annually at different cities where these branches are located.

Genetics Institutes

There are four chairs of genetics in Japanese state universities, one in the Faculty of Science of Tokyo University, which I have mentioned already, another in the Faculty of Agriculture in Kyoto University, still another in the Faculty of Medicine in Osaka University, and the fourth one in the Faculty of Science in Okayama University. However, genetics forms an important part of the courses of the biology departments in most of the universities in Japan. Some medical schools also have lectures on genetics, although the hours devoted to genetics are unreasonably few.

The establishment of the National Institute of Genetics in 1949, at Misima, was an important event in the history of genetics in Japan. The institute has six departments. About 30 research members studying materials ranging from man to virus are occupied in various fields of this science. Although they are working under the pressure of severe handicaps as a result of various difficulties of present-day life in Japan, they will undoubtedly produce in their studies something that will contribute to the future advancement of genetics—at least we are hoping so.

References and Notes

1. A. Weismann and C. Ischikawa, "Uber die Bildung der Richtungskörper bei tierischen Eiern" *Ber. naturforsch. Ges. Freiburg Breisgau* 3 (1887); "Uber Befruchtungserscheinungen bei den Dauereiern der Daphniden," *Biol. Zentr.* 8 (1888); "Uber Parakopulation im Daphnidenei, sowie über Reifung und Befruchtung desselben," *Zool. Jahrb. Abt.* 24 (1889).
2. K. Toyama, "Mendel's law of heredity as applied to the silkworm cross," *Biol. Zentr.* 26 (1906).
3. ———, "Maternal inheritance and Mendelism," *J. Genet.* 2, No. 4 (1913).
4. Y. Tanaka *et al.*, *Genetics of Silkworm* (Tokyo, 1952) (in Japanese).
5. Y. Tazima *et al.*, *The Recent Advances in Gene Analysis of the Silkworm* (Tokyo, 1951) (in Japanese).
6. Y. Tanaka, "A Study of Mendelian factors in the silkworm, *Bombyx mori*," *J. Coll. Agr. Tôhoku Imp. Univ.* 5, No. 4 (1913); "Gametic coupling and repulsion in silkworm," *ibid.* 5, No. 5 (1913).
7. H. Hashimoto, "Genetic studies on tetroploid females in the silkworm," *Bull. Imp. Sericultural Expt. Sta.* 8, No. 7 (1933) (in Japanese); and several other papers.
8. Y. Tazima, "A simple method of distinguishing sex of silkworm by means of pattern characters," *J. Sericult. Sci. Japan* 12, No. 3 (1941) (in Japanese); and many other papers.
9. T. Yokoyama, "Sericultural Experiment Station as headquarters for sericultural technical improvements," *Silk Digest* 86 (1953).
10. T. Higurashi, "Experiments of the improvement of fish race," *J. Imp. Fisheries Inst. Japan* 10 (1914) (in Japanese).
11. Y. Matsui, "Genetical studies on gold-fish of Japan," *ibid.* 30, No. 1 (1934).
12. M. Ishihara, "On the inheritance of body-color in *Oryzias latipes*," *Mitt. med. Fak. Univ. Kyushu.* 4, No. 1 (1917).
13. T. Aida, "On the inheritance of color in a fresh-water fish, *Aplocheilus latipes* Tenminck and Schlegel, with special reference to sex-linked inheritance," *Genetics* 6 (1921).
14. H. Kikkawa, "Mechanism of pigment formation in *Bombyx* and *Drosophila*," *Genetics* 26, No. 6 (1941).
15. T. Furuhata, "On the heredity of the blood group," *Japan Med. World* 7, No. 7 (1927).
16. T. Komai, *Pedigrees of Hereditary Diseases and Abnormalities Found in the Japanese Race* (Kyoto, 1934); *Pedigrees of Hereditary Diseases and Abnormalities Found in the Japanese Race*, 1934–1943 (Tokyo, 1947).
17. S. Ikeno, "The spermatozoid of *Cycas revoluta*," *Botan. Mag. Tokyo* 10 (1896) (in Japanese).
18. S. Hirase, "On the spermatozoid of *Ginkgo biloba*," *ibid.* 10 (1896) (in Japanese).
19. S. Ikeno, "Eine Monographie über die Erblichkeitsforschungen bei der Reispflanze. *Bibliogr. Genet.* 3 (1927); "Eine Monographie der Erblichkeitsforschungen an den Plantaginaceen, *ibid.* 3 (1927).
20. ———, *Zikken-Idengaku* (Tokyo, ed. 1, 1913).
21. Y. Hoshino, "On the inheritance of flowering time in peas and rice," *J. Coll. Agr. Tôhoku Imp. Univ. Sapporo* 6 (1915).
22. H. Kihara, "Cytologische und genetische Studien bei wichtigen Getreidearten mit besonderer Rücksichtigkeit auf das Verhalten der Chromosomen und die Sterilität in den Bastarden," *Mem. Coll. Sci. Kyoto Imp. Univ. Ser. B* 1, No. 1 (1924); and many other papers.
23. H. Kihara and F. Lilienfeld, "A new synthesized wheat," *Proc. 8th Intern. Congr. Genet.* (1948).
24. Y. Imai, "Genetic studies in morning glories, I," *Botan. Mag. Tokyo* 33 (1919) (in Japanese); and many other papers.

