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# DEVELOPMENT OF ALTERNATIVE ENERGY SCIENCE AND ENGINEERING IN THE CARIBBEAN

(NSF Grant No. INT-8302757

FINAL REPORT

Submitted to

NATIONAL SCIENCE FOUNDATION

By

Juan A. Bonnet, Jr.
Principal Investigator and Chairman
UNICA Science and Technology Commission

December 22, 1983

CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
UNIVERSITY OF PUERTO RICO — U.S. DEPARTMENT OF ENERGY

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# TABLE OF CONTENTS

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## I. EXECUTIVE SUMMARY

This was the third phase of a project whose primary objective is to develop the scientific and engineering capabilities of the universities and research institutes of the Caribbean and thereby to assist in the introduction of alternative energy solutions into the region. The project was conceived by the Science and Technology Commission of the Association of Caribbean Universities and Research Institutes (UNICA) and carried out under the leadership of the Center for Energy and Environment Research of the University of Puerto Rico. The financial support of the National Science Foundation greatly facilitated the accomplishment of the project's objective.

This part of the project consisted in a four-day Solar Energy Utilization Workshop for the Caribbean Basin held at the University of Florida in Gainesville. The workshop was carried out by personnel from the Solar Energy and Energy Conversion Laboratory, and the International Training Center for the Training in Alternative Energy Program. It included the basics of solar energy conversion and utilization with presentations on specific problems found in the Caribbean Basin. It also included site visits to review solar hardware development and demonstration projects in the Gainesville area. All the major lectures were videotaped.

A discussion workshop was held on the last day to develop specific organizational and research plans that will permit UNICA to strengthen its institutional capabilities to facilitate the search for solution to the pressing energy problems of the Caribbean Basin. Based on the cumulative experience of this workshop and the two previous ones-on wind energy in Barbados, December 1981, and on biomass energy in Puerto Rico in April 1982--a detailed proposal to implement cooperative projects is being prepared to be submitted to international funding institutions. The overall plan proposes, among other things, the compilation of a directory of Caribbean human and institutional capabilities and the creation of a Caribbean research endowment fund. In the education and training areas it provides for technical curriculum review, an energy auditors training program, a Caribbean universities information network and speakers bureau, and faculty enrichment through interchange programs. It also contemplates solar hardware information dissemination, technology transfer activities, improvement of solar systems maintenance, solar wind measuring equipment utilization, and video facilities.

The prioritization of this agenda resulted from discussions and interchanges with the end users, the UNICA contact persons. That in itself is one of the major accomplishments of this project.

The ensuing report summarizes the project's main activities and accomplishments.

# II. PROJECT REPORT

## 1. General

The universities and research institutes of the Caribbean region constitute an indispensable underutilized source of knowledge, expertise and institutional resources and facilities. This project is a major first step toward establishing a regional program of action to reinforce and expand these resources and apply them to the solution of the energy problems of the Caribbean Basin which are draining many of the national economies. On the other hand, the large potential for solar energy available in the area is not being properly exploited.

In this project, as far as we know, for the first time a representative group of the human resources in academic institutions of the Caribbean Basin, members of UNICA, has been brought together to analyze, discuss and develop joint planning for cooperative research projects in non-conventional natural energy sources. This goal was successfully accomplished as shown in the workshop conclusions and recommendations.

As the third phase of the project, a solar energy utilization seminar/workshop for the Caribbean Basin was carried out June 7-10, 1983 at the University of Florida in Gainesville. This report consists of two substantive parts and a set of complementary appendices. The conclusions and recommendations are extracted from the solar energy workshop but also include very important inputs from the previous two workshops, on wind and on biomass, which were funded under previous grants from NSF and the Exxon Educational Foundation.

## 2. Publications

One technical paper describing the procedures used to carry out this project was prepared. The paper entitled "Development of Alternative Energy Science and Engineering in the Caribbean" was prepared by J.A. Bonnet, Jr. and W. Koehler and presented at the II Interuniversity

Symposium of Energy held at the Universidad de Santiago de Chile, November 14-19, 1983. A copy of the paper is included as Appendix D.

A second paper, "Status of Renewable Energy Programs in Caribbean Islands" by the same authors, is being prepared based on the conclusions of this project and other information gathered. This paper will be presented at ENERGEX '84 in Regina, Saskatchewan, Canada, May 14-19, 1984.

## 3. Workshop Site and Content

The Solar Energy Utilization Workshop was organized and carried out by the Solar Energy and Energy Conversion Laboratory (SEECL) of the University of Florida. The International Training Center for the Training in Alternative Energy Technology (TAET) was utilized as the site. In addition, site visits were made to the Energy Research and Educational Park (EREP) and other solar utilization projects in the Gainesville area. Faculty and administrative personnel for the seminar were drawn from the TAET and SEECL programs.

The seminar stressed the fundamentals of solar energy utilization, emphasizing that the best available source should be used. Among the topics covered were characteristics of solar energy, measurement and modeling techniques for the Caribbean, heat transfer, preparation of materials, and standards and system optimization for tropical use. Applications for tropical elements were discussed and hardware prototypes shown and visited, including solar devices for water heating, space cooling, refrigeration, cooking, conversion to mechanical energy or to electrical energy, fresh water production, and the use of solar energy in preserving crops by drying and refrigeration. The papers "Solar Energy Conversion Research and Development at the University of Florida" and "The International Training Center in Alternative Energy Technology," both by Dr. Erich Farber, Co-principal Investigator of this project, describe the setting and many of the demonstration sites visited. A copy of the first of these two papers is included as Appendix E.

Demonstration sites of actual solar installations in the city of Gainesville were toured. This visit included a solar powered coin laundry, apartment buildings, a hospital, and the Gainesville airport. This latter is the world's largest solar powered building.

The workshop schedule is included as Appendix A.

A list of lectueres is included as Appendix C and a list of the participants as Appendix B.

## 4. Summary of Recommendations

The detailed conclusions and recommendations are included as Part III of this report. A summary of the main conclusions and recommendations follows:

a. Publication of a Caribbean directory of human and institutional resources in energy.

b. Establishment of a research endowment fund.

c. Establishment a program of regional faculty interchange.

d. Development of curriculum on energy conversion and alternatives courses.

e. Development of training programs in maintenance of energy hardware.

f. Establishment of UNICA speakers bureau.

g. Establismnet of extramural science student programs.

h. Acquisition of video equipment.

i. Acquisition of solar insulation and wind measurement instrumentation.

j. Establishment of energy audit programs.

k. Estabishment of a certification program for solar equipment.

l. Transferring solar equipment manufacturing technologies.

m. Energy system design, performance and maintenance workshop.

n. Cooperate and participate in energy demonstration projects of of the Caribbean Development Bank and the Organization of American States.

## 5. Evaluation

A comparison with previous workshops is not possible since not all the UNICA contact persons attended all three; some attended only two of the workshops. The general feeling is that the project is moving toward establishing a unique base for a more solid program to enhance the capabilities of UNICA member institutions.

On the last day of the seminar/workshop an evaluation questionnaire was distributed to each participant to elicit his views and reactions toward the activity. The results of the evaluation indicate that 55% of the respondents gave an overall rating of "good" and 27% of "excellent." The tabulation included here shows the percentage of the ratings given by the participants of the three UNICA alternative energy workshops.

A general review indicates that the solar workshop (#3) was superior in organization and logistics to the previous two. From the standpoint of speakers, workshop discussion and overall, the wind workshop (#1) was rated better than the others, but there is not a significant overall difference. In all cases more than 75% of the participatns agree that the workshops were successful to a greater or lesser degree in meeting UNICA goals.

It is important to remark here than non-UNICA contact persons who attended the seminars were also given the opportunity to answer the questionnaire. As one of the respondents wrote: "Keep up the good work, your life (in the Caribbean) depends on it."

# EVALUATION OF UNICA WORKSHOPS

| | I. WIND / 1981 (29 respondents) % Rating | II. BIOMASS / 1982 (13 respondents) % Rating | III. SOLAR / 1983 (11 respondents) % Rating |
|---|---|---|---|
| 1. Organization and Logistics | | | |
| Excellent | 27.18 | 31 | 45 |
| Good | 58.6 | 46 | 55 |
| Fair | 13.8 | 23 | 0 |
| Poor | 0 | 0 | 0 |
| 2. Speakers | | | |
| Excellent | 13.8 | 15 | 27 |
| Good | 72.4 | 62 | 55 |
| Fair | 13.8 | 23 | 18 |
| Poor | 0 | 0 | 0 |
| 3. Workshop Discussion | | | |
| Excellent | 55.2 | 15 | 27 |
| Good | 44.8 | 69 | 55 |
| Fair | 0 | 16 | 9 |
| Poor | 0 | 0 | 9 |
| 4. Overall | | | |
| Excellent | 22.4 | 0 | 27 |
| Good | 77.6 | 92 | 55 |
| Fair | 0 | 8 | 18 |
| Poor | 0 | 0 | 0 |
| 5. UNICA Goals | | | |
| Very successful | 21 | 0 | 27 |
| Successful | 40 | 46 | 27 |
| Somewhat successful | 12 | 46 | 27 |
| Not successful | 4 | 0 | 0 |
| Unaware | 23 | 8 | 18 |

# III. WORKSHOP CONCLUSIONS AND RECOMMENDATIONS

## 1. Introduction

The participants in the Solar Energy Utilization Workshop met on June 10 to discuss the completion of specific UNICA organizational and research plans and the planning of cooperative projects in order to develop and extend the scientific and engineering capability of Caribbean universities and research institutes so that they may be able to contribute effectively to the wider use of alternative sources of energy in the region.

