENERGY POSSIBILITIES OF WIND TURBINES

The energy available to a wind turbine is solely that of the kinetic energy of the wind traversing the area swept by the rotor. We can get an idea of what this means in terms of design by taking a look at the basic
Figure 1. The theoretical relationship of power to the diameter of a wind turbine. The curves show the diameters required for an output of one kilowatt at various wind speeds. The lower curve represents the optimum condition, in which all the wind energy is available to the turbine. The upper curve represents the practical condition, with the turbine having a power coefficient (efficiency) of 0.4.

expression for this energy, $pAV_a^{3/2}$, where $p$ is the air density, $A$ is the swept area (represented for the familiar propeller or Dutch-type turbine, for example, by the expression $\pi d^2/4$, where $d$ is the diameter of the rotor blades), and $V_a$ is the wind speed. Since nothing can be done to control the air density, except within small limits of altitude in siting, it is apparent that the size of rotor required for a given output is determined by the local wind speed. The cubic relationship is a powerful one, and therefore accurate knowledge of average speed is highly important in designing the turbine. This relationship is shown in Figure 1.

In the Ithaca district, for example, the average wind speed is about 11 mph, and therefore, according to the Figure 1 data, a rotor diameter of about 14 feet would be adequate if all the wind energy could be converted to output power. It can be shown by simple application of momentum and energy relationships, however, that there is a limit to energy utilization and that the maximum attainable is about 60 percent of the amount available. In addition, there will be aerodynamic losses in the blading,
and transmission and electrical losses, so that the overall efficiency would be perhaps 40 percent. For the Ithaca area, then, the rotor diameter actually required would be about 22 feet. This would be halved for a wind velocity of about 17.5 mph.

Average wind velocities throughout the United States are of the order of 10 to 15 mph, with quite a bit of local variation and with sites along the coasts and at the higher elevations having higher values. It is apparent, then, that except in unusually advantageous locations such as Mt. Washington in New Hampshire, the generation of substantial amounts of power would require large wind turbines.

The evaluation of turbines is complicated, of course, by the variability of wind velocities. The criteria must include not only possible or probable output in kilowatts, but also in kilowatt-hours over a period of time. And there is the problem of how to rate the system: one can specify so much power output, but at what wind speed? The phrase "a turbine of 100-kilowatt output," for example, means little without knowledge of the wind speed for which this is attained. Curves of average wind speed versus duration have a general shape similar to the black S-shaped line in Figure 2, representing very few days of very high wind speed, a large number of days with a medium-velocity wind, and some days with a dead calm. The corresponding power-duration curve can be drawn with ordinate proportional to the cube of the speed, as shown by the light line in color.

In designing a wind-powered system, the effects of wind-speed variation must be taken into account. The system must be designed for a rated power; that is, the rotor must develop and the load absorb a certain maximum power at the corresponding rated wind speed. This rated speed is 25 to 70 percent greater than the average speed, the higher values being more usual. At wind speeds higher than the rated value, there must be a "spoiling" device (which may function similarly to the feathering of a propeller) or automatic control of the electrical system to avoid overloading. At wind speeds lower than the rated value, the power developed will be less than the rated value, and it is usual to have a "cut-in" point at which the unit is stopped at some low speed below which there is no significant useful power. The
Figure 3. A Darrieus type of wind turbine designed by Sandia Laboratories. This vertical-axis "egg beater" design features an airfoil blade bent approximately in the shape of a "troposkein," which is somewhat similar to a catenary curve. Advantages claimed for this turbine include relatively low construction cost, low-stress blading, higher speed, utilization of wind from any direction, and the ability to power an electric generator mounted at ground level.

actual output power curve then looks like the heavy colored line in Figure 2, and the total energy delivered (the product of power and duration) is represented by the shaded area under this line.

The selection of a certain rated velocity and power output entails some loss of available energy, and this may be significant owing to the cube law of power. To take advantage of this "lost" energy, however, it would be necessary to use a system of larger size and capacity, and hence greater first cost. Optimizing a design requires knowledge of the particular wind speed duration and careful analysis of costs.

Another problem that may arise is what to do when the wind stops blowing. Depending on the nature of the intended application, it may be necessary to provide for energy storage to compensate for low-power and zero-power intervals.

ADVANTAGES AND PROBLEMS OF THE DIFFERENT TYPES OF WIND TURBINES

It is useful to classify wind turbines into types, and two such major classifications are (1) lift or drag types, and (2) horizontal- or vertical-axis types.

The archetypal machine, the Dutch windmill or the multi-bladed farm turbine, depends on the lift force on a blade, a force that is perpendicular to the mean direction of the air flow. This is analogous to the force on an aircraft wing or, more directly, to that on an aircraft propeller, except that in the latter case the propeller is moving the air and torque is supplied; hence this kind of turbine is often called the propeller type. All turbines have a drag component which reduces output and efficiency, but those in the drag classification employ it as the prime means of producing useful torque. In drag types, this torque is produced mainly by the resistance to the air given by a surface moving generally in the direction of the airflow, as with a paddle wheel. In many turbines, the action is a combination of lift and drag. In general, the lift type is considerably more efficient.

The propeller type of wind turbine is the major, if not the only example of those in the horizontal-axis classification. Vertical-axis types are legion, and it is said that it is not possible to think of a really new design—they have all been invented years ago. Vertical-axis machines have several advantages. One of the major ones is that the generator can be on or close to the ground instead of at the top of a tower, and so the tower structure can be lighter and simpler or possibly can be replaced by guy wires. Another major benefit is that most turbines with a vertical axis can operate with wind from any direction. Turbines of the horizontal-axis propeller type must have their plane of rotation normal to the wind direction, and this requires a means of swinging the rotor into the wind and, in all but small units, a device to control the rate of swing. Also, tower structure can interfere with the airflow for propeller turbines and, in particular, can cause vibrational stresses. (That this problem is still with us is shown by the trouble with the NASA 100-kilowatt test unit that was started up in September, 1975. As reported by the press, vibration problems arose in the blades as a result of disturbances caused by the airflow over the staircase inside the tower; considerable modification of the internal structure was required).

EFFICIENCY AND ROTATIONAL SPEED AS CRITERIA IN WIND TURBINE DESIGN

Vertical-axis machines have two great disadvantages, however: their efficiency (or coefficient of performance, as it is usually called) is generally much less than that of the propeller type, and their rotational speed for optimum operation is much lower. Rotational speed is especially important for electricity generation; with vertical-axis turbines, a considerable speed-increasing transmission is necessary. The ratio of rotor tip speed to wind speed is typically 5/1 or 6/1 for propeller types, whereas for vertical-axis types the ratio cannot exceed unity.

A vertical-axis turbine that looks promising is the Darrieus or "eggbeater" type, diagrammed in Figure 3, which was originally proposed by the French inventor Darrieus some forty-five years ago. In recent
years, the design has been investigated by the National Research Council of Canada, and it is now receiving considerable attention in several places in the United States, notably at the Sandia Laboratories in Albuquerque. The Darrieus is a lift type of turbine, with an airfoil blade designed to give minimum bending stress in rotation. Its advantages are its prospects for good efficiency, its light weight (and hence lower cost), and its high speed. It seems adaptable to many locations—the top of buildings, for example—and can be esthetically satisfying.

APPLYING WIND ENERGY FOR USEFUL POWER

Because of the fundamentally low specific energy of the wind, developers are directing their efforts toward concentrating the energy, much as developers of solar energy units are attempting to concentrate radiation. The basic idea is to use the higher kinetic energy of vortices, produced either naturally by flow around certain shapes (for example, tips of airfoils or delta wings) or artificially by causing the wind to flow through tangential ducts (see Figure 4). Obviously, the total energy available is not increased, but what is available is directed into a smaller cross-sectional area, allowing much smaller rotors for equivalent power.

The crucial question is how wind energy can best be utilized to provide an economic alternative to the sources currently available. It must be noted at the outset that some particular difficulties are encountered in the direct generation of electric power. These are (1) the generally low rotational speed, (2) the continually varying wind speed, and (3) the lack of any usable power
when the wind speed is too low or there is a dead calm. To meet these difficulties, a variable-speed transmission or blade configuration (variable-pitch blades) is needed, and either a storage system or a source of stand-by power. These provisions can be complex and in any case are costly. Simpler generating equipment is required for generating DC power, but this has the disadvantage of being limited to certain uses or requiring an inverter.

For the near future, it appears certain that wind turbine units designed to produce electrical power will have to be of the horizontal-axis, propeller type—the "conventional" design—and the output of a single unit is unlikely to exceed 1,500 to 2,000 kilowatts.

PROPOSALS FOR WIND POWER AS A MAJOR ENERGY SOURCE

Very large schemes for wind-power facilities capable of providing for a substantial portion—perhaps the major part—of the nation’s energy needs have been proposed, however. Systems such as those suggested by William E. Heronemus of the University of Massachusetts would feature a great number of multi-unit structures spaced a few hundred feet apart on land or water (sea or lake) that would yield power in the hundreds of megawatts. This may be technically feasible and the cost quoted would be competitive, but such windpower "parks" seem problematical unless future construction of nuclear plants is halted for reasons of safety or eventual pollution by waste products. Drawbacks of such windmill parks are that the surface area required for an output equivalent to that of even one nuclear reactor plant would be enormous, and such a system would probably be very objectionable in its effect on landscape or on navigation if located off-shore.

The Energy Research and Development Administration (ERDA) has had a program for Wind Energy Conversion Systems (WECS) that has produced several conceptual design studies, a parametric analysis of selected concepts, and a preliminary design based on selected optimized concepts. It has recently been announced that a contract has been let to Hamilton Standard and General Electric for construction of a 1,500-kilowatt WECS. ERDA is also sponsoring siting studies and investigations of innovative units. It still remains to test the use of WECS in large electrical networks, but several dozen public utilities have expressed interest in supplying facilities when the time comes. So it would seem as though the wind turbine concept should be receiving a thorough test in the next few years.

APPLICATIONS OF SMALL WIND ENERGY CONVERSION SYSTEMS

There is a place for small-to-medium WECS for special applications, such as at sites remote from transport for fuel, or where electric transmission would be too expensive. An example is the proposed installation on Block Island, Rhode Island, for the New England Telephone Company; this facility is expected to produce about 22,000 kilowatt-hours per year, enough to operate the telephone service and supply power to company buildings. Many other applications suggest themselves—for lightships, drilling platforms, warning lights on hills and mountains, and so forth.