World Symposium on Applied Solar Energy

Guy Benveniste and Merritt L. Kastens

With the purpose of fomenting and accelerating solar energy research and utilization, the Association for Applied Solar Energy, the University of Arizona, and Stanford Research Institute sponsored the first World Symposium on Applied Solar Energy and the associated Conference on Solar Energy in Tucson and Phoenix last November. More than 1000 scientists, industrialists, and interested laymen gathered to listen to 130 papers and addresses and to discuss ways to use the energy of the sun. The meetings were made particularly significant by the large attendance from abroad. From all over the world, nearly every laboratory or organization concerned with solar energy research sent representatives to Phoenix. Thanks to the Ford and Rockefeller Foundations, UNESCO, the Office of Naval Research, the U.S. Air Force, the National Science Foundation, and the National Academy of Sciences, 130 foreign delegates from 31 different nations were able to join their American colleagues in the Valley of the Sun.

The participants were also able to observe nearly 100 working exhibits of practical developments at a special engineering exhibit located in the strong Phoenix sunshine. Exhibitors from this country and abroad participated in this special event.

The significance of these meetings will probably be felt as an upsurge of activity and research follows the discussions and evaluations that took place. There is little doubt that the papers discussed, and the close relationships that were established among scientists, engineers, economists, industrialists, and businessmen will advance the day when we may rely more directly on solar energy.

The papers delivered at the conference in Tucson were more technical in nature, while those presented in Phoenix were of more general interest and served as an introduction to solar energy research for the many nonspecialists who attended the meetings. The subjects of the papers at both meetings can be roughly divided into three categories: (i) solar energy measurements; (ii) increasing the world's supply of energy (mechanical, electric, and chemical); and (iii) increasing the world's supply of food (for both animal and human consumption).

Within these categories, some papers were devoted to basic research considerations, some to engineering problems related to the use of solar energy, and still others to the economic and industrial significance of the technical possibilities of solar energy.

The authors are, respectively, research engineer and assistant director of Stanford Research Institute, Menlo Park, California.

Solar Energy Measurements

A technical conference cosponsored by UNESCO on solar energy measurements was held in Tucson at the beginning of the symposium. This conference was under the chairmanship of S. Fritz of the U.S. Weather Bureau.

Although many radiation-measuring stations exist in many countries, it is apparent that data about insolation are not readily available for large areas. The problems considered in Tucson included the type of additional information that is most needed—the degree of measurement accuracy that is sufficient for most uses and the instruments that are required to perform these measurements correctly and simply enough to permit their widespread use throughout the world.

A. J. Drummond of the Union of South Africa reported that probably the best integrated solar measuring network in existence to date is under the sponsorship of the Weather Bureau of the Union of South Africa. However, even the delegates from South Africa were very much aware that this network is not extensive enough and that a much larger network of stations is needed. These new stations need not all make measurements with the accuracy and detail with which they are now made in most meteorological stations. But by combining the more general radiation data that would be obtained for large areas with the detailed data available in the existing stations, sufficient knowledge would be gained about the characteristics and distribution of solar radiation to allow for planning the construction of solar houses, solar engines, solar furnaces, and other applications for utilizing the sun's energy.

A total of 14 papers was presented during the radiation measurement conference. Among these, the papers of H. Stratmann of the Kohlenstoffbiologische Forschungsstation in Essen, Germany; R. Kassander of the University of Arizona; L. Morikoëfer of the Physikalisch-Meteorologisches Observatorium at Davos Platz, Switzerland; and F. Tonne of the Institut für Tageslicht Technik in Stuttgart, Germany, described radiation measurement instruments. M. Migeotte of the Université de Liège, Belgium; R. Dogniaux of the Institut Royal Meteorologique de Belgique; and A. J. Drummond also described instruments that they believed to be well suited for "mass utilization." Unfortunately, there was no agreement on the type of instruments best suited for these measurements. Of the various suggestions made, none were accepted by all those present. However, P. Courvoisier of the International Radiation Commission said after the meeting, "After all, we have not come here to solve all the problems at one time. Now we can go back, knowing what is wanted, and in due course someone will come up with the right ideas at the right time."