In the previous two alternative energy workshops, on wind and biomass, the participants were divided in three discussion groups: education and training needs, research and development needs, and demonstration needs. In this workshop, it was decided to work as one group to discuss the same three topics.

The group began reviewing the recommendations made in the previous workshops and decided to pursue the recommendations on a practical and reliable way taking into consideration the work going on at the Caribbean Development Bank, CARICOM, the Caribbean Meteorological Institute, etc.

Following is a review of the major conclusions and recommendations:

## 2. Education and Training

A human and institutional resource assessment of Caribbean technological and scientific capabilities is needed immediately. In many cases foreign expertise and/or organizations are used due to a lack of knowledge of the capabilities available in the Caribbean region. This situation prevents further development of the Caribbean resources available, and in many cases results in inappropriate or irrelevant recommendations by foreign consultants, which often generate deep resentments. Of course, in cases of non-available expertise, the new knowledge if properly channelled (technology transfer), is generally well received.

The publication of a directory of Caribbean resources will serve in part to solve this problem. The first issue of the human and institutional Caribbean Basin directory should be prepared and a method devised to update it at least annually. The directory should also include a list of energy courses that are offered in the region. The directory should be given ample distribution.

UNICA institutions feel that the greatest contribution in solar technology could be in preparing and reviewing technical curricula to teach energy saving techniques and renewable energy alternatives. This is especially true in the case of welders, electricians, plumbers, electronic technicians, and others: Special emphasis was given to the enhancement of the techniques to maintain/conserve energy producing equipment such as diesel generators and gas turbines. Many failures and poor performance of this equipment are usual occurrences in the area. UNICA should also support and work closer with CARICOM in their seminars and training courses.

The establishment of energy auditors training and certification procedures and the development of standards, including certification for solar alternative hardware, was given high priority by the group. Energy audit technicians are almost non-existent and UNICA institutions should establish curricula and courses to train energy auditors and help the government to establish an energy management certification program. The establishment of extramural science student programs for high school students was also considered.

In addition, the establishment of a UNICA speakers bureau to address professional and social groups on energy matters was recommended. The UNICA contact persons in this project could form the nucleus of such regional energy speakers bureau. In this way the university could also participate as a catalyst of social change in the Caribbean society.

The need for funds for regional interchange of professors was also recommended. This is especially necessary among different linguistic groups since because of their language, culture and political ties, technical information transfer between them is in many cases non-existent. This project has greatly helped in establishing the first link for a commonality of scientific interest, and some interchange on a direct basis has already occurred. A more formal and extensive program was recommended.

UNICA member institutions are aware of the proliferation of courses and educational materials, including latest technical conferences, that are available in videotape but many of them do not have the videotape and television monitor to be able to benefit by renting or buying this material. The group understands that the acquisition of such equipment will be of great help in their academic and faculty continuing education.

### 3. Research and Development

After reviewing some of the research and development efforts going on at specific institutions and taking into consideration the regional role of UNICA, it was decided that the major role that could be played in the Caribbean Basin is to help enlarge and improve the solar data base available. Almost none of the UNICA institutions has a single solar insulation or wind measurement instrumentation. On the other hand, the Caribbean Meteorological Institute has ongoing programs to measure solar and wind potentials in the Eastern Caribbean, the Dominican Republic and Puerto Rico. A program to regionalize, standardize and provide additional adequate measuring instrumentation at UNICA institutions is regarded as the first R&D priority. Proper mechanisms to collect, analyze, collate and distribute the information are needed.

The other area of commonality of interest was energy system design and maintenance. The interaction between components fails in many cases. More important, the group feels that the matching to end users and the cultural impacts of new technology to their countries is a highly sensitive area that needs further research. The new technology must closely match the social and cultural needs. The evaluation of projects existing or under construction could be an important "grass roots" contribution of UNICA to the region.

From the standpoint of technology transfer the group recommended that UNICA assume an advisory role in transferring knowledge about manufacturing technologies processes. The solar water heater is a good example where already local manufacturers of flat plate collectors have established themselves in Barbados, Trinidad, Puerto Rico, Dominican Republic and other countries. The certification process of such products to meet local needs could also be catalyzed by UNICA. Solar cookers, solar stills, solar distillation units, solar steam, solar air conditioners, wind turbine generators, etc., are examples of technologies that, with proper training, can be manufactured locally in many cases. Manuals and training through UNICA member institutions to private concerns could help such possibilities.

It was recommended that UNICA establish a research endowmnet fund to be distributed on the basis of strict competition of scientific proposals and peer review. The established foundation for higher education operating in the Colombia could be used as a model.

The UNICA newsletter should be expanded to include information related to R&D projects and courses at member institutions. UNICA contact persons could become a scientific correspondence bureau for the newsletter.

## 4. Demonstration

After a long discussion, it was decided by the UNICA contact persons that it was not realistic to recommend specific energy demonstration projects. This decision was based mainly on the fact that there seems to be an adequate number of energy demonstration projects in the

Caribbean sponsored by the UN, the World Bank, IADB, OAS, USAID, CIDA, CARICOM, etc., and even if they are of interest to the universities of the region at present that has a lower priority when compared with other more urgent needs.

UNICA's intention is to cooperate as much as possible with established programs of CARICOM, CDB and OAS.

## 5. Conclusion

It was concluded that UNICA should undertake the preparation of a proposal to implement the recommendations referred to above. The program delineated in this report is realistic and has been developed by the users after more than two years of discussion and three workshop meetings. It is anticipated that it could be carried out in about three years with a budget of about $300,000. The proposal should include three annual review meetings involving the UNICA contact persons. Besides carrying out the review, it is recommended that three specific topics be used for presentations/discussions at the meetings. The three recommended topics, in order of preference, are: (1) technology transfer; (2) energy systems designs, performance and maintenance; (3) science and technology.

# LIST OF APPENDICES

A -- Workshop Schedule

B -- List of Participants

C -- Seminar Lecturers Resumés

D -- Bonnet, Juan A., Jr. and Koehler, W., 1983. "Development of Alternative Energy Science and Engineering in the Caribbean," presented at the II Interuniversity Symposium of Energy, University of Santiago, Chile, November 14 to 19, 1983.

E -- Farber, Erich A., 1974. "Solar Energy Conversion R&D at the University of Florida," Buildings Systems Design, February/March.

# SOLAR ENERGY UTILIZATION WORKSHOP
June 7-10, 1983

## SCHEDULE

| Day | Time | Lecturer | Topics |
|---|---|---|---|
| June 7/83 | 0830 | Farber | Welcome and Introduction |
| | 0900 | Farber | Solar Energy: An Overview |
| | 1000 | | Coffee Break |
| | 1030 | Pagano | Characteristics of Solar Radiation |
| | 1115 | Soderstrom | Solar Measurements and Modeling for the Caribbean |
| | 1200 | | Lunch |
| | 1300 | | Tour of TAET and EREP* |
| June 8/83 | 0830 | Farber | Heat Transfer Properties of Materials Collectors |
| | 1000 | | Coffee Break |
| | 1030 | Soderstrom | Standard and Systems Optimization for Tropical Use |
| | 1200 | | Lunch |
| | 1330 | | Tour of Solar Facilities in Gainesville area |
| June 9/83 | 0830 | Farber | Applications of Solar Energy |
| | 1000 | | Coffee Break |
| | 1030 | Pagano | Applications (continued) |
| | 1115 | Soderstrom | Applications in Tropical Climates |
| | 1200 | | Lunch |
| | 1330 | Chau | Agricultural Applications |
| | 1430 | Farber | Photovoltaics |
| | 1500 | | Coffee Break |
| | 1530 | Bush | End Use Matching |
| | 1630 | Bonnet | Workshop (Group Discussion) |
| June 10/83 | 0830 | Bonnet | Workshop (Group Discussion) |
| | 1245 | | Closing Luncheon |

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*TAET = Training Alternative Energy Technology Center

*EREP = Energy Research and Education Park

# SOLAR ENERGY UTILIZATION WORKSHOP
June 7-10, 1983

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## SEMINAR LECTURERS RESUMES

ERICH A. FARBER

Dr. Farber holds the rank of disinguished service professor at the Univeristy of Florida. He is an internationally recognized pioneer in the field of solar energy and has dedicated more than a quarter of a century to the SEECL at the University of Florida. This is one of the largest solar energy laboratories with national and international recognition. Under his leadership the TAET program was initiated at the University of Florida.