Small units, say 15 kilowatts and under, are mostly the concern of individual entrepreneurs, and there are many of these. Wind power has caught the imagination of inventors and environmental enthusiasts. But established suppliers are few, low-power units are expensive, and the heralded cheap construction of the enthusiastic amateur has yet to prove itself.
CONVERSION TO THERMAL ENERGY: A FEASIBLE WAY OF USING WIND TURBINES

It seems to me that the best application of wind turbines is not in the generation of electricity for light and power, but in converting the mechanical power into thermal energy, either directly by paddlewheel action in water or air in an enclosed, insulated container, or by using the simplest form of generator, with which controlled voltage and current are not essential and the output goes to resistance heating. Such a scheme largely solves the storage problem, and all power produced can be used. Even very small units would be useful, as the wind energy could be used simply as preheating for water or space-heating, with conventional power units supplying the remainder.

Another application requiring energy only as heat is that of absorption refrigeration. This has received much attention, as it combines well with solar heating, but although the technology is of long standing, it has always had disadvantages as compared with systems based on mechanical compression. If small units for use with air-conditioning systems could be made

A wind-operated, voltage-regulated generator capable of supplying a thousand watts of electricity on a breezy day was designed last spring by five Master of Engineering students in electrical engineering and mechanical engineering. Mark Adamiak, who received the M.Eng. (Electrical) degree in May, is shown with the device, which was mounted on the roof of Phillips Hall. The other collaborators were Robert Carter, William Dougherty, and Jacques Charles in mechanical engineering, and James Bolognue in electrical engineering.

The device is essentially a combination of the Savonius and Darrieus windmills, with the added feature of a voltage regulator that makes the generator suitable for direct use in a household circuit. The Savonius rotor gets the device started and two Darrieus blades are the main source of power. The regulator is designed to cut off current when it falls below a specified level. The designers estimate that the device can supply 1,000 watts of electricity with a wind at 22.5 miles per hour; the average output in the Ithaca area would be 3,000 to 4,000 kilowatt-hours a year. Cost of the materials for the prototype was about $750, including the price of the most expensive part, the generator, which the group purchased used for $350. Batteries for electricity storage would, of course, increase the cost.

Help in supporting the project was provided by Adamiak's father, an electrical contractor from Roxbury, New York. The Adamiaks plan to install at least one of the windmills on their farm, and Mark believes that commercial production is a good possibility.
viable and reasonably economical, however, there could be a fair market, and their use would be of particular help in relieving peak loads of the utility systems.

Although probably representing a small market, the ancient use of windmills for pumping might be revived, especially for applications that are nonessential or marginally so, such as ornamental ponds and fountains. Some irrigation or drainage pumping might also be returned to wind power. These considerations do not seem fanciful when one recalls the discontinuance of many such energy-consuming devices during the "energy crisis" of not too long ago.

Finally, there is the prospect of wind power for use in parts of the world where electrical transmission is difficult or economically impossible. The Caribbean, for example, is such a region, and there are a large number of islands throughout the rest of the world. Developing countries represent a special challenge. Very simple WECS that could be constructed of local materials with local industry are needed, and efforts are being made in several parts of the globe to foster such development. Such units would fit the "small is beautiful" creed.

ACTIVITY AT CORNELL IN WIND-POWER RESEARCH

At Cornell there is interest in wind power in several areas. Groups in mechanical engineering and in electrical engineering, for example, cooperated last year in a student project to build a Darrieus-type rotor with electrical generator and control gear. Professor Robert L. Wehe and I were advisers from the mechanical engineering faculty and Professor William H. Erickson was the electrical engineering faculty sponsor. This year the performance of small-scale models is being studied in the Sibley School of Mechanical and Aerospace Engineering with use of a wind tunnel to simulate wind conditions. Difficulties arise with such small units owing to the very low output, the effects of mechanical friction, and the scaling effect itself (Reynold's number), but wind-tunnel testing does allow comparative information on performance to be obtained much more simply than is possible with field testing. It is planned to experiment with different versions of vertical axis machines and the results should be useful for assessing new designs, materials, and construction methods.

A short-term project this summer and fall under Professor Simpson Linke of the School of Electrical Engineering was a study of the costs of transmission and distribution of electrical power from wind turbines. This investigation, part of a Brookhaven National Laboratory Regional Energy Studies Program, sponsored by ERDA, considered three possible types of large-scale installations: a wind farm of 500-megawatt output comprising units of 1.5 megawatts spread over five to ten square miles of flat land; clusters of three 1.5 megawatt units situated on mountain peaks; and a line of ten units spaced two thousand feet apart along a ridge. The overall study should provide a realistic picture of the effects of siting on transmission costs for wind-power electricity systems.

An ERDA-sponsored project on the direct conversion of wind-turbine power to thermal energy by churning action is being investigated in the Department of Agricultural Engineering under the direction of Professor Donald R. Price and Dr. Stanley A. Weeks. The proposed application is to heat water for a dairy farm. A conventional propeller-type turbine with a rotor diameter of about 10 meters will be tested.

These few examples of Cornell projects serve to demonstrate how many pos-
sibilities there are to pursue in developing wind power as a source of energy, and how many interesting problems there are to solve. The important thing to recognize is that the major thrust in work on alternative energy systems must be in the direction of not only assessing and reducing the total dollar cost over a period of time, but of maximizing the net useful energy production, taking into account that used in initial manufacture and ongoing maintenance. The technology is available or attainable; the feasibility of such systems depends primarily on these two factors.

Dennis G. Shepherd, a member of the Cornell mechanical engineering faculty for twenty-eight years, received a chair appointment as the John Edson Sweet Professor of Engineering in October. During his years at the University he has served as head of the Department of Thermal Engineering and as director of the Sibley School of Mechanical Engineering (from 1965 to 1972). At the present time he is supervising the professional master's degree program in mechanical engineering.

A specialist in thermal power, fluid dynamics, and turbomachinery, Shepherd has had a special interest in alternative energy sources, particularly wind power, for the past several years. He has made a study of a peak-load system using off-peak electric power to make and store liquid air, and last spring, during a sabbatic leave at University College in Cardiff, Wales, he was concerned with the analysis and design of power plants utilizing geothermal energy.

Shepherd received his professional education at the University of Michigan, which granted him B.S. degrees in engineering physics and in engineering mathematics in 1934. After graduation and before coming to Cornell, he participated in the pioneering research and development work on turbojet engines and gas turbines in his native England and in Canada. He is active in professional organizations and has served as a consultant to a number of industrial firms.

He has published five books and numerous chapters and papers on the subjects of turbomachinery, gas turbines, fluid mechanics, and aerospace propulsion. His honors include the 1976 Worcester Reed Warner Medal given by the American Society of Mechanical Engineers ''for noteworthy contributions to the permanent literature of engineering,' and he has held a Guggenheim fellowship and a senior visiting fellowship of the Organization for European Economic Cooperation. At Cornell he has twice been the recipient of the annual Tau Beta Pi—Cornell Society of Engineers Excellence in Teaching Award.
Suppose one wished to have a log cabin. One method of approach would be to fell trees and cut and notch the logs with a hand ax. An alternative would be to buy a prefabricated log cabin and have it assembled on the site. If one happens to live in the vicinity of Ithaca, New York, a third possibility now exists: An enterprising young college graduate and his crew will build a log cabin to your specifications, using chain saws to cut and notch the logs.

These three methods represent three levels of technology. Building with the hand ax is low (and primitive) technology; assembling the prefabricated unit requires the existence of a high-technology factory; and custom building with the sophisticated power saw falls somewhere in between, in a range that has come to be characterized as intermediate technology.

The term intermediate technology has become a familiar one. It was first introduced in 1973 by E. F. Schumacher, a British economist, in his book Small Is Beautiful. More recently the general public has been made aware of the concept, probably because of publicity in Newsweek and the showing in the Nova series on educational television of a BBC film, The Other Way, and because such well-known people as Elliot Richardson, Ralph Nader, and Governor Edmund G. Brown, Jr., of California have endorsed the concept.

The name is misleading, however. It invites the question: Intermediate with respect to what? And since technology has evolved chronologically from a primitive level through intermediate stages to advanced technology, the implication may seem to be that advocates of intermediate technology are recommending a return to antiquated methods. This is far from true. As Schumacher is careful to explain, intermediate technology is defined as being intermediate with respect to low and high technology where the level of technology is measured not by chronology or sophistication but by capitalization per worker (Schumacher calls it equipment cost per workplace). Accordingly, intermediate technology is a rather precise economic concept.

This is illustrated in the log cabin-building alternatives. The low-technology hand ax is a very simple and inexpensive tool. The prefabricated cabin was made in a high-technology (capital-intensive) factory. And the chain saw establishes the third alternative as intermediate technology, since the cost of the equipment is lower than that of the factory but higher than that of the ax.

Another example, which illustrates that intermediate technology does not imply a return to older methods, is the development of the internal combustion engine in the nineteenth century. The Industrial Revolution came to England in two distinct stages. In the first, textile manufacturing moved out of the human-powered cottage to the small shop with a ten-horsepower undershot water wheel. These little shops were strung out along swiftly moving streams in the English countryside. They were not the “dark satanic mills” of Blake’s lament. Those came in the second stage, when the industry moved to crowded, smoky cities to exploit the one hundred or more horsepower made available by Boulton and Watt steam engines. The steam engine, requiring as it did a furnace, boiler, condenser, pumps, and other accessories, was a capital-intensive power source. The hope of many was that the development of the internal combustion engine would provide a cheap, self-contained power source. Thus, although the internal combustion engine was newer, more advanced, and more sophisticated, it was properly viewed as an intermediate-
Dave Hunsberger (left), local log-cabin builder, uses modern equipment in his craft, which he sees as a scientific way of returning to nature.

technology power source when compared to the capital-intensive (high-technology) complete steam-power plant.

Intermediate technology, then, is not inferior, old-fashioned, or unsophisticated. To be sure, low technology tends to be primitive and of such low productivity that it does not enable a society to rise above mere subsistence. High technology, on the other hand, is often so highly capitalized that it tends to deny participation in the production process to all but giant corporations. Intermediate technology is, of course, somewhere in between. It is easy to see that intermediate technology is better in most respects than low technology; there are relatively few proponents of low technology. But in modern industrial societies, the assumption has been that high technology is superior to intermediate technology. This is the key question. Advocates of the concept claim that intermediate technology is the appropriate level for many functions that are now performed by high technology.

THE HUMAN ASPECTS OF AN ECONOMIC CONCEPT

Intermediate technology has a number of secondary characteristics that people have come to identify with it. It is less energy-intensive than high technology and has less environmental impact. It tends to be small in size, to be regional or local in scope, and to use indigenous materials as much as possible. None of these, however, is an essential or identifying characteristic; intermediate technology is identified by its intermediate level of capitalization. Members of the United States Congress, increasingly aware of the concept, call it "light-capital technology."