Increasing World Energy Supplies

How to convert solar energy into mechanical, electric, or even chemical energy—this was the main problem and one that nearly everyone at the symposium was anxious to talk about. Physicists, physical chemists, engineers, and economists attacked the problem according to their own disciplines, and the industrialists and businessmen who had joined them attempted to evaluate and correlate the various approaches. The conversion processes considered were (i) thermal conversion processes—flat-plate collectors and concentrators; (ii) electric conversion processes—photoelectric cells, photogalvanic cells, and thermocouples; and (iii) photochemical processes.

Thermal Conversion Processes

Flat-plate collectors. In the solar energy field there are two schools of thought. One is dedicated to concentrating solar energy, while the other is devoted to collecting solar energy with flat-plate collectors at relatively low temperatures. The flat-plate collectors make use of the hothouse effect, absorbing the radiation on a dark surface and inhibiting reradiation loss by appropriate insulation and usually one or more parts of glass cover plates. These flat-plate collectors have been studied for several years, particularly by H. C. Hottel at Massachusetts Institute of Technology (*1*). Their characteristics are well known and they are efficient as long as the output temperatures needed are low. Flat-plate collectors used to heat water to a temperature of about 50° to 70°C may well operate with an average efficiency of 50 percent; they are very inefficient at temperatures above 100°C.

Up until the present, most flat-plate collectors have been used in hot-water installations, space-heating installations, and in mechanical pumps.

Solar water heaters using flat-plate collectors have been in use in the southern part of the United States for many years. Their usefulness has therefore already been described in the literature (*2*).

H. Heywood of the Imperial College of Science and Technology, London; I. Tanashita of Keio University, Tokyo; and L. F. Yissar of Holon, Israel, described installations that have been built in their countries. These installations consist usually of a flat-plate collector area (from 30 to 60 square feet, depending on climate and consumption) connected to an insulated storage tank (50 to 100 gallons) that is located about 2 feet above the collector to permit thermosiphon flow of the heated water. These installations were described as economical and efficient.

J. Hobson of Stanford Research Institute indicated in a paper concerned with the economics of solar energy that, as a rule of thumb, solar water heaters are economical wherever competing fuels cost more than $1 per million British thermal units—assuming, of course, that there is enough sunshine. He believes that a vast rural market exists for such heaters and that solar water heaters could be manufactured in the United States in large quantities for this potential market.

Space heating and space cooling were considered in several papers. R. W. Bliss, Jr., of Amado, Ariz.; M. Telkes of New York University; G. O. G. Löf of Denver, Colo.; and H. C. Hottel of Massachusetts Institute of Technology described their experiences with the solar houses they have built in the past and the improvements they would now propose. A paper describing a system using solar-energy collectors in conjunction with a heat pump installation was described by P. Sporn and E. R. Ambrose of American Gas and Electric Service Corporation. Various other papers were presented and were followed by a discusison of the architectural problems of solar collectors.

The papers indicated that solar collectors with auxiliary conventional heat sources can supply all space-heating requirements of dwellings with adequate roof area in regions with average or better-than-average climates. The installations that have been built in the United States have been comparatively expensive, and the cost of producing solar British thermal units for space heating has competed with difficulty with the cost of conventional heat sources. To date, most of the solar installations built in the United States have been built in or near cities, where fossil fuels are relatively inexpensive. The solar houses built in Denver, Colo., (*3*), Cambridge, Mass., (*4*), and Dover, Mass., (*5*), were all located near adequate fuel markets. The only exception, the Bliss solar installation built in the southern Arizona desert, still has to compete with installations using bottled gas, which is fairly inexpensive in that part of the United States. The Bliss house, using an outdoor, hot-air solar collector and rock bin for storage, can be both heated and partially cooled by means of its solar-collector installation. The cooling cycle consists essentially of storing the coolness of the night desert air in the "rock-bin" storage system; the cool air is used during the day by circulating house air through the rock pile. The installation is reported to have cost $4,000 (*6*), which is quite an investment for a small space-heating-and-semicooling plant, even in this country, where we are willing to pay more than other peoples to be comfortable during cold and hot spells.

Still, there should be little doubt that space heating, and ultimately, space cooling will become important uses of solar energy. It is inevitable that in all areas of the world where fuels are relatively expensive and where some sunshine and roof space are available, man will sooner or later turn to the sun to heat his home.

Further research in finding ways of integrating solar collectors into the design of homes and of reducing heat losses and costs is bound to make this application of the sun's energy an economical possibility. This research effort is important since space heating and cooling energy requirements represent about 30 percent of all the energy that is consumed in the United States today.