He has traveled world-wide as an invited consultant to many countries. In addition, he served as a consultant to USAID and VITA. The idea for the TAET for the third world participants, in fact, came from the idea of efficiency in disseminating information by bringing the participants to the University of Florida.

JUAN A. BONNET, JR.

Dr. Bonnet is Director of the Center for Energy and Environment Research of the University of Puerto Rico. Previously he was Assistant Executive Director for Planning and Engineering of the Puerto Rico Electric Power Authority.

Dr. Bonnet received his B.S. in Chemical Engineering from the University of Michigan in 1960 and his Ph.D in Nuclear Engineering in 1971 from the same university. He is a registered Professional Engineer, Certified Energy Auditor and Chemist. He is currently the President of the Board of Examiners of Engineers, Architects and Surveyors of Puerto Rico. He is Associate Professor at the Bayamõn Technological University College and a member of the System-wide University Board.

He was Technical Director of the XVII Convention of the Pan American Union of Engineering Associations (UPADI-82) held in San Juan in August 1982. He is the Chairman of the Science and Technology Commission of the Caribbean Association of Universities and Research Institutes (UNICA). He is also a member of several energy and environmental advisory committees in Puerto Rico and the U.S. He is a member of the Puerto Rican Academy of Arts and Sciences and the New York Academy of Science. He was honored with the 1981 Mobil Award for outstanding scientific accomplishments in Puerto Rico.

He has published numerous articles in scientific journals and many of his technical papers have been included in conference proceedings or abstracts.

KENNETH G. SODERSTROM

Dr. Soderstrom has been a faculty member of the Mechanical Engineering Department of the University of Puerto Rico (UPR) for over 20 years. Most recently he was the Associate Director of the Center for Energy and Environment Research (CEER) of UPR. As Associate Director of CEER he was responsible for the Mayaguez laboratory operations which included three of the five scientific divisions of the Center, namely, Solar, OTEC and Marine Ecology. For over a decade Dr. Soderstrom has been dedicating his reserach efforts to development technology transfer in alternative energy through programs of CEER. He has traveled extensively throughout the Caribbean area in relation to international programs of CEER. His msot recent research and publications have been concentrated on application of solar energy to tropical environments. He is presently on sabbatical leave from UPR and is a Visiting Professor in the Mechanical Engineering Department of the University of Florida and participates actively in both TAET and SEECL programs.

ROBERTO PAGANO

Dr. Pagano is the Technical Director of the TAET Program, a position he has held for the last four years. He has traveled extensively throughout Africa and Europe and is multi-lingual in English, Italian and French. In addition to his involvement with teaching and technical direction of the TAET program, between sessions he makes follow-up visits as a consultant to countries of the participants' origin for additional training and advice in adaption of the appropriate energy technology. Dr. Pagano also brings to this program his experience in energy, resources, and environment system analysis in which he was involved at MITRE Corporation, prior to his appointment as Technical Director pf the TAET Program.

## MARTIN J. BUSH

Dr. Bush is one of the regular faculty members of the TAET program. He has been with the program for over two years and teaches in many areas of alternative technologies, such as energy needs and uses, including use of different fuels, decision analysis, solar energy collection and storage. His basic background is in fuel technology and chemical engineering. He has lived in the U.K., Canada, and for three years in Trinidad as a lecturer at the University of the West Indies.

## KHE VAN CHAU

Dr. Chau is an Assistant Professor in Agricultural Engineering, University of Florida, specializing in grain drying and storage, and solar energy. His Ph.D. dissertation (from the University of California) was on solar collectors. Dr. Chau is a native of Viet Nam and worked in that country for several years in agricultural engineering and became the Director-General for Planning and Technical Affairs, Ministry of Agriculture before returning to the U.S. in 1975. He has extensive experience in tropical, developing countries. He is familiar with, and has visited the Philippines, Thailand, Taiwan, and India. Dr. Chau has been the lecturer in charge of solar crop drying for the "Training on Alternative Energy Technologies" during the past 3 years. He has also served as an instructor in many short courses and workshop on solar crop drying for Florida county agents. He is the author or co-author of numerous technical papers on solar collector design and analysis, and solar drying under hot and humid conditions.

II SIMPOSIO INTERUNIVERSITARIO DE ENERGIA
Santiago de Chile, Noviembre de 1983

# DEVELOPMENT OF ALTERNATIVE ENERGY SCIENCE AND ENGINEERING IN THE CARIBBEAN

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Abstract. This paper describes a pilot project designed to improve the capabilities of Caribbean universities and research institutes in helping solve the energy problems of the region. Most of the region is almost completely dependent on imported petroleum to satisfy its energy needs. That dependency has exacerbated economic problems with the escalation of petroleum prices in the past ten years. A potential solution to reduce both the high degree of dependence and economic costs is to develop other energy systems. The region is blessed with solar, wind, ocean, biomass, and geothermal resources that could be exploited to reduce and displace oil consumption.

One approach is to develop the scientific and engineering capabilities of regional universities. Under the auspices of the Association of Caribbean Universities and Research Institutions (UNICA), with U.S. National Science Foundation support, a project to foster cooperative research efforts to assist in the introduction of alternative energy solutions has been developed.

The UNICA project utilized the research workshop format. A network of scientists and engineers working in energy was established to promote cooperation, interchange of technical information and development of joint projects. Three workshops were convened on the most promising energy alternatives: wind energy in Barbados in December 1981; tropical biomass in Puerto Rico in April 1982; and solar energy utilization in Florida in June 1983. In each of the workshops a list of needs and priorities in education and training, research and development, and demonstration projects was worked out and are discussed in this paper. Basic energy data on Caribbean Basin countries was collected in order to perform system analysis of energy alternatives. The project has already stimulated technological interchanges in the region.

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*Chairman of the Science and Technology Commission of the Association of Caribbean Universities and Research Institutes (UNICA).

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## A. Introduction

The 51 inhabited islands of the Caribbean archipelago have a total land area of about 230,000 square kilometers and a total population of approximately 20 million. It is a complex region, strategically located, with a diverse ethoric, cultural and political base. It is a mosaic not only of independent states but entities having varying relationship with the United Sates and European powers.

The Caribbean community has a very rich potential in inexhaustible alternative energy sources. In addition to geothermal energy, which is abundant in locations such as St. Lucia, many feasible inexhaustible solar-related alternative energy sources exist. This is largely due to the fact that the Caribbean, lying between latitude 10°N and 25°N, has a resulting year-round solar insolation of approximately 2000 BTU per square foot per day. A few of the more common of the solar-related resources are trade winds, ocean waves, moderate ocean currents, extensive ocean thermal masses, year-round biomass production, agriculture, and mariculture. Table 1 summarizes geographic, demographic and other data on the Caribbean region. Only one of these island-states produces fossil fuels. This is Trinidad, which has 1/45th of the land area and 1/20th of the population. The size of its foreign exchange reserves places it among the first six of all the nations in the British Commonwealth. The other 50 island-communities depend on imported fossil fuels for 99% of their energy requirements. It is estimated that 37,950,000 Bbls. of oil per year are imported by these islands.

Since the 1950s, the Caribbean has made strenuous efforts to diversify its economy by providing more jobs through industrialization and by expanding tourism. As in so many developing countries throughout the world, these early efforts were almost totally based on the use of imported fossil fuels. By the end of the 1980s most of the archipelago will be a potential disaster area unless the dependence on imported fossil fuels is reduced and the use of alternative sources of energy is greatly increased. Four of the major obstacles to progress are: (a) lack of manpower; (b) inadequate research in the use of existing technology and adaptation or modification of the various technologies to the social and physical environment; (c) lack of a grass roots cooperative energy program involving the universities and research institutes of the region; and (d) lack of investment capital.

A system of cooperation is of great importance in a region whose history has been one of fragmentation and dependence on external markets and external authority. A long history of dependence on external rulers has left many of the Caribbean peoples a bitter legacy of resentment, even of hatred. The ideological conflicts that characterize the contemporary Caribbean are evidence of this, just as the boat people from Cuba and Haiti and the illegal immigration into Puerto Rico from the Dominican Republic are indicators of growing poverty and discontent. Aid from the industrialized countries is important, but it cannot of itself provide a solution. Caribbean development depends, in the last resort, on the capability of the Caribbean people to analyze their problems and, with assistance from others, to find solutions for them. Cooperative relationships between individual United States and Caribbean universities, though valuable in themselves, do not fully meet the need for transforming donor-recipient relationships into a large partnership of scholars and scientists.