But regardless of its economic definition, many find intermediate technology attractive because of its secondary characteristics, particularly those which change the nature of production to make it a more humanitarian process. These characteristics help restore a number of valuable aspects of industry and agriculture that have been lost in the development of modern high technology. They include pride of workmanship, a sense of self-worth, a feeling that one has some control of his own life, and a general feeling of human...
importance in a world increasingly dominated by machines. Ivan Illich expresses this concept as the "convivial community" in his book *Tools for Conviviality*. (Illich uses the word tools in the very general sense of technology and conviviality in the sense of congeniality.) Environmentalists commonly speak of "soft technology" or "living lightly on the land" to emphasize the gentle environmental impact of intermediate technology. Schumacher used the phrase "economics as if people mattered" as the subtitle of his book and also uses the expression "technology with a human face."

ENTERPRISES TOO EXPENSIVE FOR THE PRIVATE SECTOR

The term appropriate technology is often used in recognition of the fact that intermediate technology is not always the appropriate level. The quarterly journal published by Schumacher's Intermediate Technology Development Group is, in fact, entitled *Appropriate Technology*. The problem here is that clarifying debate is avoided—who would advocate using inappropriate technology?

The fact is that technology in the United States has become so capital-intensive that some of it is out of reach of even the richest corporations. Examples are nuclear power, satellite communication systems, SST proposals, and shale-oil and many other alternative energy proposals. All of these require federal subsidies because they are too expensive to be undertaken by private enterprise. When General Motors brings out a significant model change, such as the Vega or the Chevette, it requires a capital investment of about one-half billion dollars. How much would it cost for a newly formed company to enter the automotive industry? It is virtually an impossibility. Even the Chrysler Corporation, in its newly announced policy, admits that it can no longer afford to make radical changes in its cars. This is the dead end of super-high technology.

It should be noted that the automotive industry was an intermediate-technology industry early in the century. Capitalization was so low that almost any entrepreneur could go into the business and many did: more than fifteen hundred such enterprises were started (and failed) by World War I. Cars were produced by carriage builders in the United States in simple woodworking shops; wheels, engines, and other parts were purchased and assembled in the manufacturer's garage (the famous British MG symbol stands for Morris' Garage). Henry Ford, with his moving assembly line, transformed the industry into a high technology.

Intermediate technology is indeed the appropriate technology for much of what modern industrial societies achieve by high technology. In his book *The Closing Circle*, Barry Commoner describes many of the shifts from intermediate technology (although he does not use the term) to high technology that the twentieth century has witnessed. These shifts have been from labor-intensive to capital-intensive production, from low environmental impact to high impact, from modest energy requirements to energy-intensive processes, and from things that people can do for themselves in local industries to what only giant corporations can do. Examples of these shifts are from iron and wood as basic materials to aluminum and plastics, from natural fibers to synthetic fibers, from soap to detergents, and from natural foods to highly processed, so-called convenience foods—which are artificially colored, flavored, and preserved, as well as oversweetened, overpriced, and often rendered carcinogenic.
“Intermediate technology is indeed the appropriate technology for much of what modern industrial societies achieve by high technology.”

FOSSIL-FUEL FARMING AND THE BLIGHTING OF AGRICULTURE

Agriculture is the paradigm example of intermediate technology; it is the origin of the concept and the area where it enjoys the widest acceptance.

The technological level of agriculture may be classified in a chronological sense. Primitive or low technology was prevalent almost everywhere until the Middle Ages. It was characterized by scratch plowing, slash-and-burn or shifting cultivation, fall planting of grains and two-field rotation, and the use of human or ox power. The revolution in agriculture in Northern Europe in the Middle Ages introduced the modern wheeled and sophisticated iron plow, the spring planting of legumes in three-field rotation with the fall planting of grains, and the use of farm animals with the growing of crops and the use of organic fertilizers. This was intermediate technology. Modern high-technology agriculture is characterized by gigantic size, a single crop, no rotation, artificial fertilizers, herbicides, pesticides, and diesel-powered machinery (sometimes it is called fossil-fuel farming). It is the abandonment of cooperation with nature and a declaration of war against her.

When Norman Borlaug won the Nobel Peace Prize in 1970 for his major role in the green revolution, the chairman of the award committee said, “We do not any longer have to be pessimistic about the economic future of developing countries.” By introducing new strains of wheat and other grains which respond primarily to capital-intensive fossil-fuel farming, proponents of the green revolution were able to achieve dramatic improvement in food production. But they also made agriculture inaccessible to the poor, who then flocked to the cities to seek nonexistent jobs. The recent increase in oil prices has made the problem even worse. It is now generally recognized that intermediate technology would have been a better substitute for low technology than high technology has proved to be. It would have achieved a similar dramatic increase in yield with far less economic and social disruption. Modern organic farming actually yields a higher output per acre for some crops (although a lower output per man) than fossil-fuel farming. It makes no sense to introduce capital-intensive technology in the Third World, where there is a shortage of capital and a surplus of labor. Even in the United States there exists a shortage of capital (reflected in high interest rates) and a surplus of labor (witnessed by greater unemployment than in most other industrialized nations). Why are we in the United States so proud of the fact that only three and one-half percent of the work force is engaged in agriculture when seven and one-half percent is doing nothing at all?

It is in agriculture, also, that the grotesque extremes of high technology are observed. Agriculture is inherently and traditionally less capital-intensive than manufacturing, yet a Kansas wheat field, for example, has lost nearly all of the characteristics of the human, earthy activity of man in contact with nature that has been associated with agriculture since its origin. Agribusiness has transformed it into an outdoor factory for turning fossil fuel into grain. The production of beef is no longer associated with the grazing of animals and their husbandry in a natural habitat. Beef cattle are now inhumanely reduced to mere meat machines, standing in crowded feed-lots surrounded by their own excrement. The ultimate atrocity may be veal production in which calves are
right: Area residents sell produce, prepared foods, and crafts at a farmers' market in Ithaca, New York, where Cornell is located.

deliberately fed an iron-deficient diet so that they will become anemic and their flesh will be a marketable light color. They are also restrained from moving to maximize their weight gain and to prevent muscle development that would make their flesh less tender. By the time of slaughter they are often too weak to stand.

**ENERGY USE, LIFE-STYLE, AND LEVEL OF TECHNOLOGY**

It is mainly agriculture and manufacturing that are simply and obviously related to the primary and identifying characteristic of technology level, which is the intensity of capitalization. Other areas of technology—those that are often the favorite subjects of proponents of intermediate technology—are more readily associated with secondary characteristics such as size, degree of centralization, degree of conviviality, and environmental impact.

The subject of energy generation, for example, is best classified according to these secondary characteristics. Steam electric-generating stations, whether they be nuclear or fossil-fueled, are logically very large, centralized, and nonconvivial. The economies of scale are real and compelling and the specialization and expertise
The home-style solar, wind, and water-powered devices to supply "free" energy that are showing up all around the country are good examples of intermediate technology, since they require capitalization, but at a level modest enough to be accessible to individuals. These installations are built mostly by people who have an interest in saving money or the environment or both and who are intrigued by the challenge of utilizing whatever potential for producing energy their particular piece of property offers.

Right: An Ithaca resident who has been in the heating business for forty years recently constructed a backyard solar collector for heating hot water. Elwood Glover estimates that the unit will pay for itself in five to seven years. In the system, heat collected by the solar panels is conducted to fluid circulating inside adjacent copper tubing; the tubing is run to the basement of the house where it coils around a fresh-water pipe and heats the water by conduction; and the heated water is stored in a tank for household use. Back-up electrical heating is available if needed.

Left: An old mill site near Cornell is being converted to a modern hydroelectric plant by Keith Boncek, a computer operator at the University. A student in the Master of Engineering (Electrical) degree program, Michael Massina, is working on the generating system as his design project under the supervision of Professor Simpson Linke. Massina’s task will be to design an inverter to convert DC current generated by the turbine to AC current for household use. When this picture was taken in late September, workers and local enthusiasts were getting ready to install pipe to conduct water from below the dam to a turbine near the old mill house. Boncek would like to hook his system into the local utility’s lines and thereby sell power when he generates an excess, although such a scheme entails difficult technical and other problems. In one way or another, Boncek says, the plant will be used to provide heating and electrical power.

demanded by their manufacture, operation, and maintenance make them unsuitable as informal neighborhood projects. Wind and direct solar energy, on the other hand, are inherently decentralized or dispersed, available to anyone, and hence convivial in nature and small in scale.

In spite of this, the conventional wisdom of bigger is better has resulted in proposals to gather this dispersed energy to a central point on a vast scale and then redistribute it. One such plan is to exploit the energy in the offshore winds of the Eastern Seaboard. It postulates eighty-three wind units, each of which would consist of a central core and 165 orbital wind stations distributed in a circle three and one-half miles in diameter. The electric power would be fed to the central core, where it would be converted from AC to DC and used to distill sea water and then dissociate it. The hydrogen would finally be piped ashore as a source of energy. Another such plan would collect solar energy in space and transmit it as microwave energy to the earth. It proposes a twenty-five-square-mile collector, in synchronous orbit, covered with silicon solar
cells. The microwave antenna would be one square mile in area and the receiving antenna thirty-six square miles. These distortions of the inherently small may be as illogical and grotesque as the concept of a congenial neighborhood nuclear power plant. Bigger is not always better—nor is small always beautiful. Perhaps a better slogan, in spite of its redundancy, would be optimum is best.

As a final observation, a contrast between France and England may be noted. These two countries have about the same standard of living, as measured by the gross national product per capita. England, however, is a highly industrialized country, whereas France is to a much larger extent agricultural. Not only is agriculture inherently less capital-intensive than manufacturing, but grape culture is particularly so. As a result, even with the same standard of living, the energy consumption per capita is only about half as great in France as in England. This difference in technological level permeates and colors the entire societies. The bread consumed in England comes primarily from just two bakeries. The average Frenchman buys his bread at a neighborhood bakery. He knows the baker and the bread is unwrapped and often still warm when he buys it. Because of its local production and marketing, it requires no artificial anything. It is real bread and tastes nothing like the plastic-like substitute that Englishmen and Americans eat. Bread is but a single indication of the differences in lifestyle that accompany differences in technological level.

Perhaps it is in this difference in lifestyle that hope lies. Surely one cannot hope to force or convince major corporations to shift from high to intermediate technology in order to save the environment, to conserve depleted resources, to provide jobs, or to make life more pleasant or even bearable. Social change can, however, result in a rebirth of intermediate technology. The process is, in fact, under way. The prevalence of cotton blue jeans has seriously disrupted the synthetic fiber industry. Farmers' markets, organic farming, local crafts, local bakeries, health food stores and restaurants, and other manifestations of intermediate technology are springing up everywhere. Evidence that these are not mere transient fads but manifestations of deep social change is growing. It is a basis for both hope and optimism.

Bart Conta, professor in the Sibley School of Mechanical and Aerospace Engineering, has a major interest in the historical and cultural implications of technology. In addition to teaching in his specialty fields of thermodynamics and energy conversion, he offers a course in the history of technology. This past summer he taught a short course in the concept and implementation of intermediate technology, the subject of this article.