Another interesting use of flat-plate collectors is in mechanical pumps. Using the sun to generate power has been the dream of men for many years. During the last century, many American engineers devoted much time and effort to developing solar pumps. The attempts of Ericson (1888), Boys (1900), and Shuman (1906) are well known today (*7*). Their efforts usually failed because the equipment developed was bulky and expensive and because, at that time, the competing fuel—coal—was becoming less and less expensive as mining techniques were improved constantly.

The hundreds of Arizona farmers who visited the solar exhibit in Phoenix observed a simple Italian solar pump in action. Such was their interest that it has been conservatively estimated that 50 of these pumps, manufactured by the Somor Company in Lecco, Italy, could have been sold on the spot if they had been available.

This pump utilizes an ordinary flat-plate collector to vaporize sulfur dioxide which drives a simple, one-cylinder motor that is cooled by the pumped water. The pump converts solar energy into mechanical energy at about 4-percent efficiency.

In his paper on the "Economics of solar energy," J. Hobson estimated the cost of this power to be, in optimum circumstances, between 5 and 10 cents per kilowatt hour. This figure reflects the high initial price of these devices and the low load factor under which they must operate with intermittent solar energy. However, 10 cents per kilowatt hour is not expensive power where other fuels are not available and where man must depend on animal power or even his own power for his daily bread.

Some recent developments with selective surfaces indicate that it may be possible to reduce the cost of flat-plate collectors appreciably in the near future. Probably of greatest interest in this respect was a paper presented by H. Tabor of the Research Council of Israel. He reported on the possible use of selective surfaces to obtain substantially higher temperatures than are possible with ordinary flat-plate collectors.

A selective surface can be defined as a good absorber of sunlight and a poor emitter of thermal radiations. Sunlight comes mostly in short wavelengths of 300 to 2000 millimicrons. On the other hand (from Wien's displacement law), the thermal radiation emitted by a body heated to 300° to 400°C has wavelengths mostly above 2000 millimicrons. A selective surface is therefore absorptive to short-wavelength radiations and reflective to long-wavelength radiations. It absorbs sunlight readily and emits little heat.

Naturally, most good conductors with a low emissivity coefficient will also be highly reflective. Tabor gave the example of a highly polished aluminum plate that may have an emissivity of 0.039 at 400°F but is at the same time a poor absorber of sunlight. The approach Tabor took was to deposit a very thin film on the bright metal base to make the surface appear black in the visible spectrum. These deposits can be made with metallic smoke films like the gold smoke filters that were produced by Harris and others at Massachusetts Institute of Technology (*8*) or by other techniques such as electrolytic plating and chemical or electrochemical surface treatment. Tabor experimented with blackening of copper and silver by sulfides, stopping the process when a very thin layer had been produced. He obtained an apparently black surface with a low emissivity. He also obtained such selective surfaces by depositing a very thin black nickel layer on various metals. In this way, he obtained a collecting surface, nearly black to the visible spectrum and therefore a good absorber of sunlight, but still highly reflective to long-wavelength radiation and a poor emitter of heat.

Even with such selective surfaces, the solar collector still requires a glass cover to reduce convection heat losses. Tabor believes a collector-motor device using a surface with an emissivity $E = 0.1$ and with the space between the metal and the glass partially evacuated could yield a yearly over-all theoretical Carnot efficiency of 14 percent and an average temperature of 172°C. If no vacuum is used, the estimated over-all efficiency is about 8 percent. It is therefore probable that solar pumps using such surfaces could operate at average efficiencies of about 10 percent, 3 times as high as presently. Such an increase in efficiency without a corresponding increase in the cost of the collectors could mean a very substantial cost reduction. A pilot plant was built in Israel, and further experimental tests will be carried on in the near future.

Concentrators. To a "flat-plate collector man," all attempts to concentrate solar energy are hopelessly expensive and difficult, since moving mirrors and structures are required. To a "concentrator man," all attempts to use flat-plate collectors are a waste of time, since the collectors are clumsy, large areas are required, and no high temperatures are attainable. However, the meetings in Tucson and Phoenix indicated that concentrators also can certainly be used successfully. They have been used in many different ways. Small parabolic reflectors with an area of about 1 square meter have been shaped into solar cookers; large accurate parabolic reflectors are used as solar furnaces; cylindroparabolic collectors have been used in steam-boiler installations, and, finally, arrays of flat mirrors aimed at a single target can be used for many purposes.

Depending on the concentration ratio, temperatures can be reached all the way from ambient temperature to 3500°C. If reasonable efficiencies are desired, it can be shown that flat-plate collectors are best used for temperatures up to 70° or 80°C, selective-surface collectors up to 175°C, and concentrators from 100°C to 3500°C. The main disadvantage of concentrators is that the collector or an auxiliary mirror must track the sun, and the mechanism that is required to do this is usually expensive.