Because of the urgency of the energy situation in the Caribbean, it is crucial to the orderly economic and cultural development of the region that a degree of energy self-sufficiency be developed at an early date. If this does not occur, disastrous consequences will result as the price of imported fuel escalates beyond the reach of all but the most well-endowed (or most heavily subsidized) communities, thus forcing them into either a position of complete dependence on those who have oil, or into a position of extreme poverty, beyond which economic and political survival may become impossible.

The universities and research institutes of the Caribbean region constitute an important under-utilized resource of knowledge, expertise and institutional facilities. This resource is under-utilized largely because (a) the region is not looked upon as a whole; (b) because there is little communication among the scientists of the region; (c) and because the Caribbean community does not perceive its universities as being intimately involved in the development process. Yet a great deal of valuable work is being done in its universities and research institutes. Consequently it is essential that Caribbean universities and research institutes should be utilized to their fullest to achieve greater self sufficiency in basic necessities such as energy and food.

The Association of Caribbean Universities and Research Institutions (UNICA) has sought to provide a forum of cooperation necessary to develop solutions to the problems of energy in the Caribbean. To do so UNICA has launched a program to foster cooperative research effort aimed at assisting in the introduction of alternative energy solutions.

This project provided for and depended upon the active cooperation of universities and research institutes from the Spanish, English, French, and Dutch speaking Caribbean. The levels of research work varied, and required the more advanced centers to provide technical assistance to those which are less advanced. In this way the effort to find viable programs for the use of alternative sources of energy was shared by all the institutions involved. The project attempts to make full use of a network of Caribbean institutions, providing a mechanism for training at appropriate centers within the region, and involving many participants in research programs and in the preparation of a comprehensive regional program for using alternative sources of energy. Through this method, the quality of science and engineering research was improved, and the potential for stimulation for technology transfer and for further cooperative efforts were realized.

The project focused on the need for the countries of the Caribbean archipelago to achieve greater self-sufficiency in energy; on the role that Caribbean universities and research institutes can play in meeting this need; and on the fact that the region has a rich potential in inexhaustible alternative sources. It represents the first indispensable step in using the existing network of research centers, schools of natural sciences and engineering, and other related university departments in a coordinated program to help meet the region's energy needs. Furthermore, it points the way to an exciting concept of the region as a laboratory for the development of alternative sources of energy, in which lessons can be learned and demonstrations carried out that will be of benefit to other countries that have similar needs.

## B. Development

The objective of the project was to develop and extend the scientific and engineering capability of Caribbean universities and research institutes so that they will be able to contribute effectively to the wider use of alternative sources of energy in the region.

### 1. Mechanism for Achievement

#### a. The Association of Caribbean Universities and Research Institutes (UNICA)

In the late 1960s, perceptive Caribbean educators saw the future development of the Caribbean community as a matter of regional concern. To meet their common needs they created UNICA, a voluntary association of Caribbean universities and research institutes dedicated to positive, carefully directed efforts for Caribbean development. Founded in 1968 by 16 universities located in ten Caribbean countries, the organization now has 45 member institutions representing a constituency of more than 300,000 students and 30,000 faculty.

### 2. Expected Significance

The success of the project has had a profound effect on the creation of a program to develop economic independence and energy self-sufficiency within the Caribbean. And that should lead to greater social and economic progress. The Caribbean may thus serve as a model of the benefits which can accrue through the development of the local scientific and engineering capabilities of regional universities as they work together to solve problems of immediate national and regional significance.

### 3. Project Description

#### a. Overview

The project, limited in time and specificity of its purposes, represents the first important step toward a major coordinated program of research and technology adaptation to be undertaken by the universities and research institutes of the region.

The work was carried out in three phases. The first phase involved planning activities, identification of UNICA institutional contact persons and background literature searchs. The second phase involved the holding of three workshops dealing with various aspects of the alternative energy problem: on wind, biomass and solar utilization. The third phase involves the completion of research plans and proposals resulting from the workshops, the preparation of education and manpower training plans, and the compilation of reports on the alternative energy data base and organization which has been generated. Funding for this project came from grants from the U.S. National Science Foundation and the Exxon Education Foundation.

b. Procedure

1. Phase One

Phase One of the project consisted of all planning activities. The steps completed in Phase One included:

(1) Appoint members of the UNICA Commission on Science and Technology and receive their agreements to serve. This was completed before June 1980 and the following persons agreed to serve:

* Dr. Erich Farber, Director of the Solar Energy Institute, University of Florida, Gainesville.

* Professor Gerald Lalor, Pro-Vice-Chancellor of the University of the West Indies, Kingston, Jamaica and Head of the Department of Chemistry.

* Dr. Juan A. Bonnet, Jr., Director of the Center for Energy and Environment Research of the University of Puerto Rico.

* Eng. Francisco Gutiërrez, Director of the Institute of Petroleum, Central University of Venezuela.

* Dr. Howard P. Harrenstien, Civil Engineering Department, University of Miami.

(2) Convene a meeting of the UNICA Commission on Science and Technology and discuss the need for a cooperative program of alternative energy science and engineering research and education for the Caribbean. Prepare an outline draft of a plausible workshop plan.

(3) Contact all UNICA member universities and ask their chancellors or presidents to appoint university faculty liaison representatives to work on the alternative energy program. In order to implement the project this Commission requested from the universities and research institutes which are members of UNICA to appoint official contact persons knowledgeable in energy matters who could provide information on the energy state of affairs of their respective islands, participate in workshops, and serve as a focus to initiate educational and research activities in their institutions. A questionnaire was circulated to all UNICA contact persons and two follow-up notices were sent to assure maximum response. This experience reflected the reality of lack of information about energy and renewable energy matters in the Caribbean. After a search in general and specialized libraries and other information centers in the Caribbean, it was found that the best data were available at the Caribbean Development Bank in Barbados, the Island Resources Foundation in the Virgin Islands and the Center for Energy and Environment Research in Puerto Rico.

(4) Convene various meetings of the UNICA Commission on Science and Technology in conjunction with the November 24-25, 1980, Center for Energy and Environment Research - organized Symposium on Alternative Domestic Energy Systems for Puerto Rico, and the December 15-17, 1980 Clean Energy Research Institute-organized Third Miami Conference on Alternative Energy. At these meetings, prepare a questionnaire on alternative energy to be completed by the UNICA faculty liaison representatives.

(5) Receive and compile the results of the questionnaires at CEER. This activity was completed and resulted in the paper "Energy Alternatives for the Caribbean". The paper represents the most up to date general description of renewable alternative energy projects and potential in the Caribbean and constitutes a major contribution of this project.

Phase One activities were conducted primarily in San Juan, Puerto Rico and Miami, Florida, using the facilities of CEER and the Clean Energy Research Institute (CERI) respectively.

2. Phase Two

Phase Two consisted of the organization and conduct of three alternative energy workshops. Attendance at all workshops was by invitation only, and consisted of the UNICA contact persons, the UNICA Science and Technology Commission members, and invited industrial and investment representatives, key liaison faculty from supporting universities, involved faculty from the region who are known to be active in alternative energy research, and selected governmental personnel. Assignments were issued in advance, and the workshops were held in the vicinity of the most suitable places for demonstrations of viability and feasibility of the concept. The three workshops were concerned with:

(1) Wind as an Energy Alternative for the Caribbean
(2) Biomass as an Energy Alternative for the Caribbean.
(3) Solar utilization.

The subjects were carefully chosen to emphasize those technologies which show the most promise of being cost-effective in short term. The choice also drew on the Puerto Rico experience in developing an understanding of the most viable energy alternatives. A paper was prepared titled "Alternative Energy in the Caribbean."

Each workshop was planned following the project needs and host institution capabilities but each contained certain essential aspects, or areas of emphasis. In general, these areas were:

(1) State of the art in the particular technology,
(2) Estimates of the magnitude of achievable resources,
(3) Identification of barriers to commercialization,
(4) Socio-economic considerations,
(5) Plan for meeting science and engineering education requirements,
(6) Identification of needs in basic research,
(7) Time-frame for meaningful demonstrations,
(8) Time-frame for maximum contribution to energy self-sufficiency,
(9) Identification of sources of investment capital.

Wind was given first priority, as it is generally considered to be the most likely candidate as a short term cost-effective alternative energy source. Wind energy may be converted directly to mechanical energy and then to electricity without involving the Carnot cycle and the unavoidable thermodynamic losses which are associated with such energy conversion. In addition, the Caribbean is an area in which the trade winds are predictable and of sufficient magnitude to provide a reasonable level of power. It is logical to concentrate on this source as one which could provide an early payoff. The chances of early success should motivate and stimulate the growth of science and engineering capabilities in local universities, since needs for manpower training and local engineering capability should be quickly realized. Because of existing expertise and presence of the Caribbean Meteorological Institute and the Caribbean Development Bank, the wind workshop was held in Bridgetown, Barbados in December 1981.