Conta received his undergraduate education at the University of Rochester, earning the B.S. degree in 1936, and studied at Cornell for the M.S. in engineering, granted in 1937. He joined the faculty here at that time. In the 1940s he spent a year as a research engineer with the Texaco Corporation and four years as professor of mechanical engineering at Syracuse University, and he spent successive sabbatic leaves from Cornell at the DuPont Company in the Year in Industry Program; at the Universidad del Valle in Cali, Columbia, as a Ford Foundation visiting professor; at the University of California at Berkeley as a National Science Foundation science faculty fellow; and in England studying the history of technology.

At Cornell he has served as the graduate field representative in mechanical engineering and has been a member of the University Senate and of the Faculty Council of Representatives. He is registered as a professional engineer in New York State and has been a consultant to several industrial firms.
RURAL DOMESTIC ENERGY
SELF-SUFFICIENCY
A Cooperative Student Research Project

by Alan Wyatt and Laura Masin

Many people have come to realize that our modern industrial way of life and its reliance on ever-increasing amounts of energy is rapidly approaching a time of reckoning. There is a growing feeling that the necessity for an environmentally sustainable human relationship with nature calls for a grass-roots social reconstruction in response to ecological and resource limits and that appropriate technologies responsive to both society and nature can evolve to replace an endless sophistication of technology. In response to these attitudes, a movement toward decreased energy consumption and a shift to renewable energy resources has begun. Applied on a small scale, renewable resources can provide for basic needs such as space and water heating, lighting, and water pumping, and also reduce the environmental impact and capital cost of the currently massive energy industry and distribution system.

In October of last year, a group of Cornell University and Ithaca College students with an interest in these ideas met to discuss the possibility of working together on a summer research project that would develop some specific plans for more self-sufficient living. We knew of the National Science Foundation program in Student Originated Studies that funds summer projects by groups of students working full-time on research problems of their own design; the purpose of the program is to give undergraduates experience in self-initiated original research, from the art of proposal writing to the reporting and analysis of findings. Our group decided to propose a project in which a particular household would be used as a case study to create a process model for rural domestic energy self-sufficiency.

BLUEBERRY HILL: CASE STUDY AND PROCESS MODEL

The household we arranged to study is at Blueberry Hill, a 127-acre site near Danby, New York, in the hilly area of southern Tompkins County. Once a dairy farm, the land now comprises 52 acres of fields and 75 acres of woodland. An old two-story farmhouse on the site is the home of a nonfarming family of five.

Because it was recognized that the particular degree of energy conservation and self-sufficiency that people might wish to pursue would vary considerably, we developed two scenarios. The first supposes a family of five, in which the adults have full-time jobs in town; it is assumed that the family has a reasonable level of environmental awareness and concern, but that lifestyle will not be drastically altered. The second scenario is also for a family of five, but in this case they are homesteaders with limited money but lots of time and willingness to significantly alter their way of life.

Each of these scenarios was developed in five steps, which constitute a process model that can be used by other households: (1) In a preliminary assessment of the household’s present energy demands, an inventory is made of energy used in the form of electricity, heating and cooking fuel, and indirect expenditures in purchased items such as prepared or packaged food and materials. (2) Needs are reassessed and conservation measures recommended. (3) Information about the resources of the site is applied to the development of options for replacing present energy sources with renewable ones that minimize environmental damage. (4) These options are evaluated in terms of their potential use in providing space heating, water heating, electric power, and food cooling and preservation, with all evaluations based on considerations of
Blueberry Hill, site of the energy self-sufficiency study, lies in hilly terrain in Tompkins County, New York.

...economics, time and labor requirements, environmental impact, and energetics (the estimation of full energy cost of goods and services from production to consumption).

(5) For each scenario, systems are integrated into an optimal household strategy incorporating considerations of ecology, economics, life-style, and esthetics.

PRELIMINARY STUDIES OF ECOLOGY AND SOIL

We began our project with a study of the land, concentrating on those aspects that are especially pertinent to energy-resource potential: ecology, soil, forest resources, and climate.

We decided to inventory the plant and animal life on Blueberry Hill partly as a way of developing a general awareness and understanding of the land, and partly to discover specific assets. Familiarity with the land has practical advantages, such as the ability to recognize changes that could affect its usefulness; changes in vegetation brought about by pollution, for example, would be noticed by one familiar with the land. A knowledge of what vegetation reveals about factors such as soil nutrients and pH, drainage, and susceptibility to flooding is valuable in land-use planning. The potential for self-sufficient living is enhanced by knowledge of the presence and location of wild foods. Our ecological inventory included trees and shrubs, herbaceous plants, vertebrates, pond flora and fauna, and edible wild plants.

Soil samples were taken from eighteen parcels within the cleared fields for chemical analysis of available phosphorus and potassium, total phosphorus, and pH, and for determination of soil texture and drainage. We also assessed the agricultural potential by consulting the Tompkins County Soil Survey for information on the basic soil types of the property. This information, combined with climate data and past experience, helped us judge what sorts of crops could best be grown on the site. The fair prospects for soil productivity and the cool, short growing season of the region indicated that the site has a comparatively low "human carrying capacity" for food, although it could probably supply food for twenty-five people.

We also grew a garden, whose measured inputs and outputs helped in understanding the site's ability to provide food.
Although the garden sustained significant damage from several severe hailstorms and heavy deer browsing, our records suggested that with four hundred person-hours of labor, the one-sixteenth-acre garden could easily produce $1.25 \times 10^5$ kilocalories of food energy.

MANAGING A WOODLOT TO PRODUCE FUEL

Wood virtually disappeared from the American energy scene by the end of the nineteenth century, but now there is a rising interest in bringing it back for heating and cooking, especially in rural areas. Although the traditionally higher value for lumber has led foresters to look down upon the prospect of management for fuel-wood production, it appears that it is time to think about this option. Two cogent factors are: (1) the price of wood is now competitive with that of oil (figures of 3.0 cents for wood and 2.9 cents for oil per 10,000 BTU are calculated on the basis of wood priced at 60 dollars per standard cord and yielding 20 million BTU per cord and oil priced at 41 cents per gallon and yielding 140,000 BTU per gallon); and (2) species with low lumber value, such as beech and red maple, and sometimes even valuable lumber species, such as hard maple, can now be sold for more as cordwood than as lumber. With oil and gas reserves declining and prices increasing, the economic value of cordwood stands to increase even further.

Our objective in the forest study was to determine whether or not it is possible to increase the energy value of a woodlot and if so, how. It is known that higher-density species such as hickory and oak have higher fuel values than lower-density species such as pine, soft maple, and birch. To manage a forest for maximum fuel production, therefore, one would selectively thin for those species that put on the most weight per unit of time. (One could consider also other methods such as coppicing—encouraging rapid early growth by reproducing forest stands from sprouts or root suckers rather than from seedlings—or planting dense stands of fast-growing species for early and frequent harvesting.) We carried out a study of growth rates for all the species (mostly beech and maple) within a one-acre study plot on our site and found that on the average, sugar maple was growing faster than beech. Since sugar maple has a density similar to that of beech, has a higher lumber value, and is useful as a source of maple syrup, we recommended management to favor sugar maple over beech.

Another consideration is that in much of New England and upstate New York, there is a strong possibility that beech will be wiped out by the spreading nectria (beech scale) infection. Because the particular stand we studied is relatively old (eighty years) and past its period of vigorous growth, a tree density of about 175 to 200 trees per acre would probably be optimum. In a more vigorous stand (or in this one after management for twenty or more years), a lower density of about 150 trees per acre might prove more productive.

In any case, even with conventional management for lumber, a one-acre woodlot can usually provide one-half to one cord of wood annually from thinnings. Since one cord is equivalent to about 20 million BTU of energy, we calculated (on the basis of heat-loss estimates) that ten to twelve acres of forest should supply enough fuel for all the space and winter water-heating needs of our test household.

CLIMATE MEASUREMENTS AND ENERGY NEEDS

As part of our general site investigation, we conducted a climatological inventory.

"... a movement toward decreased energy consumption and a shift to renewable energy resources has begun."
Right: This flat-plate solar water heater, installed near the barn at Blueberry Hill, was built by members of the Alternative Energy Group at Cornell. Flow-rate test equipment is at left. The storage tank in the background was used in a separate test of a thermosyphon natural circulation system.

Temperature and rainfall measurements were made with small, simple, and sometimes homemade devices. Solar radiation was measured with a pyrheliometer and recorded many times a day in conjunction with tests of a solar hot-water collector. Peak readings of up to 400 BTU per square foot per hour—unexpectedly high—were obtained, even though the summer was a cloudy one; it seems that the smog-free location, high winds, and relatively high altitude combined to give the high values. For wind-speed measurements, we mounted totalizing anemometers at heights of about forty feet (on top of a silo) and ten feet. Testing over a one-month period indicated that the wind at forty feet is about two and one-half times as strong as that at ten feet—a big difference in terms of wind power, which is computed as a cube of the wind speed. Recently, a new anemometer, which records wind speeds every two seconds, has been set up next to our totalizer and we will be analyzing the data from the two instruments to assess their comparative usefulness.

In considering self-sufficiency, we needed first to know how much energy was being used to operate the household in what ways. Our estimate included direct use of oil and of electricity (this came to the very high yearly total of 20,000 kilowatt-hours) plus indirect energy consumption. Albert Fritsch, in his Lifestyle Index (1974) has made an attempt at quantifying the hidden energy costs that are associated with all goods and services, from hot dogs to health care to newspapers and theater tickets; we used his guidelines to estimate a total of 740 kilowatt-hours per person per year for our household.

Next we identified measures that could be taken to save energy, such as installing storm windows, weatherstripping, and additional insulation; turning down the water-heater thermostat; and disconnecting the dishwasher heating element. Then, in preparation for assessing alternative energy sources, we made a technical study of the structure and exposure of the house, prepared estimates of heat loss and heat gain on a month-to-month basis, and made a brief study of sun angles and orientation.

SOLAR COLLECTORS FOR HOT-WATER SYSTEMS

With technology commercially available today, solar energy can be used effectively for water heating, space heating, and air conditioning in much of the United States. In the Northeast, however, the low level of insolation makes space heating and air conditioning expensive and architecturally awkward, and therefore we chose to concentrate our study on water heating.