The papers presented by J. A. Duffie of the University of Wisconsin; M. L. Ghai of General Electric Company; and M. Telkes of New York University described various models of solar cookers. J. Hobson indicated in his paper that there is little doubt that solar cookers are economical. There is no doubt, too, that those developed to date (*9*)—mostly outdoor solar cookers where food is cooked at the focus of a small parabolic reflector—are not yet liked and accepted by the people for whom they are intended and that they are not an acceptable substitute for the age-old custom of cooking with charcoal or wood or even cattle dung, as in India or Egypt. The solar cooker cannot after all replace the conventional brazier completely, at least not at night or on rainy days. Also, and more important, these cookers now sell for about $15 (*10*) and there are few poor people, especially in India and in Egypt, who can afford them.

New research efforts must be directed

toward designing a more practical and economical solar cooker before any vast number of the poor populations of the earth agree to change their customary cooking methods. Meanwhile various American manufacturers are examining the possibility of marketing cookers for the large barbecue and picnic market in this country.

Much interest was shown in solar furnaces at the symposium. F. Trombe of the French National Center for Scientific Research, reported on the work at the Mont Louis Laboratory in the Pyrenees, where a 35-foot furnace—the largest in the world—has been in operation for several years. There is no doubt that the solar furnace is a well-established high-temperature research tool that permits operation free from contamination by flames, magnetic fields, and the like, at temperatures as high as 3000° to 3500°C.

Some of the participants expressed the belief that the solar furnace is also a potentially useful industrial tool. To introduce French industry to the possibilities of this tool, G. Dupouy, director of the French National Center for Scientific Research, announced that construction was beginning on a 1000-kilowatt furnace (10 times larger than the one at Mont Louis) to be located in the Pyrenees not far from existing installations. This furnace will be used for the production of ceramic and metallurgical materials.

The most interesting report on steam generation was prepared by V. A. Baum of the heliotechnical laboratory of the U.S.S.R. Academy of Science. Some years ago the Soviets built a large (80 square meters) parabolic concentrator to generate steam, which was used in a refrigeration cycle. Although this installation was bulky and expensive, it was the first time solar energy was used for the production of ice. Baum reported that he could produce 250 kilograms of ice per day with this unit.

In his paper, Baum described the plans for a centralized 1000-kilowatt solar power plant now on the drafting boards of his laboratory. This plant will be able to generate steam at 350°C and 16 atmospheres pressure. It would consist of a central black-body boiler on a 40-meter tower at the focus of 23 concentric railroad tracks on which railroad cars with flat mirrors would focus the sun's rays to the unique target. The mirrors would follow the apparent path of the sun by traveling during the day around the track. The target would also rotate slowly during the day to follow the sun. This plant would then produce steam for electric-power generation and use low-pressure steam to heat homes in winter and to cool them in the summer with a refrigeration unit.

Some interesting work with concentrators has also been done in India by K. N. Mathur and K. L. Khanna at the National Physical Laboratory of India and by A. L. Gardner of the Indian National Scientific Documentation Centre. Their interest has been mostly hot-air engines (*11*), and Gardner has developed very simple and very cheap concentrators consisting of arrays of flat mirrors aimed at a single target.

One cannot leave this particular subject without mentioning the pioneering work in this country of Charles Abbott of the Smithsonian Institution, who has built (*12*), and is still building, small solar engines with specially designed flash boilers to permit rapid steam generation under exposure to sunshine.

Electric Conversion Processes

Photovoltaic cells. Much attention was devoted at the symposium to recent developments with voltaic cells for converting sunlight directly into electric energy. Nine papers were devoted to this subject. G. L. Pearson and M. B. Prince of Bell Telephone Laboratories reported some of their work with silicon cells that has received considerable attention in the press and technical literature (*13*). The converter developed by Bell Laboratories consists essentially of a silicon crystal with a small amount of arsenic impurity covered with a very thin layer of boron impurities (about 10^{-4} inch deep). The crystal so prepared is about 1 inch in diameter and 0.04 inch thick. A number of such small crystals or wafers may be connected in series and assembled on a common backing; they convert solar energy into electricity at convenient direct-current voltages. These cells are now being tested in operating telephone repeaters near Americus, Ga.

The papers presented at Tucson and Phoenix did not add much to what has already been said on the subject. Silicon cell batteries have reached, in the laboratory, conversion efficiencies of 11 percent, and the theoretical maximum efficiency that could be reached is about double that figure. It was suggested by E. D. Jackson of Texas Instruments, Inc., that by placing spectrally selected semiconductor cells one on top of the other in stacks, higher efficiencies could be obtained per unit area. Jackson calculates that three such selected wafers could possibly boost the total spectral absorption from 45 to 69 percent, while a stack of ten such units would increase this possibly to 86 percent, at the same time increasing the cost of the collecting area at least tenfold. With land costs at their present level, it is doubtful that such arrangements could have much economic significance except perhaps in spaceship power-supply installations.