Biomass was the second form of alternative energy considered since agriculture has traditionally been the principal source of income in the Caribbean. The year-round solar insolation, coupled with frequent rains on windward shores, provides one of the finest environments on earth for prolific biomass production. As imported fossil fuel prices rise, it is critical that this biomass potential be converted to clean-burning substitute fuels, such as methanol and ethanol. There is reason to believe that ethanol production from sugar cane is already cost-effective, particularly if attention is given to the productive use of wastes which are generated by the process. This second workshop was held in San Juan, Puerto Rico at CEER in April 1982.

The third and final workshop --solar energy utilization-- was held at the University of Florida, in Gainesville, in June 1983. This workshop's orientation was toward the completion of specific organizational and research plans, and the planning of cooperative projects. Gainesville is considered the Solar Capital of the World.

### 3. Phase Three

Phase three constitutes the reporting and implementation phase. The plan is to compile a narrative of the accomplishments of the project, and to report on the plans that individual institutions have made to enhance their science and engineering capabilities in support of alternative energy commercialization in their regions. This is underway at present.

It is anticipated that these plans will include mechanisms for demonstration and for training and education of the local manpower, involving university faculty and students as resource personnel. It is also anticipated that this phase will solidify the interactive and co-operative nature of UNICA, with the result that growing trust and scientific and technological interchange among sister institutions will emerge.

This phase will also be used to finalize plans for continuance of similar types of activities into the future, being careful to build upon the experiences of the past and upon the capabilities which were acquired in the conduct of the initial project. Goals in basic research are to be identified, and recommendations made to granting agencies, industry, and financial institutions for the timely support of this research are to be identified, and recommendations made to granting agencies, industry, and financial institutions for the timely support of this research.

## 1. Project Application Potential

A list of renewable energy technologies which are deemed technologically suitable for the Caribbean, in rank order of estimated commercial readiness, is as follows:

1. Solar hot water
2. Co-generation
3. Hydroelectric
4. Electricity from solid waste
5. Small wind machines
6. Large wind machines
7. Electricity from bagasse
8. Solar ponds
9. Photovoltaics
10. Ocean thermal energy conversion
11. Geothermal energy conversion
12. Other

The value of contribution in barrels of oil saved per year for each alternative energy technology at the end of full commercialization by the year 2000 has been calculated. This is presented in Table 2, where it can be observed that the combined contribution from the sources listed totals 154,230,000 Bbls. of oil saved per year. Consequently, the region could theoretically provide all necessary primary fuels for its electrical generation needs.

As is shown in Table 3, many technologies are undergoing research, development and/or demonstration in the Caribbean region. They range from off-shore oil exploration to geothermal to biomass. The table also demonstrate the wide range of donors or executing agencies, which include international and regional organizations, foundations and countries. The table also substantiates our conclusion that wind, biomass, and solar are appropriate alternative energy sources for the Caribbean.

## Workshop Summaries

### 1. Wind as an Energy Alternative for the Caribbean Workshop

The first UNICA workshop was carried out in Bridgetown, Barbados on December 6-9, 1981. Some 50 persons participated. The first part of the workshop consisted of background papers on wind energy. Especially significant was the participation of Dr. T.S. Anderson, President of the USA Wind Energy Association, an organization which has a keen interest in the Caribbean. Following the general presentations, the participants were divided in three workshop groups addresing the following subjects:

(1) Education and Training Needs
(2) Research and Development Needs
(3) Demonstration Needs

Each of the workshop session groups produced a report.

It is interesting to note that the recommendations are similar and that they focus on information needs and lack of human resources. A generalization and prioritization follows:

(1) A resource assessment of human and institutional capabilities, wind resources, and demonstration projects in the region is needed.

(2) After the first recommendation is implemented, detailed action plans and proposals to implement the other workshop recommendations are needed.

(3) Sources of funding to continue this project and to implement the most important recommendations should be sought.

The group believes that if the above recommendations are implemented the scientific and engineering capabilities of the universities and research institutes in the region will be greatly enhanced and strengthened in wind as an appropriate energy source for the Caribbean region.

### 2. Biomass as an Energy Alternative for the Caribbean

The second workshop for UNICA contact persons was held in San Juan, Puerto Rico on April 28-29, 1982. It is significant that the same UNICA contact persons who attended the wind workshop were also able to attend this workshop. The liaison initiated among UNICA contact persons facilitated the establishment of direct contact between some of the UNICA member institutions.

This workshop was carried out immediately following the Seminar on Fuels and Feedstocks for Tropical Biomass II held in San Juan, Puerto Rico on April 26-27, 1982. Many of the UNICA contact persons were also able to attend this seminar, which provided them with more thorough knowledge of biomass as an energy resource.

The biomass workshops indicated that the group feels that:

(1) Research, development and demonstration projects in biomass as an energy source must be established in the Caribbean region. Funding to carry out such projects is critically needed.

(2) Provision of training and education on Caribbean tropical biomass is a must.

(3) UNICA should increase its information dissemination and technology transfer activities in the region.

(4) The role of the UNICA Foundation to secure funds to implement the recommendations of workshops is very important.

The Caribbean agricultural programs, especially in sugar cane and other food crops, are undergoing great economic stress. The possibility of a reorientation to biomass for energy and food combined is an alternative that must be pursued immediately. This is one of the main reasons for recommendation number one. The group feels that the only reason this energy alternative is not being developed faster is lack of funding.

3. Solar Energy Utilization

The third workshop was held June 6-10, 1983 at Gainesville, Florida.

During this workshop the basics of solar energy conversion and utilization were covered and expanded to specific problems found in the Caribbean Basin. Presentations on solar radiation measurements and modeling in the Caribbean, Heat transfer, materials, collectors, applications of solar thermal, dryers, distillation, photovoltaics and system analyses were delivered. All presentations were video-taped. Visits to field installations were carried out.

The solar workshop carefully reviewed the recommendations made during the previous workshops and the group recommended that priority be given to:

1. Research, development and demonstration projects in solar, biomass, wind, and other appropriate energy systems.
2. Expand Education, and training in appropriate energy technology and uses through the UNICA network. Increase university and research institute interest.
3. Data are often insufficient in the Caribbean to permit the level of planning desired. Develop a data collection and analysis capability drawing on existing regional expertise.
4. Expand internal UNICA communications through newsletter, workshops, etc.
5. Analyze experience and develop an expanded appropriate energy network.
6. Develop and maintain the practice of collaboration research and exchange of data among UNICA members.
7. Seek external funding to finance increased energy technology development and transfer in the region.

## D. Conclusion

The Caribbean region is richly endowed with renewable alternative energy sources which could in time provide energy self-sufficiency to the region. Three of the main sources--wind, biomass and solar --have been studied and analyzed. It is shown that these three provide the most promising begining to resource utilization and petroleum substitution.

Caribbean universities and research institutes could and should help in the development and utilization of these energy sources. The three UNICA sponsored workshops provide a mechanism to transfer technological and scientific knowledge within the Caribbean, one which will develop indigenous capabilities. Clearly these efforts must be expanded and institutionalized to further alternative energy development in the region.

This paper points out some of the impediments to cooperation as well as delineating a system of cooperation. One is insufficient data. Another is the inchoate network among universities and research institutes in the Caribbean. This paper describes an effort for a more realistic plan for education, training, research and development and for deeper data collection and evaluation.

This is a pioneering effort occurring at a historical moment when there is a renewed interest in the "rediscovery" of the Caribbean region. This paper should be useful to all funding and development agencies which are becoming aware of the region and willing to do something helpful based on solid ground. This effort is a very healthy seed. Let us hope that somebody will water and nurture it for the benefit of the Caribbean community.

# SOLAR ENERGY CONVERSION RESEARCH & DEVELOPMENT AT THE UNIVERSITY OF FLORIDA

DR. ERICH A. FARBER, Professor & Research Professor of Mechanical Engineering and
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Widespread concern with our energy situation and crisis, and what meeting the ever increasing demand of this energy does to the environment through pollution, prompted the writing of this paper. It presents the over-all activities of the Solar Energy & Energy Conversion Laboratory of the University of Florida rather than the technical details of one particular investigation.

The laboratory has looked into old methods of converting solar energy into the forms of energy needed, has used the present state of the art, and has pioneered in many areas of solar energy utilization.

It is obvious from all surveys and reports that we are using our fossil fuels at a tremendous and ever increasing rate so that in the not too distant future these supplies of energy, so vital to our present growth of civilization, will be depleted. For this reason it is of utmost importance that we look for other more permanent sources of energy and learn to use them before the dire need arises. Solar energy is readily available, well distributed, inexhaustible for all practical purposes, and has no pollution effects upon the environment when converted and utilized.

Our present usage of energy can be compared to a family or group living off their savings, stored in a bank, and being steadily depleted. This process cannot go on very long unless some "income" is added to the savings.