Our group had two homemade solar collectors available: a flat-plate water heater and a “bread box” concentrator. Both were tested for efficiency, heat gained per day, and water temperature provided. The “bread box” consisted of two 55-gallon oil drums set in an insulated box which could be opened during the day, concentrating solar energy onto the black water tanks, and closed at night to hold the collected energy. This model was inexpensive and could easily be built at home, but our tests showed that it had a very low efficiency: it could collect a fair amount of energy, but could not heat its full load of water very hot. The flat-plate collector, however, worked well. Our initial tests showed that it could heat water to 150°F and had an efficiency of 20 to 80 percent, depending on water-flow rate. On the basis of this information, we designed an inexpensive water-heating system with 35 square feet of collector surface, a pump, and a water-storage unit, that could provide forty gallons of hot water a day on sunny days from May to September. We also connected our flat-plate collector to a tank and let it function by a thermosyphon natural circulation system. This arrangement had the advantage of not requiring a pump, but it was slightly less efficient.

APPRAISAL OF WIND POWER AS A SOURCE OF ENERGY

The other renewable source of energy we investigated was the wind. From the viewpoint of energetics, wind power seems very attractive: one study showed that, on the basis of the ratio of energy input to energy output, small wind electric plants
are nine times as efficient as coal-fired electric power stations. But wind power has to make economic sense also. One consideration is initial cost, and one finds that the equipment now on the market is often sophisticated and expensive. The crucial factor, though, is the amount of wind available. Because of the cubic relationship of power to wind speed, small differences in velocity can be very significant. For example, winds averaging 12 mph can produce twice the amount of energy as winds averaging 10 mph. This makes accurate site measurements very important. Our research provided information for realistic appraisals of how wind power could be used effectively at our site.

EVALUATING WASTE SYSTEM ALTERNATIVES

At the outset of the project we decided to investigate alternatives to the conventional flush toilet for human waste disposal. Our primary concern, in the context of the project, was the energy efficiency of the various options. We constructed an outdoor methane-generating privy using a 55-gallon oil drum to collect the wastes and a chute assembly to provide a relatively air-tight connection between the drum and the toilet seat. The methane-generating process is initiated by adding an appropriate amount of carbonaceous material, such as straw or newspaper, when the drum is one-fourth full. This system has the advantages of being a completely self-contained process that uses no water at all and recycles waste into a useful form. (The methane generated from the waste of a few people and chickens and one cow could provide sufficient cooking fuel for a household during the May-to-September period when a wood stove was not in use.) A more sophisticated and convenient indoor composting toilet, such as a commercial fiberglass model, is also a possibility.

We made some rough calculations of relative energy efficiencies on available in-house systems and concluded that the fiberglass composting toilet and a flush toilet with septic system are probably comparable in energy input, and that both of these probably involve less energy cost than the household share of an urban sewer system. Our ultimate conclusion, though, is that the whole issue of waste-system evaluation has a lot more to do with water pollution than with energy costs.
Table 1

<table>
<thead>
<tr>
<th>Option</th>
<th>Cost per Year</th>
<th>Energetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Oil furnace with forced-air ducting</td>
<td>$618</td>
<td>7.8</td>
</tr>
<tr>
<td>2. Oil furnace with supplementary Franklin wood stove used during evening hours with purchased wood</td>
<td>615</td>
<td></td>
</tr>
<tr>
<td>3. Air-tight wood stove with existing oil furnace as backup with purchased wood</td>
<td>288</td>
<td>136</td>
</tr>
<tr>
<td>4. Forced-air wood furnace with forced-air ducting and built-in backup oil unit with purchased wood</td>
<td>255</td>
<td>31</td>
</tr>
</tbody>
</table>

SCENARIO I: LITTLE TIME OR LABOR REQUIRED

One of the two scenarios we developed is applicable to our test household under the assumption that the family is willing to expend a moderate amount of money but little time or labor.

Space-heating need was calculated at 137 billion BTU a year, with a maximum heat-loss rate of 56,000 BTU per hour in January. Four heating-system options using oil, wood, or combinations of these two fuels, were evaluated in terms of annual cost (with all initial investments amortized over twenty years), energetics, and environmental impact. To compute the energetics figures, the energy required to manufacture equipment was added to the energy used to refine and process any fuel oil used. The calculations are summarized in Table I.

The forced-air wood furnace was chosen as the option for Scenario I because it has a high energy efficiency and a cost comparable to that of the conventional heating system if a small portion of the wood supply is gathered from the site, and because wood is preferable to oil in terms of environmental impact. The environmental cost of oil is high: extraction, refining, processing, and distribution are all energy-intensive and contribute greatly to air and water pollution; wood, on the other hand, has a beneficial environmental influence while it is growing and burns as a fairly clean fuel in an air-tight, down-draft stove or furnace. The wood furnace was considered preferable to the wood stove system because although stoves are very energy-efficient, they probably be too time-consuming for working people to tend.

The economic advantage of a wood-heating system is increased by the fact that with a coil passed around the flue or through the combustion chamber it can produce hot water sufficient for household use during the cold months. A complementary system of wood-fueled hot water in winter and solar-heated hot water in summer works well in this climate.

Since the solar system would have to work only during the summer, no anti-freeze or drain valves to protect the collectors would be needed. The method chosen was to heat water in a tank by cycling it through the collectors, and then pass cold well water through the tank to collect heat. The solar system we proposed calls for panels with 90 square feet of collector surface at a 47° angle on the roof and a pump drive controlled with a differential thermostat. Since our climate data showed that it would be sunny only about 60 percent of the time (May through September), we prescribed a 250-gallon storage tank to be set in the basement. The total cost would be about $850.

We also investigated the feasibility of a small-scale wind electric plant on the site. Since such systems are limited in power and energy, the household use of electric-
ity would have to be reduced to perhaps 30 percent of the present level. On this basis, and assuming an average 10-mph wind (which we feel could be assured with a 60-foot tower), we assessed five options (summarized in Table II): (1) A 6,000-watt Electro plant including a synchronous inverter which converts 110-volt DC power to 240/110-volt AC power. On a windy day, any surplus power would be fed into the utility grid, effectively "running the meter backward" and giving energy credit. (The problem with this plan is that local utilities do not now allow such use.) (2) The same plant but with power stored in a battery bank and fed to a simpler inverter. Certain 220-volt appliances would be powered by the utility. (3) Same as option 2, except that transformers are used to permit operation of the 220-volt appliances. (4) An 800-watt, 12-volt DC Sencenbaugh plant with batteries and a 500-watt inverter for partial supply, with the utility providing the rest. (5) Total supply by the utility company.

Since commercially available systems with storage are very expensive and the most attractive option (1) is not now possible, we recommended continued use of the utility service. Under other conditions, such as location in an area with higher average wind speeds, the availability of improved storage systems, or escalated electricity costs, the possibility of wind-generated electricity should be reconsidered.

This scenario also calls for efforts to produce and store food. Recommendations are for a small garden, nut and fruit trees, soil-building techniques including composting, canning (less energy-consuming than freezing), and the use of an inexpensive solar food dehydrator for preserving fruits and vegetables.

### Table II

**COSTS OF WIND-POWERED ELECTRICITY (SCENARIO I)**

<table>
<thead>
<tr>
<th>Option</th>
<th>Initial Cost</th>
<th>Total Cost over 20 Years</th>
<th>% of Demand Provided by Wind</th>
<th>Cost per KW-Hour (cents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,000-W plant with synchronous inverter</td>
<td>$8,150</td>
<td>$8,250</td>
<td>95</td>
<td>9</td>
</tr>
<tr>
<td>6,000-W plant with batteries and 1-KW inverter</td>
<td>10,075</td>
<td>12,125</td>
<td>49.5</td>
<td>22.5</td>
</tr>
<tr>
<td>6,000-W plant with 1,000-W inverter and transformers</td>
<td>10,275</td>
<td>12,325</td>
<td>51.5</td>
<td>22</td>
</tr>
<tr>
<td>800-W plant with batteries and 500-W inverter</td>
<td>3,200</td>
<td>4,000</td>
<td>14.7</td>
<td>25</td>
</tr>
<tr>
<td>Local utility supply</td>
<td>0</td>
<td>14*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Based on an assumed price rise of one cent per kilowatt-hour each year for twenty years

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**SCENARIO II FOR GREATER ENERGY SELF-SUFFICIENCY**

The second scenario involves a far greater change in the life and operation of the household. We assume that the people are willing to devote a great deal of time and effort but that capital expenses must be minimal. The plan is based on home-built equipment and organic farming.

For electric power, we prescribed a 1,200-watt wind plant that can be home-built for about $2,000, including the costs of a wooden and concrete tower, batteries, and wiring, and that could easily run lights and a small refrigerator. An old-style water-pumping windmill was suggested to relieve the drain on the electricity supply; a storage tank in the attic would provide house pressure.

As a flush-toilet system would put a large load on the water supply, the methane-generating toilet we designed was suggested. An oil drum, mounted on a dolly extending under the bathroom floor would collect wastes from an indoor facility. This human waste, and also animal waste, could be stored in drums during
the winter and used, along with plant material, to generate methane during the warm summer months. After digestion, the waste could be used as compost.

In the winter, a wood stove would be used for cooking and heating the kitchen area, and the remainder of the house would be heated with a retrofitted fireplace and two large wood stoves made from oil drums. Water heating during the winter would be provided by coils on or inside these wood stoves; in the summer, home-built solar panels with a thermosyphon would provide water heating.

The land would be used far more extensively than in Scenario I. A large garden, a small greenhouse, a field of grain, and an orchard for fruit and for apiculture would be major sources of food. Canning, solar drying, and ice-house storage would be used for food preservation. Chickens, goats, and a cow would be raised for milk, eggs, meat, and manure. A tractor sometimes powered by methane would be used for planting and harvesting the grain.

This plan would provide for all energy needs and most of the food. Total capital outlay would be $3,000 to $4,000.

The two scenarios we have described are the specific results of our summer project, but we feel we have accomplished more than drawing up proposed changes for a certain household. We hope our concrete recommendations for one rural house will apply also to other houses, although each situation, each piece of land, is unique and deserves individual consideration. We also hope that our study, which has extended our own understanding of the values and possibilities of decentralized, more self-sufficient living, will serve to encourage this kind of understanding in others.

The project described in this article had its origins in a workshop on design and environmental analysis offered at Cornell last spring by Gary Coates of the College of Human Ecology faculty. Fourteen of the students, from both Cornell and Ithaca College and representing a variety of academic majors, organized and participated in the summer project, with Coates serving as faculty adviser. Many of the project participants are members of the Alternative Energy Group at Cornell, which maintains an office and library in Anabel Taylor Hall and sponsors a weekly seminar open to the public. Many of these students are working also with the recently formed Community Energy Network, which helps local people develop plans for using renewable sources of energy.

Alan Wyatt, one of the authors of this article, is a mechanical engineering major who will complete work for his baccalaureate degree this term. He is a consultant for the Community Energy Network and hopes to continue work in the field of small-scale wind and solar energy generation after graduation. Laura Masin was a graduate student in natural resources last year. At the present time she is working half-time for Community Energy Network and half-time at Cornell's art museum. A 1972 graduate of the University of California at Santa Barbara, she has worked for the national forests service and for the park service as an interpretive naturalist at Yosemite, and hopes to develop a career in the area of public education on resources problems.