No final economic evaluation of these cells is possible at this early stage, but W. R. Cherry of the Signal Corps Engineering Laboratory indicated that present cost of 1 kilowatt hour obtained from a photovoltaic cell may be around $140 while 1 kilowatt hour obtained from flashlight cells may cost only $23.70. At such prices, he indicated, applications are bound to be limited. On the other hand, D. Wolfe of the Radio Corporation of America suggested at the final session in Phoenix that in the future mass production techniques may well bring these prototype costs down 100- or even 1000-fold.

Discussion of other photovoltaic materials included reports by D. C. Reynolds of Wright Air Development Center on experience with cadmium sulfide cells. Reynolds and his coworkers have been able to obtain an over-all conversion efficiency of about 1 percent. Another paper by J. Loferski of the Radio Corporation of America indicated that cadmium telluride, gallium arsenide, and indium phosphide would be the most efficient materials for photovoltaic converters. However, the gain in efficiency of these materials over silicon is not very large, while costs might be even higher.

Thermocouples. One session in Tucson was also devoted to thermocouples and to thermoelectric generators. T. Momota of the Electrotechnical Laboratory, Tokyo, reported experiments with reduced titanium dioxide semiconductors in which efficiencies slightly in excess of 1 percent at 550°K were obtained. From his results, he predicted that lead telluride might permit efficiencies as high as 16 percent. M. Telkes of New York University suggested the possible use of a zinc antimony alloy system with efficiencies above 3 percent.

Further research in this field may ultimately yield a much cheaper collecting surface with, perhaps, lower efficiencies than the silicon converter mentioned previously. The thermocouple material is relatively inexpensive, and the collector—even with a glass cover—may cost much less than silicon or other photovoltaic materials. It is still questionable whether such thermocouples can give useful efficiencies and thus make it possible to realize the advantage of their lower installation cost. Further research may give us answers to these questions.

Photogalvanic cells. One paper by K. M. Sancier of Stanford Research Institute described the various types of photogalvanic cells that have been known for years. His experience with certain of these cells indicated a conversion efficiency not far different from those attainable with thermocouples. He described a prototype cyclic photogalvanic cell with a counter half cell consisting of a graphite-oxygen electrode and the photogalvanic half cell—a copper-copper oxide cell that developed an efficiency of 0.1 percent. These cells might be used as a continuous power source without the consumption of electrode material or electrolyte. This paper indicated that further research in this field may prove profitable.

Photochemical Conversion Processes

Probably one of the most promising attempts at converting solar energy to power is through the production of hydrogen by the photochemical breakdown of water under exposure to sunlight. Various organic and inorganic photocatlysts that will absorb sunlight and transmit the absorbed energy to a second reactant that will initiate the decomposition of water are used in most reactions. In the decomposition reaction, the photocatalyst and all other reagents are regenerated so that only water is consumed. It is still too early to know whether such experiments will be completely successful; but if they are, fairly high maximum efficiencies of the order of 30 to 40 percent could be expected.

The obvious advantages of obtaining hydrogen in such a reaction are (i) the collecting surface could be relatively simple, requiring no insulation; (ii) hydrogen can be stored easily and cheaply; (iii) hydrogen may be converted into electric energy at very high efficiency in hydrogen-oxygen fuel cells such as those now being developed in England.

L. J. Heidt of Massachusetts Institute of Technology has been working for several years with reactions that use ultraviolet light and solutions that contain ceric perchlorate and perchloric acid. The maximum theoretical efficiency of this reaction is low since only a small portion of the sun's spectrum can be used. Until now, only small quantities of hydrogen have been obtained. R. J. Marcus of Stanford Research Institute (*14*) has been experimenting with slightly more complex photochemical reactions to obtain hydrogen and oxygen from water.

Increasing the World's Food Supply

Solar energy has been used for a long time to supply man with food. Unfortunately, the present food supply is not sufficient to feed all the inhabitants of the world with an adequate diet, and science is being called upon to explore new and more efficient techniques of food production.

The interest of the biologists and engineers at Tucson and Phoenix was concentrated on the problems of (i) increasing the world supply of fresh water with solar stills to convert saline or brackish waters into fresh water for domestic or agricultural uses, (ii) finding more efficient plant cultures to increase the world supply of food directly, and (iii) increasing the rate of growth of certain crops by using reflectors or other auxiliary heat collectors.

Solar stills. The interest in converting saline water into fresh water has been spearheaded in this country by the saline conversion program of the Department of the Interior. The seven papers on solar water conversion described much of the research that has been carried on under this program.