In the field of energy, the most abundant "income" is solar energy. This incoming energy was, usually in very in-efficient processes and over millions of years, converted into our fossil fuels. With these savings rapidly disappearing, we will have to learn to use this income directly in the form of radiant energy, by converting it into the forms of energy needed.

This conversion from solar energy into the desired forms should be done in the fewest possible steps and along the most direct route. This procedure will insure the most efficient way of doing this and will keep the equipment necessary simplest.

Solar energy has certain characteristics. It is intermittent, only available during the day in a particular location on the surface of the earth. In spectral character, it approximates a black body source of about 10,000F, modified by gaseous layers of both the sun and the earth's atmosphere.

It arrives on the surface of the earth both as direct radiation and diffuse radiation. The former portion can be concentrated if it is desirable.

A knowledge of the specific properties of materials under solar irradiation will then allow the collection and/or concentration and absorption of this energy.

If night time operation or operation during bad weather conditions is necessary or desirable, storage has to be provided. For many applications this is not necessary. The energy could be stored in a conventional manner as potential energy (pumped water, etc.), as heat in hot water storage tanks or rock bins, as chemical energy utilizing chemical processes, latent heat or heat of fusion, etc.

In other words, the technology has been developed to convert and utilize solar energy. The economics and sociological acceptance has still to be worked out in many cases. These problems vary from region to region and therefore take on a local character to be worked out by the potential users.

To be most effective, local materials should be used in fabricating by local methods and labor fitting the economics and habits of the local civilization.

With this introduction of a general nature the paper will now go into some of the work done by our group. The best way to do this is to take you on a tour through the Solar Energy Laboratory of the University of Florida in the United States of America.

## UF Solar Energy Laboratory

The University of Florida Solar Energy Laboratory is one of the largest laboratories of this kind and a tour through it will give an idea what such laboratories look like and the kind of work which is carried out in them. The work carried out at this laboratory is supported by work and persons all over the world and proper credit should be given to them. Fig. 1 presents the entrance, within the gate to the laboratory and two of the four buildings.

Stepping around these two buildings one can see some of the equipment of the laboratory which will be discussed in more detail in the paper and the following illustrations. Fig. 2 shows this equipment with engines of various types in the foreground, behind them collectors and concentrators of various types. On the left of the picture are a small solar air-conditioning system and two solar water heaters, a solar still and parabolic concentrators. Also visible are a solar power plant, a solar still, the solar furnace and solar calorimeter to investigate the solar properties of materials. In the background, partially visible, is a 5 ton solar air-conditioning piece of equipment.

## Solar Properties

The first step in utilizing solar energy is to find materials which will withstand the exposure necessary in the equipment to be built. To do this we take some of these materials and expose them under rather realistic operating conditions to the weather and the sun. Fig. 3 shows different plastics exposed to the environment, stretched over cans which are filled with water or sand or wet soil, etc. If these materials deteriorate after a short time the investigation is terminated.

Those materials which, however, withstood this exposure test satisfactorily are then investigated in our Solar Calorimeter as to their reflection, absorption and transmission characteristics under actual solar irradiation.

The Solar Calorimeter, Fig. 4, can be oriented into any desired position; it can be made to follow the sun; it can simulate severe winter conditions or extreme summer environments. It is further instrumented with many, many thermocouples to be able to obtain complete heat balances. This instrument, the only one of its kind, is constantly used to investigate new types of materials such as

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Fig. 1. Entrance to the University of Florida — Solar Energy Laboratory.

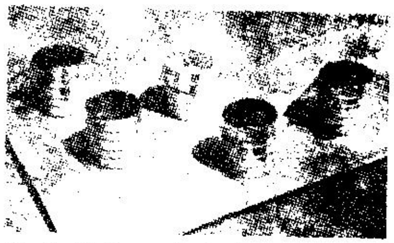

Fig. 3. Exposure test of some plastic films.

Fig. 2. View of some of the solar energy conversion equipment in the laboratory.

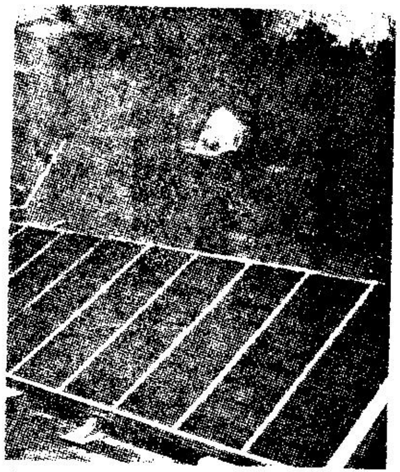

Fig. 6. Florida solar water heater.

Fig. 4. The solar calorimeter.

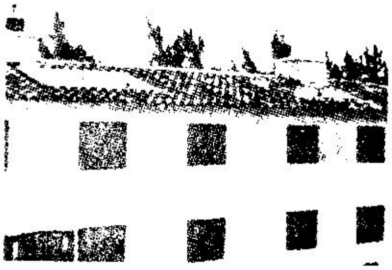

Fig. 7. Solar water heaters in apartment house.

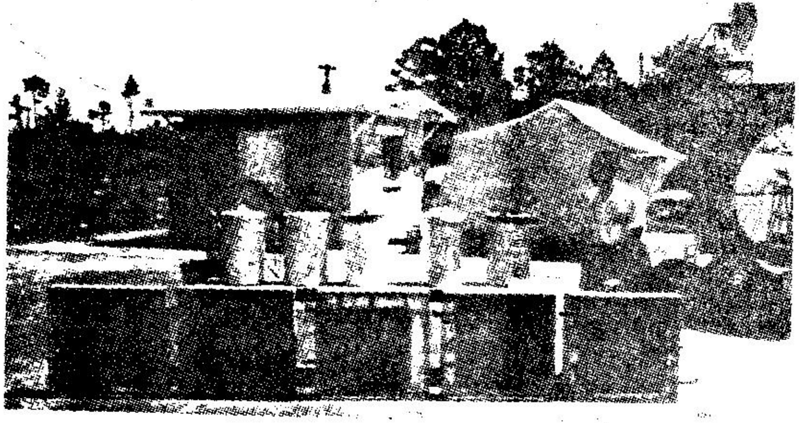

Fig. 5. Experimental flat plate collectors.

Fig. 8. Swimming pool solar heater.

glasses with tinting or coatings; laminated glasses and plastic materials, venetian blinds, Thermopane windows, plastic bubbles for aircraft, fabric used for clothing, curtains and draperies, water cooled venetian blinds, etc.

With the properties determined a selection can be made to obtain the best results in any desired application.

## Solar Water Heating

In Fig. 5, five different flat plate collectors used for water heating are presented. They consist of a box with glass or plastic covers

Fig. 9. Solar air heater.

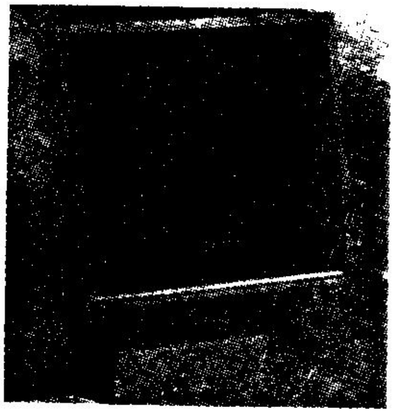

Fig. 10. Solar oven.

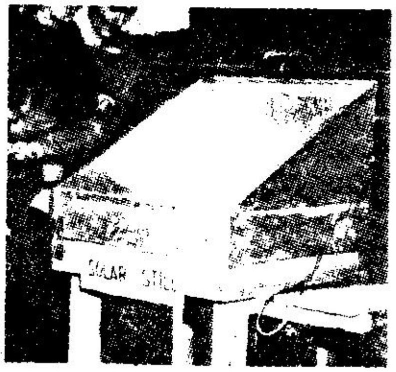

Fig. 11. Small solar still.

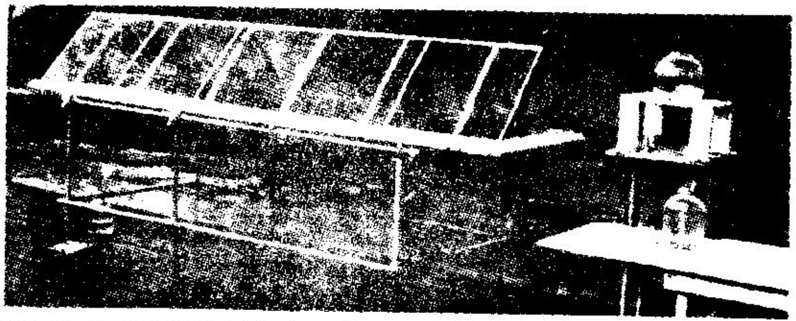

Fig. 12. Larger solar still, also able to collect rain water.