The authors were assisted in the preparation of this article by Brian Caldwell, Michael Shepherd, and Alex Wilson. The other members of the project team are Jon Alvarez, Mark Connors, Alycia Dykstra, Sandy Jensen, Jeani Lewis, Denise Nedell, Jeff Powell, Jack Smith, and Bruce Snead.
National Prospects for Solar Energy Use

Use of the sun to provide a fifth of the nation's total energy needs by the year 2020 was cited as a possibility by a representative of the Energy Research and Development Administration (ERDA) in a talk to Cornell freshman engineering students this fall. William R. Cherry, a branch chief in the Division of Solar Energy of ERDA, spoke on "The National Solar Energy Program" as one of ten lecturers in a series that is part of the required course, Engineering Perspectives. The theme for the fall lecture series was "Energy and the Environment.”

Total reliance on direct solar energy would be impractical or impossible, Cherry said, but if it were to be accomplished, the use of 3.5 percent of the nation's land area would be required for the installations. (This compares with about 1.5 percent now taken up by population centers, or about 15 percent used for agriculture.) A more realistic prospect, he said, is the production of 8 to 10 percent of the nation's total energy requirement by the year 2000, with solar installations established in the most advantageous locations. ERDA is sponsoring research in solar energy technology and studying the effectiveness of installed systems around the country.

The main uses of direct solar radiation, Cherry said, are for space heating, air conditioning, water heating, and the production of electrical power. He showed pictures and diagrams of installations for a variety of applications, including home use, agricultural operations such as grain drying or greenhouse heating, and industrial processes such as food or textile drying. In most cases, a significant percentage of Many kinds of engineers, including environmental specialists, are needed to work on the development of the wide range of possible solar-energy systems, William R. Cherry told freshmen engineers in his talk at Cornell.

The fall lecture series that included Cherry’s talk was arranged by Robert H. Lieberman, assistant professor in the College’s Division of Basic Studies and coordinator of the course in Engineering Perspectives. The purpose of the course, which also includes two mini-courses selected by the individual students, is to help beginning students acquire some familiarity with various engineering fields and career opportunities.
Impending shortages and rising costs of fossil fuels have created interest in the use of solar energy and have made it more economically competitive. This renewable source of energy could significantly reduce the nation's demand for fossil fuels; for example, if 10 percent of the projected demand for heating and cooling buildings (12 percent of the total) were to be met with solar energy by the year 2000, the annual savings in fossil fuels (calculated at $8 per 10^6 Kcal) would be more than $4 billion.

Below: A typical solar collector for residential heating and cooling. The thickness (A direction) is 3 to 6 inches, the length (B direction) is 4 to 20 feet, and the width (C direction) is 10 to 50 feet. The tubing is one-half to one inch in diameter, and the insulation is 2 to 4 inches thick. The slope is dependent on location and on winter-summer load comparisons.

(From diagrams and information supplied by William R. Cherry.)

The total energy requirements was obtained from the solar units.

There are three major types of solar collectors, Cherry said: (1) flat-plate collectors which include black-painted fins or panels to absorb the radiation, tubing to conduct a fluid, usually water, for heat exchange, and often a facility for hot-water storage; (2) evacuated tubular collectors, under development by several industrial firms; and (3) concentrators, in which mirrors are used to focus sunlight on a smaller collecting device. In addition, systems for small-scale generation of electric power with photovoltaic cells are being investigated and are proving to be especially useful in isolated locations such as on “Texas towers” or on mountain tops.

Other systems that have been installed for special-purpose uses include an inflatable plastic collector used for drying grain; a “solar pond” filled with salt water in gradated layers of different concentrations, used to produce hot water for greenhouse heating; and shallow freshwater ponds used to provide heated water for industrial plants. Very hot tem-
tem are jointly sponsored by ERDA and the National Aeronautics and Space Administration (NASA).


In addition to attending the lectures, the students take two mini-courses selected from some twenty-five offered by faculty members in the various schools and departments of the College.
Water Power from Fall Creek in Cornell’s Past—and Perhaps its Future

The more than four-hundred-foot drop from Beebe Lake through Fall Creek Gorge to Cayuga’s waters provides Cornell University not only a spectacular scenic attraction, but a nonexhaustible energy resource. Compared to the huge power requirement of the University today, it is a small resource, to be sure, but it’s there, and a plan to reactivate a disused power plant in the gorge is being seriously considered.

The old and recent photographs collected here illustrate some of the history of Fall Creek as a source of power. The story goes back at least to 1794, when the first of many mills was built along the upper banks of the stream near the edge of the present Cornell campus. In 1829, long before he founded his university, Ezra Cornell was utilizing water power to operate flour and plaster mills at the foot of Ithaca Falls. Additional power potential was provided in 1838, when a dam creating Beebe Lake was built by Ezra Cornell. The University’s use of Fall Creek to obtain mechanical and hydroelectric power extended through most of its history—and it may not be over yet. Scenic Fall Creek, an historic paradigm of the “small is beautiful” energy concept, may become a modern example.

(Help in assembling photographs and information was gratefully received from Howard G. Smith, George Lyon, Peter Murphy, Richard McDowell, Noel Detsch, Donald F. Berth, Isabel Peard, and Nancy Dean. The loan of many of these pictures from the University archives collection is acknowledged with thanks.)

Right: This mill on the Beebe Lake inlet was one of many situated in the nineteenth century along Fall Creek near the village now called Forest Home, one of the oldest settled communities in this part of New York. The first mill in this area, a grist mill, was built in 1794 by the first settler, Joseph S. Sydney (the town’s first name was Sydney’s Mills). This was followed by mills for sawing wood, flouring, mitten and hosiery knitting, leather tanning, woodworking, and cider pressing, and for such manufactures as gun powder, plaster, paper, woolen cloth and yarn, and furniture. (The gun-powder mill, which was damaged by a spectacular explosion in 1949, was the precursor of the present Ithaca Gun Company.) This and the mill pictures on the opposite page are from the album of the late Albert Force and are now in the Cornell University archives.
1. This 1867 view of Fall Creek at the Forest Home dam is from a stereopticon slide. At left of the footbridge is a saw mill, and at right is a turning mill.

2. The Empire Grist Mill, located in Forest Home (then called Free Hollow) was destroyed by fire in the 1890s. Most of the old mills were lost to fire or flooding, but a few remain as parts of contemporary homes.

3. The flour and plaster mills managed by Ezra Cornell from 1829 to 1839 were built near the foot of Ithaca Falls, as shown in this reproduction of a painting. A wooden flume, visible just above and to the right of the falls, was attached to the overhanging rock. (In later years, Ithaca Falls was the site of a small single-wheel turbine which supplied a modest amount of electricity until the early 1950s. A conduit that conveyed the water to the wheel is still at the site, now a small park.)

4. The wooden flume that ran to the mills by Ithaca Falls was replaced under the direction of Ezra Cornell (then twenty-three years old) by a 200-foot tunnel blasted through solid rock. The upper end of this tunnel can be seen today from the Stewart Avenue bridge.
5. Cornell's first hydroelectric power plant in the gorge was this wooden structure, which appears to have been situated on the same site as the replacement building now standing. Before this first hydroelectric plant was built, mechanical power derived from the creek was brought up the south side of the gorge by a system of shafts and pulleys to a mechanical engineering laboratory that stood west of the spot where Triphammer Bridge now crosses the gorge.

6. Around the turn of the century, a trolley-car system that ran between town and campus was powered by a generating plant in the gorge near the present location of the Ithaca Gun Company. Only traces of this facility remain. Other industries located in the gorge area included a paper mill. Water rights were shared by these companies and Cornell University.

7. This trolley stop at the campus end of the line was near Boardman Hall, the present site of Olin Library on the Arts Quadrangle.
8. The Beebe Lake reservoir is created by a dam above Triphammer Falls on the Cornell campus. This photograph was taken before construction of the present dam was begun in the summer of 1898.

9. By the winter of 1900 skaters were out on the lake and a hydraulics laboratory and a canal for experimental work were completed.

10. In subsequent years additional stories were built on top of the original hydraulics laboratory building. At the time this picture was taken, the canal—later abandoned after it fell into disrepair—was still intact. The hydraulics laboratory has not been used since 1959.
The photographs on this page, part of the College of Engineering archives collection, were taken during the construction in 1898 of the Beebe Lake dam, the canal, and the original hydraulics laboratory building.
Below: This is the hydroelectric plant, visible from the suspension bridge over Fall Creek Gorge, that supplied power to the University from the early 1940s until 1960 and that is now under consideration for restoration.
This could supply about 500 kilowatts of electricity (the total used for the endowed campus is about 15,000). The project would require major renovation and automation of the facilities, and the dredging of Beebe Lake so as to ensure a sufficient supply of water throughout the year. The plans are still preliminary.

Below: The present scene from the Triphammer Bridge includes the old hydraulics laboratory next to Triphammer Falls. This laboratory has not been used since Hollister Hall, the present civil engineering facility, was completed in 1959.

Right: The water wheel in this winter scene near the footbridge across Beebe Lake was once used for hydraulics experiments. The building is the recently constructed chilled-water plant.
Two Chair Professors Join Chemical Engineering Faculty

An expanded program in chemical engineering at Cornell is under way this year with the addition of two chair professors to the faculty of the School of Chemical Engineering. The new members are Keith E. Gubbins, the Thomas R. Briggs Professor of Engineering, and Cornell graduate Robert P. Merrill, the Herbert Fisk Johnson Professor of Industrial Chemistry.

The addition of these two faculty members will augment the present scope of instruction and research in chemical engineering at Cornell and increase the level of School and interdisciplinary research, according to Edmund T. Cranch, dean of the College of Engineering, and Julian C. Smith, director of the School of Chemical Engineering.

Gubbins came to Cornell from the University of Florida, where he had been since 1962, first as a postdoctoral fellow and then as a member of the chemical engineering faculty. He was born in England and educated at the University of London, earning the B.Sc. degree in chemistry (with first class honors) from Queen Mary College in 1958, and the Ph.D. in chemical engineering from King's College in 1962. In 1971-72 he was an Eppley Foundation fellow in chemical engineering at Imperial College, London, and subsequently he has held appointments as visiting professor in the physics department at the University of Guelph, Ontario, Canada, and as visiting professor in physics at the University of Kent in England.

Gubbins is a specialist in the application of statistical mechanics to the properties of liquids and liquid mixtures, particularly transport and thermodynamic properties. The overall method used in his research is to combine theoretical work, computer simulation, and experiment to develop theories valid for practical applications. At the present time, the major effort is to extend the theory of molecular liquids to nonspherical molecules, including compounds such as ethylene, hydrogen chloride, and benzene that are of importance in chemical engineering. Long-range plans are to develop a theory applicable to liquid mixtures. Much of the experimental work is being done by collaborators in other laboratories, notably those of Professor Jack Powles at the University of Kent in Canterbury, England, and Professor Lionel Staveley at Oxford University.