The solar stills developed to date, although they are adequate to supply small quantities of water for human and possibly animal consumption, are still too expensive for use in large-scale irrigation projects. New developments in the field were reported by American and Algerian researchers. Tilted stills have been developed by M. Telkes of New York University and by J. Savornin of the Université d'Alger. Plastic stills developed by J. Bjorksten and P. Lappala of Bjorksten Research Laboratory show promise of reducing costs further. The papers and the results presented indicate that although solar stills cannot produce fresh water at prices acceptable to large-scale consumers such as farms and large cities, there is no doubt that small stills can provide drinking water at reasonable prices in many areas of the world where there is none available. For example, there is considerable interest now in Australia—where sheep are raised and where fresh water is rare—in using stills to obtain fresh water from brackish waters.

Efficient plant cultures. One of the most efficient plant cultures that has received considerable study in recent years is an algae called *Chlorella*. Many papers were therefore devoted to its characteristics. While no one exactly agrees on the energy conversion efficiency of *Chlorella*, it appears that under favorable conditions, *Chlorella* will do better than most higher plants. *Chlorella* therefore may provide a technique for increasing the world's food supply and possibly even for producing fuels for use in conventional boilers. Unfortunately, to date no strain of *Chlorella* has been found that will grow profusely without somewhat complicated and costly equipment.

The results reported at the symposium by H. Tamiya of the Tokugawa Institute for Biological Research, Toyko, clearly indicate that the present estimated cost of growing *Chlorella* under the most favorable conditions is high. *Chlorella* proteins still seem to cost twice as much, roughly speaking, as proteins obtained from other sources. Tamiya estimated that *Chlorella* grown in a large 100-acre plant in Japan would cost 25.8 cents per pound. He estimated that in the United States these costs would be about 33.6 cents per pound. Taking into account the protein content of *Chlorella*, this means that *Chlorella* protein would cost about 57.3 cents per pound in Japan and probably retail at about 76 cents per pound. These prices are higher than the cost of proteins obtained from soybeans, mackerel, sardines, or whale meat in Japan, but considerably less than the cost of proteins from eggs, milk, pork, or beef. Indeed, Tamiya is hopeful that *Chlorella* can be used with other conventional foods to increase the protein consumption in his country.

There are other ways of growing *Chlorella* that show economic promise for future use. H. B. Gotaas of the University of California reported on experiments conducted in his laboratories on growing *Chlorella* in conjunction with waste disposal and sewage processing. His experiments show that very valuable food—perhaps cattle feed—may be grown on sewage at no appreciable additional cost over that of conventional sewage-treatment practices.

Of interest also from a nutritional point of view was a report by H. Fink of the University of Cologne, Germany, on an experiment in feeding rats a *Chlorella* protein diet. The experiment was reported a success. The rats not only liked *Chlorella*, but apparently showed a lesser tendency to suffer from liver necrosis, and they did just as well with *Chlorella* proteins as they did with more usual protein diets.

Mary Belle Allen of the University of California described photosynthetic nitrogen fixation with certain blue green algaes. She reported that it has been possible to grow rice with no nitrogen other than that fixed from the air by algae growing together with rice plants. In such a way it would be possible to maintain the fertility of rice fields at little additional cost.

Papers by N. W. Pirie of Rothamsted Experimental Station, Harpenden, England, and P. C. Mangelsdorf of Harvard University stressed the merits of higher plants as storers of solar energy. Their contention was that if as much time, attention, and care were devoted to certain higher plants as have been devoted to *Chlorella*, there is little doubt that increased growth efficiencies close to those demonstrated by some *Chlorella* strains would be obtained. Mangelsdorf pointed out that of approximately one-third million species of plants in the world, the world's people obtain the larger proportion of their food from approximately 12 species (potatoes, sweet potatoes, cassavas, cane, beets, rice, wheat, corn, soybeans, common beans, coconuts, and banana). The various types of plants mentioned (root plants, sugar plants, grains, beans, and trees) appeared to him as a promising field for the study of hybridization.

It is probable that in the years to come the emphasis of research will be directed toward attempts at modifying the genetics of higher plants to increase, among other things, their protein productivity.

Although no papers dwelt on the subject of agricultural aids, two exhibits at the engineering show illustrated the possible use of inexpensive collectors to increase ground heat and reduce frost damage.

Conclusions

As our fossil fuel resources dwindle, new energy sources will have to be found to satisfy man's requirements. Solar energy will play an increasingly important role in this reorientation together with such resources as fission and, possibly, fusion energy. Solar energy will also be put to more efficient use in supplementing the available world food supply.

Solar energy will best be used where the density of energy demand is low. It is doubtful that large energy consumers —aluminum plants and large manufacturing concerns—will ever rely much on solar energy. It is also doubtful that solar energy will be used significantly in crowded cities. On the other hand, it is apparent that many uses will be found for it in suburbs, in rural areas, and in isolated locations.