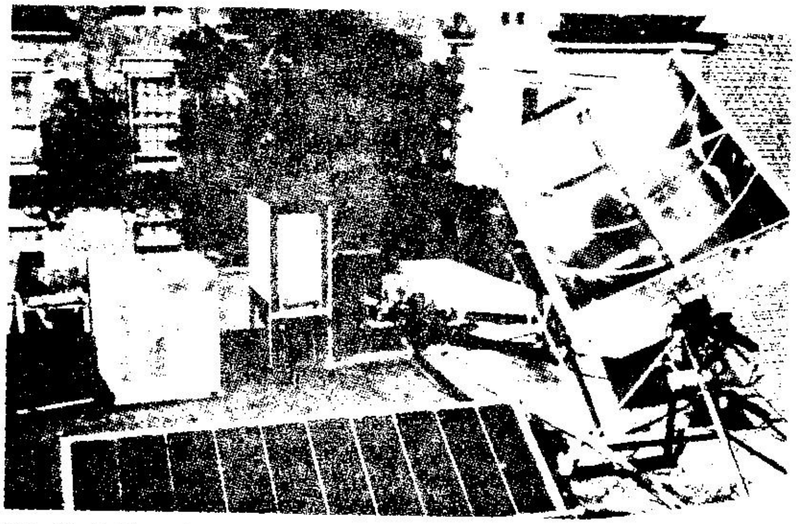

Fig. 13. Refrigerator, driven by solar energy.

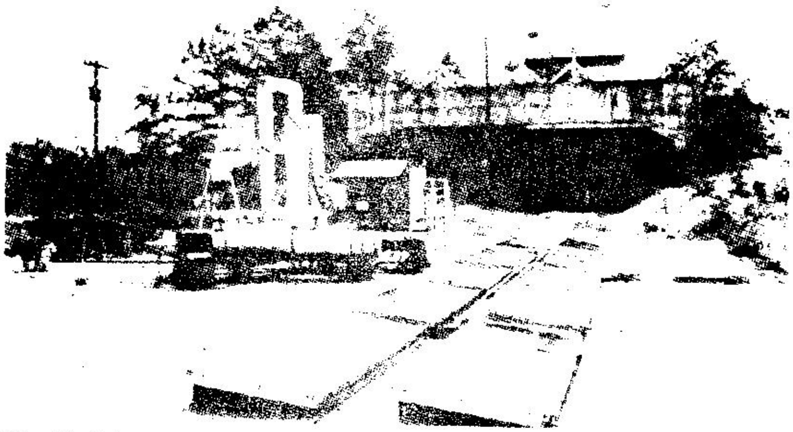

Fig. 14. 5-ton solar air conditioning system.

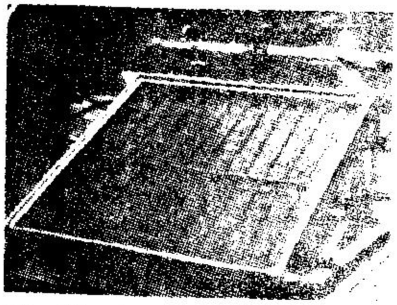

Fig. 15. Small solar refrigeration system, front.

Fig. 16. Small solar refrigeration systems, back.

(one or more) with a metallic absorber element inside, which contains the water. This water is circulated to the small water storage tanks shown above. These absorbers can be compared with each other when exposed to the sun under identical conditions and for the same length of time.

Some of the absorbers have copper plates with copper tubes soldered into them, others are two flat plates riveted, crimped or welded together. The most efficient unit found consisted of two thin flat copper plates fastened together on the edges and providing a water space of about ¼ inch, with one glass cover and one inch of styrofoam insulation behind the plates. No plastic materials were found to be as good as glass since none of the ones we could find had the characteristics of glass, namely letting through the short wave radiation but not the long wave radiation. This characteristic of glass allows it to be used in the design of a solar trap.

Fig. 6 presents a typical Florida solar water heater. It consists of a sheet metal box, 4 feet by 12 feet, covered by a layer of glass. Inside the box is a copper sheet with copper tubes soldered to it in sinusoidal configuration and connected to an 80 gal. water storage tank. This system, rather common, is found satisfactory for a typical American family of 4 with automatic washing machine, etc. Under the copper sheet is one inch of styrofoam insulation. For satisfactory operation the bottom of the hot water storage tank must be above the top of the absorber to provide circulation without a pump.

Fig. 7 shows actual installations of this type in an apartment house in Florida with each apartment having its own unit to provide the needed hot water.

These standard units may be damaged if used in freezing temperatures and for this reason we developed a dual circulation system which eliminates this problem. It consists of two tanks, one inside the other. The outer tank, being connected to the collector, is filled with an antifreeze solution. The heat is then transferred from this solution through the wall of the inner tank to the water to be used. Since in this system the primary circuit operates at atmospheric conditions (the outer tank needs only a lid on it) the collector can be constructed much cheaper and lighter. For example, it may be patterned after the most efficient design mentioned earlier. Insulation covers the outside tank.

## Swimming Pool Heating

Another type of heater which has interested many people in Florida is a swimming pool heater as shown in Fig. 8. It is one of the simplest ones and least expensive. It consists of a galvanized sheet, wrapped into plastic. The sheet is painted black (flat) like all the other absorbers. Water from the pool can be fed to these absorbers by the filter pump and then allowed to run down the front and back of the metal plate and drain back into the pool. It usually takes a collecting surface equal to the pool surface for raising the water temperature in the pool 10 degrees F. These absorbers can be constructed to form the fence around the pool which in many localities is required by law, and in addition can provide privacy.

## House Heating

If the objective is to heat a house rather than water, it can be done by hot water circulated through baseboard pipes in a conventional hot water heating system. However, it is frequently more convenient or desirable to heat a building by hot air. Fig. 9 shows such an air heater, made up of overlapping aluminum plates, painted black on the portion exposed to the sun. About ⅓ of each plate is showing, the other ⅔ shaded by the plate above. They are put into a glass covered box. The air will enter this unit on the bottom and then, streaming between the hot plates, will pick up the heat and leave on top as hot air. The circulation can be produced either by free (or natural) circulation or by a fan.

All the above mentioned collectors are ideally facing South and inclined with the horizontal at an angle equal to the local geographic latitude plus 10 degrees. This gives a little higher collection efficiency during the winter when the days are shorter.

The air heater could be designed to form the wall of a building, let us say the East wall where it could produce hot air the first thing in the morning to take the chill out of the building the first part of the day.

## Solar Baking

Another application can be a solar oven, Fig. 10, essentially a glass covered box facing into the sun. Cooking and baking temperatures can easily be reached with such a device. Periodic (about every 15 minutes) reorientation, due to the movement of the sun, is required. Flaps can be added as shown in Fig. 25 to provide some degree of concentration and thus bringing the things to be cooked up to temperature quicker. Very little heat is actually required for the cooking process, only a certain temperature for the required length of time. If one of these ovens is to be used in the late afternoon or early evening, the walls could be made thick, of clay or other materials which can store appreciable amounts of heat and thus remain warm long after the sun has gone down.

## Solar Distillation

One of the major problems in many parts of the world is the lack of fresh water. Solar energy can, with very simple equipment, convert salt or brackish water into fresh and pure water. Fig. 11 shows a simple solar still, a metal box with slanting glass facing South. Inside the box is a pan on short legs, painted black and holding the bad water. The sun shining into this pan heats the water in the pan and vaporizes it. The vapor or steam then will, when coming in contact with the cold surfaces of the box, both the glass and the metal, condense, forming the fresh which runs down the sides in the form of droplets. This fresh water can then be collected for future use. About ½ lb. of water can be produced at an average per square foot per day.

Another larger still is shown in Fig. 12. The pan is covered by glass at about 45 degrees which forms most of the condensing surface. Glass is much better than plastic since it forms film condensation, letting the solar energy through without much difficulty. Plastics in general produce dropwise condensation, each droplet forming a little crystal which reflects much of the incident solar energy. This larger still is also designed to be able to collect rain water and, in some areas such as Florida, this can double the output of the still.

The best orientation of the still depends somewhat upon the angles of the glass but is generally East-West or somewhat NE-SW.

## Solar Refrigeration and A/C

Another phase of our work is the use of solar energy for solar refrigeration and air-conditioning. At a number of international meetings it was pointed out that famine could be prevented in much of the world if the food which is raised during certain parts of the year could be preserved from spoilage, and thus preserved for use during the rest of the year. This requires refrigeration and for remote areas, or areas without electricity, solar refrigeration may well be the answer.

Some of our early work along these lines was to heat oil to rather high temperatures by concentrating solar energy and then circulating the hot oil around the generator of an ammonia absorption refrigeration system, Fig. 13. This picture is somewhat out of order since all the applications thus far dealt with solar energy in its natural state without concentration but it was put in here since it was actually our first attempt. We believe, however, that solar refrigeration without concentration holds much more promise since nonconcentrating devices can also utilize the diffuse portion of solar radiation, thus function even on cloudy days.