In the computer-simulation part of Gubbins' program, the properties of liquid molecules are calculated from input data including the applicable force laws, and the results are spot-checked against experimental data and then used to test the validity of the theory. Several hours of computer time can provide information that would be difficult or very time-consuming to obtain experimentally. Now under study are the properties of components of liquefied natural gas; later, mixtures will be analyzed.

In another project related to the overall program, neutron scattering is being used to determine thermodynamic and transport properties of polar liquids. These experiments, which require a specially designed high-flux nuclear reactor, are performed at Oak Ridge. Collaborating with Gubbins in this work is Peter Egelstaff, a nuclear specialist at the University of Guelph.

Over the past ten years, Gubbins' research has been supported by a total of seventeen grants. Current projects are supported by the National Science Foun-
Gubbins' publications include some seventy papers, as well as several books and chapters. These include *Statistical Mechanics of Polyatomic Fluids*, written with C. G. Gray and scheduled for early publication by the Oxford University Press as part of its International Series of Monographs on Chemistry; and *Applied Statistical Mechanics*, a graduate-level text written with T. M. Reed and published by McGraw-Hill in 1973. His professional activities include participating in Gordon Conferences and reviewing for a number of journals and societies. Honors he has received include several prizes and fellowships for graduate research; an award for excellence in undergraduate engineering teaching at the University of Florida in 1968 and again in 1974; and the 1974-75 Outstanding Service Award of the College of Engineering at Florida.

Merrill, a specialist in surface chemistry and physics, spent part of last summer on campus arranging for research facilities and became a regular member of the faculty in December. His laboratory is to be housed in renovated storage space on Olin Hall's ground floor, which is built on bedrock and provides stability for vibration-sensitive experiments. The facility is being set up as a "semiclean" room, with limited access, filtered air, and temperature control.

Merrill was graduated from Cornell in 1960 with the degree of Bachelor of Chemical Engineering, and received his doctorate from the Massachusetts Institute of Technology (MIT) in 1964. Subsequently he taught at MIT and then at the University of California at Berkeley, where he served as vice chairman of the Department of Chemical Engineering for the past three years.

At Cornell he will be continuing a broad program of research centered on studies of the structure and chemistry of solid surfaces and the interaction of these surfaces with gas molecules. A unique aspect of this research is the use of atomic and molecular beam scattering techniques to probe the structure of surface atoms and to study gas-solid collision dynamics. An understanding of these interactions has important applications in such processes as catalysis, corrosion and corrosion inhibition, adhesion, and the aerodynam-
ics of flight in rarefied atmospheres.

One project in collision dynamics that Merrill is heading is a three-year study supported by the National Aeronautics and Space Administration (NASA) to determine the feasibility of a space shuttle facility to measure the interaction of atomic oxygen and various metals. This work, still in its initial stages, will use ion-scattering techniques to simulate the high-intensity, high-energy oxygen beams that will be produced by the orbiting space shuttle. Molecular beam scattering is also used in a study of the catalytic decomposition of hydrazine on iridium surfaces. This work, sponsored by the Air Force Office of Scientific Research (AFOSR), is directed toward improving the operational stability of navigational rocket thrusters, which use hydrazine as a propellant. The thrusters are used, for example, in communication satellites. The mechanism of the hydrazine decomposition is not well understood and fundamental research may provide insight into the solution of some current technical problems encountered in the use of this propellant system.

Other projects Merrill is directing have potential application in a wide range of industrial problems. For example, AFOSR and the Chevron Research Corporation are sponsoring a study of the surface chemistry and physics of ruthenium, which is a particularly effective catalyst for the decomposition of nitrogen oxides in automobile emissions and for synthesis of liquid hydrocarbons from gasified coal. Experiments on oxidation catalysis and corrosive oxidation of platinum surfaces, funded by NASA and AFOSR, are pertinent to the improvement of catalytic converters for automobiles and in understanding the catalysts used in industrial processes such as the manufacture of nitric acid. The work on platinum and other noble metals will also yield information on the behavior of metals in highly reactive plasma environments and may be useful in developing materials for secondary containment vessels in nuclear reactors. A study of epitaxial oxide growth on titanium and aluminum is directed toward the solution of materials problems with alloys used for aircraft construction.

In addition to conducting his university-based research, Merrill is active as an industrial consultant. Companies he has worked with include Universal Oil Products, Gulf General Atomic, Stauffer Chemical, Lockheed Missile and Space, Abcor, and Raytheon, and he is a member of the JANEFF Working Group on Monopropellents.
New and Visiting Professors
Augment College Faculty

New faculty appointments were reported by most of the schools and departments of the college this fall.

Two dual appointments were made in the Department of Theoretical and Applied Mechanics and the Department of Materials Science and Engineering. Edward W. Hart, a visiting professor last year, was named professor of mechanics and materials science, and Ralph C. Koeller, currently on leave from the University of Colorado, was appointed visiting assistant professor.

Hart, who was here on leave from the General Electric Company Corporate Research and Development Center in 1975-76, is continuing his association with that company under a cooperative arrangement with Cornell. He has been a physicist with General Electric since 1951 and has collaborated with Cornell engineering research groups since 1971. In his new position, he will participate in the teaching programs of both departments and continue research—of interest to both General Electric and the University—on the constitutive laws governing the flow of solids. His overall research interests are both theoretical and experimental and include such subjects as the magnetic compass and its errors, neutron-proton interaction, meson field theory, dislocation theory, atomic diffusion in crystals, quantum theory of metals and alloys, thermodynamics of inhomogeneous systems, irreversibility theory, plastic deformation of metals, crack propagation, and grain boundary mechanical behavior. He has published some forty papers on work in these areas.

Hart received the B.S. degree in physics from the College of the City of New York in 1938 and the Ph.D. in theoretical physics from the University of California at Berkeley in 1950. During World War II he served as a physicist and electrical engineer with the U.S. Navy Department, and then worked with the theoretical group of the University of California Radiation Laboratory in Berkeley while he studied for the doctorate. His academic experience includes a term as Battelle Visiting Professor at Ohio State University in 1973 and occasional assignments as an adjunct professor at Rensselaer Polytechnic Institute. His honors include election as a fellow of the American Physical Society.
Koeller is spending his year at Cornell teaching in the mechanics department and participating in a cooperative research project on fracture behavior and deformation of metals, alloys, polymers, and ceramics that is being conducted by members of the two departments. His previous research has been in the areas of plate deformation and elasticity and the mechanics of mixtures of viscous fluids and elastic solids.

Koeller holds three degrees—the B.S.M.E., the M.S.M.E., and the Ph.D. in mechanics (granted in 1963)—from the Illinois Institute of Technology. A member of the Colorado faculty since 1963, he has also spent a year as project engineer for the Caterpillar Tractor Company and a year as a faculty fellow at the University of California at Berkeley.

Other appointments this year in the Department of Theoretical and Applied Mechanics are those of Henryk Zorski, visiting professor on leave from the Polish Academy of Science; Ben-Gang Kao, visiting assistant professor; and Vijay K. Varadan, who was here for the past two years as a postdoctoral research associate and visiting assistant professor, and has now joined the faculty as an assistant professor.

Zorski, head of the Department of Continuum Theory in the Institute of Fundamental Engineering Research of the Polish Academy, is teaching a graduate course in thermal stresses and participating in research projects in progress in the department. His specialty areas include elasticity and thermoelasticity, dislocations, continuum theory, and transitions from discrete systems to continua. Zorski has taught for twenty-five years, including several in the United States, and has lectured at universities and institutes around the world. He is active in international functions, including membership on editorial or advisory boards of professional journals and participation in international as well as Polish conferences.

Kao earned the B.S. degree in civil engineering and the M.S. in engineering mechanics at National Taiwan University, and then studied at the University of Minnesota for the Ph.D. in solid mechanics, granted in 1974. Since then he has worked with the Northern States Power Company in the general area of environmental engineering, and as a research associate in biomechanics at the State University of New York at Buffalo. His research interests include aspects of elasticity and viscoelasticity, finite deformation, stability, vibrations, fluid mechanics, and continuum mechanics.

Varadan studied in his native India for the B.S. degree in mechanical engineering, granted in 1964 by the University of Madras, and did his graduate work in the United States, earning the M.S. in engineering mechanics at Pennsylvania State University in 1969 and the Ph.D. in theoretical and applied mechanics at Northwestern University in 1974. His experience includes a year as a project engineer with the U.S. Textile Machine Company in Scranton, Pennsylvania, and as a postdoctoral associate at Northwestern. His research interests include fracture mechanics, plate fragmentation, biomechanics, wave propagation and scattering, self-similar solutions, and singular integral equations.

Five regular or visiting professors have joined the faculty of the School of Civil and Environmental Engineering this year. In the Department of Structural Engineer-
man mini-course, Structures, Present and Future. Appa Rao studied at the Government Engineering College at Kakinada, India, for the B.E. degree in civil engineering, granted in 1962, and earned the M.S. degree in structural engineering at the University of Hawaii in 1965. His doctoral work at Cornell was supervised by Professor George Winter, and the degree was awarded in 1968. His specialty fields include computer-aided analysis and design of structures, design of steel beams and columns with light-gauge steel diaphragm bracing, and modeling and analysis of prestressed concrete nuclear containment vessels.

Lewis, a member of the Department of Civil Engineering of the University College of Swansea, University of Wales, is here for the fall term teaching a geotechnical engineering course in foundations and a freshman mini-course, Engineering Analysis of Landslides, and participating in structural engineering research projects. He holds the B.S. and Ph.D. degrees, both in civil engineering, from Swansea, and has been a faculty member there since 1970. He also worked for five years, after completing his doctorate, as a research engineer with Imperial Oil and Chevron Standard, both of Calgary, Canada. His research and publications are in areas of geotechnical engineering, especially soils and groundwater flow, and include finite element analysis and applications of plasticity and viscoplasticity theory.

Koenig completed his Cornell Ph.D. degree in sanitary engineering this past summer. He received the B.S. degree in agricultural engineering from the University of the Philippines in 1971 and the M.S. in agricultural waste management from Cornell in 1974. A native of Austria, he worked for a summer in the Office of Land Amelioration in Tuebingen, West Germany, and taught German at Fujen University in Taiwan. As a Cornell graduate student, he served as a teaching assistant in the Department of Environmental Engineering.

Gossett, also a specialist in sanitary engineering, is particularly interested in wastewater treatment methods and toxicity problems. He holds three degrees from Stanford University: The B.S. in chemical engineering (1973), the M.S. in civil engineering (1973), and the Ph.D. in civil engineering (1976). In addition to graduate teaching and research, Gossett’s experience includes summer work with the San Mateo County (California) Engineering and Roads Department.