The symposium emphasized that scientists, engineers, and industrialists may now get together and profit from their knowledge. Much capital, much research, and much effort will be needed before solar energy can be used in the world by processes other than those nature has been using for a long time, but there is little doubt that this nearly inexhaustible supply will be put to use to improve man's standard of living.

Research is badly needed to solve many problems connected with solar energy. But more than isolated research is needed—more than that which has been done in the past. A concerted effort is required by all those concerned with these problems and by all those who realize the importance of finding new energy supplies to supplement our dwindling resources.

As a communication device, the solar symposium must be counted a success. Personal contact was established among investigators from all geographic and scientific origins. Thoughts and experiences were exchanged informally and in detail that is impossible in impersonal scientific publication.

Perhaps even more important, the status of solar technology was brought to the attention of men of government and industry who must ultimately realize any practical use of this energy source.

It may be hoped that this improved interchange of information and mutual stimulation will increase both the intensity of research effort and the rate of progress in solar engineering. If this further objective is achieved, this meeting will have advanced the day when man will be able to depend more and more on the sun for his supply of energy.

References and Notes

1. H. C. Hottel and B. B. Woertz, *Trans. Am. Soc. Mech. Engrs.* 64, 91 (1942).
2. H. M. Hawkins, *Florida Eng. and Ind. Expt. Sta. Bull. Ser. No. 18* (1947).
3. G. O. G. Löf, Selected results from design study—solar heated house at Denver, Colorado," *Proc. Space Heating with Solar Energy Symposium* (Massachusetts Institute of Technology, Cambridge, 1950).
4. A. Whillier, thesis, Massachusetts Institute of Technology, 1953.
5. M. Telkes, "Performance of the solar heated house at Dover, Massachusetts," *Proc. Space Heating with Solar Energy Symposium* (Massachusetts Institute of Technology, Cambridge, 1950).
6. The figure quoted by Bliss probably does not reflect much of the time and effort he placed into building his solar heating plant.
7. G. Benveniste, "Power from the sun," *Elec. West,* 115, No. 5, 71 (1955).
8. L. Harris, R. T. McGinnies, B. M. Siegel, *J. Opt. Soc. Amer.* 38, 583 (1948).
9. M. L. Ghai, *J. Sci. Ind. Research India* 12A, No. 3, 117 (1953).
10. The Ghai cooker developed at the National Physical Laboratory of India is now manufactured by Jeewanlal (1929) Ltd. in Calcutta.
11. K. N. Mathur and K. L. Khanna, "A brief resume of work on solar energy development at the National Physical Laboratory of India," *Proc. New Delhi Symposium on Solar and Wind Energy* (UNESCO/NS/AZ/191/Annex 21, 1954).
12. C. Abbott, "Sun power from reflectors," *Proc. 3rd ann. Conf. Atomic Energy in Industry New York* (1954).
13. M. B. Prince, *J. Appl. Phys.* 26, 534 (1955).
14. R. J. Marcus, *Science* 123, 399 (1956).

Elmer Drew Merrill, Administrator and Botanist

There are few prominent scientists of the present era who are so nearly self-taught in the field of their prominence as was Elmer Drew Merrill, whose total formal training in botany included but two one-semester courses taken as an undergraduate at Maine State College of Agriculture and Mechanic Arts (now the University of Maine). Offsetting this lack of formal training to some extent was an early interest in natural history that began even prior to his high-school days in Auburn, Maine, where he was born 15 October 1876. In Merrill's first real job, he was fortunate to be associated in a quasi-apprenticeship capacity with the agrostologist F. Lamson Scribner in the U.S. Department of Agriculture, for it was there that he gained a needed broader experience and training in systematic botany.

In 1902, Merrill went to the Philippines, where he progressed gradually to become director of the Philippine Bureau of Science, a position he left to become dean of the College of Agriculture and director of the Agricultural Experiment Station at the University of California. Six years later, he moved to the directorship of the New York Botanical Garden, and finally, in 1935, he became Arnold professor of botany, director of the Arnold Arboretum, and administrator of botanical collections at Harvard University, where he served until his retirement in 1946 at the age of 70. He then became Arnold professor of botany, emeritus.

Between 1919 and 1946, Merrill occupied administrative positions that would have effectively eliminated the possibilities of scientific research for most men. However, he was not only able to cope with administrative duties during much of his active career, but he also managed to carry on a sizable research program as well and produced more than 500 original scientific papers. His contributions to botany were in floristics, plant geography, plant nomenclature, and botanical bibliography and history. In his most recent book, *The Botany of Cook's Voyages,* published in 1954, he dealt critically with various ideas and theories relating to the area of origin of economically important plants and their dissemination during