In the School of Electrical Engineering, William H. Heetders was appointed assistant professor and Daniel Aneshansley was named acting assistant professor.

Heetders’ major research interest is in the application of engineering techniques to neurophysiological problems; his work on nerve activity involves computer techniques for recording and experiment control, and the theoretical description and analysis of information coding in biological systems. He was graduated in 1971 from the University of Michigan with a major in electrical engineering, and continued his study there for M.S. degrees in bioengineering and in electrical engineering and for the Ph.D. in bioengineering, granted in 1975. At Michigan he has also held appointments as research associate in nuclear medicine and as assistant research scientist and lecturer in the Electrical and Computer Engineering Department.

Aneshansley previously held a joint appointment at Cornell as a research associate in the College of Agriculture and Life Sciences and as an instructor in the School of Electrical Engineering. His research is in the area of animal communication, particularly in chemical defenses and ultraviolet communication in insects; his contributions have included the design of electronic instruments for use in these areas of research. He received his undergraduate education at the University of Cincinnati, which granted him the B.S. degree in electrical engineering in 1965. He came to Cornell for graduate study and earned the M.S. and Ph.D. degrees, also in electrical engineering, in 1968 and 1974, respectively. His industrial experience includes work with the National Cash Register Company and Technology, Inc., in Dayton, Ohio. He has also participated, through Cornell’s Center for Research in Education, in the development of mathematics and science programs at the elementary and junior high school levels.

In the School of Operations Research and Industrial Engineering, Robert E. Bixby was named visiting associate professor and Lee W. Schruben joined the faculty as an assistant professor.

Bixby, a former Cornell graduate student in operations research, is an associate professor in the Department of Mathematics at the University of Kentucky. He has taught at Kentucky since 1972, except for the year 1974-75, when he was a visiting assistant professor at the Mathematics Research Center of the University of Wisconsin, Madison. He did his undergraduate work at the University of California at Berkeley, which granted him the B.S. degree (with highest honors) in industrial engineering and operations research in 1968. At Cornell he earned
the M.S. degree in 1971 and the Ph.D., under the supervision of Professor Louis J. Billera, in 1972. Bixby’s specialty fields are combinatorial optimization, matroid theory, and n-person games as related to economic markets.

Schruben took his undergraduate work at Cornell, earning the B.S. degree (with honors) in industrial engineering in 1968. He received the M.S. in operations research from the University of North Carolina in 1972 and the Ph.D. in organization and management from Yale University in 1975. After completing his undergraduate studies, he worked as an instructor in data processing and programming for an adult education program in Maryland; as an operations research analyst for the Navy; and as a staff member of Operations Research, Inc., in Silver Spring, Maryland. This past year, after receiving his doctorate, he served as associate director of the Health Systems Research Division and as assistant professor of industrial and systems engineering at the University of Florida. His interests are in applied operations research and simulation, and he has worked particularly in the area of health-care-delivery systems.

A new faculty member in the Sibley School of Mechanical and Aerospace Engineering is Albert H. Burstein, who this fall was appointed an associate professor at the Cornell Medical School and director of biomechanics at the Hospital for Special Surgery in New York City. As a member also of the Sibley School faculty, he will participate in biomechanics projects here. He has conducted research in such areas as the neuromuscular and locomotor systems, skeletal and musculoskeletal strength, joint replacements, and bone properties and repair; a current grant from the National Institutes of Health supports research on the mechanical properties of normal and pathological bone.

Burstein came to Cornell from Case Western Reserve University, where he had been since 1967 as engineering director and later director of the biomechanics laboratory and as an engineering faculty member in solid mechanics, surgery, and biomedical engineering. From 1962 to 1967 he was chief research engineer at the Hospital for Joint Diseases in New York City. He holds three degrees in mechanical engineering—a bachelor’s degree from The Cooper Union, granted in 1959, a master’s from the Polytechnic Institute in Brooklyn (1961), and the Ph.D. from New York University (1968).

Burstein is active as a consultant to hospitals, medical schools, biomechanical firms, and government organizations. His honors include election to the American Academy of Orthopaedic Surgeons as an associate member, and awards for professional publications from the American Orthopedic Foot Society and the U.S. Ski Association. His publications include a text, *Orthopaedic Biomechanics*, written with V. H. Frankel and published in 1970.

A new member of the regular Sibley School faculty is Dean L. Taylor, assistant professor of mechanical engineering, whose specialty field is eigenproblems and their application in vehicle dynamics and vibration. Taylor received his undergraduate education at Oklahoma State University, which awarded him the B.S. degree in 1971; he was chosen by the Oklahoma alumni association as the outstanding graduate of that year. For graduate study, he went to Stanford University, where he received the Ph.D. degree in applied mechanics in 1975. He spent last year as an engineer in the Applied Physics Laboratory at Johns Hopkins University. His experience also includes summer work with IBM and Exxon.

In the Department of Geological Sciences, Robert W. Kay has joined the regular faculty and Godratollah Farhoudi, from Pahlavi University in Iran, is here for the year as a visiting professor.

Kay, a specialist in the application of trace element and isotope geochemistry to the petrogenesis of igneous rocks, has been appointed an assistant professor. His current research includes studies of plutonic and volcanic rocks of the Aleutian Islands, and of radiogenic isotopes in porphyry copper deposits in the Philippines. His wife, Susanne, has been appointed a research associate in the department. Kay received the B.A. degree in chemistry from Brown University in 1964, did graduate work in geology at the University of Minnesota, and earned the Ph.D. in geology at Columbia University in 1970. He was an assistant professor of geology at Columbia for five years, and for the past year was a research geophysicist at the University of California at Los Angeles.

Farhoudi specializes in the geological interpretation of remote sensing imagery, including aerial and satellite photographs, and applications such as city and natural resources planning. He received the M.S. degree from Universität Clausthal (West Germany) in 1958 and the doctorate in mine and geological surveying from Technische Universität in Berlin in 1967. He has been a member of the Department of Geology at Pahlavi Univer-
sity since 1967 and served as chairman for the past three years. His professional experience includes four years with mining and geophysical companies in West Germany.

New to the Department of Computer Science is Assistant Professor Robert S. Cartwright, a specialist in programming languages, semantics, and verification. Cartwright was graduated from Harvard College in 1971 with the A.B. degree (magna cum laude) in applied mathematics, and received the M.S. and Ph.D. degrees in computer science from Stanford University in 1973 and 1976, respectively. He has had experience as a computer programmer at the University of Missouri and in Harvard’s computer graphics laboratory, as well as in teaching and research as a graduate assistant in the Stanford Artificial Intelligence Project.

In the Division of Basic Studies, Robert H. Lieberman has been appointed assistant professor. His responsibilities include coordinating and conducting the course in Engineering Perspectives that is required of all freshmen. Lieberman is a 1962 graduate of the Polytechnic Institute of Brooklyn and studied at Cornell for the M.S. degree in electrical engineering, granted in 1965. Since then he has taught mathematics and physics at the Technical College of Skelleftea in Sweden, at Bethune–Cookman College, at the Hong Kong International School, at Hampton Institute, and, since 1969, at Ithaca College. He is the author of a novel, Paradise Rezoned (Berkley Books, 1975), and has published more than fifty short stories and articles in the United States and in translation in Sweden.

A number of visiting fellows are also at the College this year to participate in research programs.

Spending the academic year at the School of Electrical Engineering are Christen Rauscher from the Swiss Federal Institute of Technology in Zürich, and Rodney Tucker from the University of Melbourne, Australia. Toshihisa Tsukada from the Central Research Laboratory of Hitachi, Ltd., in Tokyo, was a visiting fellow for several months this fall.

In the Department of Geological Sciences, Suparka (one name only) from the Indonesian National Institute of Geology and Mining is here for the fall term; Remy Louat from ORSTROM in New Caledonia was a visitor for the month of November; and Allan Spence, professor in the Department of Engineering Science at the University of Oxford, England, was here for a month in early fall.

Visiting fellows at the School of Operations Research and Industrial Engineering for the academic year are Edward A. Danielian from the University of Yerevan in the U.S.S.R., who is here as an exchange scholar; and Frederick R. Giles, a recent Ph.D. who spent last year at the Center for Operations Research and Econometrics of the University of Louvain, Belgium. Phillip D. Straffin, associate professor of mathematics at Beloit College, Wisconsin, was here for the fall term.

Visiting fellows in the Department of Structural Engineering during parts of the fall term were Luigi Cedolin, associate professor at Politecnico in Milan, Italy, who was here as a NATO-National Research Council fellow; and Mustafe Isreb, assistant professor at the University of Riyadh in Saudi Arabia.
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 the period February through April 1976. Earlier publications inadvertently omitted from previous listings are included here in parentheses. The names of Cornell personnel are in italics.

APPLICATION AND ENGINEERING PHYSICS


Hutchins, B. A.; Rhodin, T. N.; and Demuth, J. E. 1976. Surface crystallography of the c(2x2) sodium overlayer on Al(100). Surface Science 54:419-433.


CIVIL AND ENVIRONMENTAL ENGINEERING


**COMPUTER SCIENCE**


**ELECTRICAL ENGINEERING**


### GEOLOGICAL SCIENCES


### MECHANICAL AND AEROSPACE ENGINEERING


### OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING


Weiss, L. 1976. The normal approximation to the multinomial with an increasing number of classes. *Naval Research Logistics Quarterly* 23:139-149.

### THEORETICAL AND APPLIED MECHANICS


Alternatives for Technology

The only consensus about technology these days seems to be that it has a determining role in modern life, not only economically and materially, but politically, environmentally, and socially. The directions that technology take affect all facets of human activity and constitute a major influence on the quality of life. As awareness of this reality grows, it is hardly surprising that analysis, criticism, proposals, predictions, warnings, and controversy abound. Considerations of alternatives are approached from many points of view, lead in myriad directions, intertwine and conflict in complex ways.

The articles we have assembled in this issue don't begin to provide a representation of current thought about technology alternatives, or even a cross section of attitudes and pertinent activities at the Cornell College of Engineering. (The whole area of possible nuclear fusion technology, for example, is not treated, though we hope it will be in a future issue.) But touching as they do on broad concepts, practical assessments, large-scale planning, and individual and small-scale initiative, these articles illustrate the diversity in perspective and scope that characterizes development in this crucial area.

Engineers at Cornell and elsewhere have a stake in the choice of technology alternatives, not only as citizens, but as participants in the development and implementation of specific projects, and it is fitting that faculty members and students be aware of the implications and possibilities of technical work. Now more than ever before, there is need for the exchange of ideas, and for investigation and value-conscious assessment of alternatives in the shaping of technology.

—The Editor
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