A number of small units were built before the 5-ton unit shown in Fig. 14. Flat plate collectors heat water which is then circulated to drive out the ammonia from the water in the generator of the system. This ammonia vapor is condensed and then expanded, providing the cooling effect by evaporation. After having done its work the ammonia vapor is reabsorbed, in the ammonia absorber of the system, into the water to repeat the cycle.

Figs. 15 and 16 show a smaller version of such a system with some improvements. The main one, combining the solar collector and the ammonia generator into one unit, eliminates the primary fluid and reduces the heat losses by providing a more direct path for the solar heat to get into the system and do its work. This small 4 x 4 foot unit can produce 80 lb. of ice on a good day.

It should be pointed out again that all the applications mentioned so far did not require concentration of solar energy, and therefore could utilize the diffuse portion of solar energy and work even on cloudy days.

The solar air-conditioning or refrigeration systems have an added advantage, that the demand and supply are in phase. When the sun shines hottest the need for refrigeration and air-conditioning is greatest.

## Solar Energy Concentration

For some uses, however, higher temperatures than can be obtained with flat plate, non-concentrating collectors, are needed. If this is the case, then concentration is called for. Many different methods can be used for concentration, the simplest ones stationary in design but not as good, and the better ones requiring methods which allow them to follow the sun. Fig. 17 shows a simple high temperature absorber. It consists of a number of parabolic troughs oriented horizontally and with a pipe running down the focal line of the parabolas. The system of parabolic troughs is inclined at about the local latitude. Depending upon the diameter of the pipe, adjustment may or may not be needed during the year. The solar energy is reflected by the parabolic surfaces upon the focal pipe which, painted with a good absorbing paint (flat black), absorbs this energy and transmits it to the fluid inside the pipe. This device can easily produce hot water, steam or hot oil.

Some energy is lost during the early morning and the late afternoon hours with the above method of converting solar energy to heat because of shading, but the simplicity and stationary design have considerable advantages, both economically and because the units do not need much attention.

## Solar Power Plant

If better efficiency is desired, then cylindrical parabolas can be used which are allowed to follow the sun. In the simplest form they can be made as shown in Fig. 18, a single parabola with a pipe at the focal line. This particular absorber is used to produce steam to operate a small steam engine, which in turn drives a small generator and lights up a light bulb, thus demonstrating what a solar power plant could look like. The 2 x 5 foot absorber is the equivalent of 500 watts of electrical heat.

A large cylindrical parabolic absorber is shown in Fig. 19 having dimensions of 6 x 8 feet with a glass covered focal tube. The glass cover reduces the losses from the heated tube. Depending upon the needs, different diameter tubes can be used. Copper has been found best, again painted with a good absorbing high temperature paint. This absorber is mounted on a rotating axis parallel to the earth's axis. It is adjusted to face East in the morning and then, by an electrically driven worm gear reduction unit, is made to follow the sun all day. Where electricity is not available, a heavy weight with a clock work timing unit can be used as well. The construcion of such a large device must be rather rigid since wind loads in windy areas may make it difficult to keep the unit directly facing the sun and to keep it from oscillating.

This unit has been used to produce steam for the operation of a fractional horsepower steam engine, to provide 800F oil to operate a solar refrigerator, etc.

Other methods of concentrating solar energy are lenses both of glass and other materials (including liquid lenses), but they are not widely used because of their cost in large sizes and their weight. However Fresnel lenses, specially made from plastic sheets, with grooves cut or embossed so as to focus the rays, can be produced rather inexpensively, are unbreakable, and can be of large size and light weight. The lens shown in Fig. 20 is of this type and can produce a temperature of 2000F.

A very effective way of concentrating solar energy is to take flat pieces of reflecting materials (for better results they can even be slightly curved) such as mirrors or reflecting metal surfaces, and orient them in such manner as to reflect the solar radiation on one spot. Front surface reflecting mirrors are giving better performance than, for instance, back silvered mirrors where some of the energy is absorbed in the glass. Very large concentrators of this type have been built with thousands of these mirrors used in some of the large solar furnaces in the world.

## Solar Cooking

A few concentrating panels of this type are shown in Fig. 21, where three of them concentrated upon a board will make this board flash into fire. Such mirrors can also be set up in a different pattern like the one shown in Fig. 22 where the mirrors are set up into a circular pattern, heating the fluid in the jar at the focal region of the device.

If higher concentration, and thus higher temperatures, and smaller focal regions are desired, then either small mirrors are needed or continuously curved surfaces can be employed. In this manner excellent concentrating mirrors even of optical quality can be made but they are very expensive and there is a practical limit to the size of these configurations.

Two such mirrors of fair quality are shown in Fig. 23, the one on the left being strong enough to hold its shape by being properly formed, the one on the right being sup-

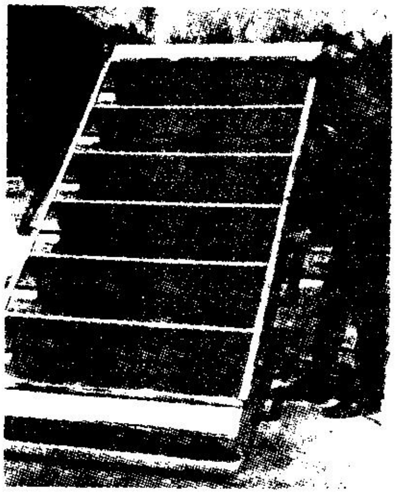

Fig. 17. Stationary high temperature absorber.

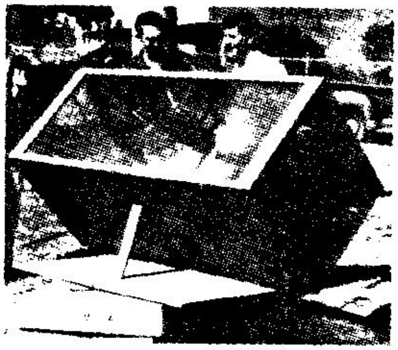

Fig. 18. Solar steam boiler of solar steam power plant.

Fig. 19. 6 x 8 cylindrical parabolic absorber.

Fig. 20. Plastic fresnel lens.

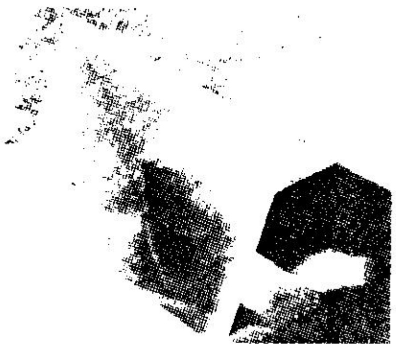

Fig. 21. Solar concentrating panels.

Fig. 22. Solar cooker.

Fig. 23. Parabolic solar concentrators.

Fig. 24. Collapsible solar cooker.

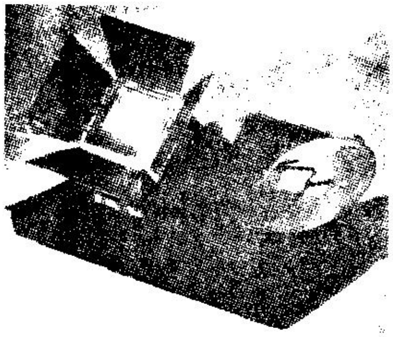

Fig. 25. Solar oven and solar cooker.

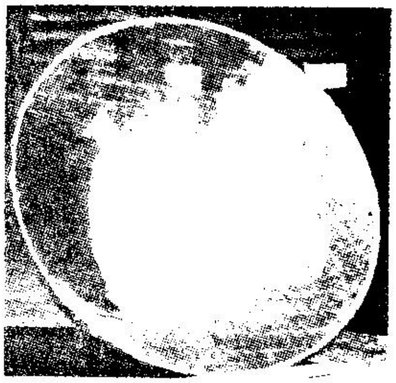

Fig. 26. Concentrating mirrors.

ported by ribs from wood in this case which are cut out forming parabolas. Then thin, highly reflecting metal sheets are held loosely to these ribs to allow for expansion when the metal sheets are slightly heated, thus avoiding distortion. This type of construction is especially important in large sizes. This type of construction was also used in the large parabolic cylindrical concentrator mentioned earlier.

The two concentrators of Fig. 23 were used as solar cookers where only a moderate amount of concentration is needed and too good a concentrator may burn holes into the containers used if great care is not taken. So, not-too-good quality is more desirable for this application.

If such concentrators are used for solar cooking, it may be desirable to design them for easy portability, thus either in sections which can be collapsed for moving, or of coated cloths of an umbrella design which can be folded when not in use. This type is shown in Fig. 24.

An oven and a cooker of moderate concentration are shown in Fig. 25. The flaps on the oven can be adjusted to regulate the degree of concentration needed. An oven of this design will shorten the cooking and baking time by bringing the food up to the desired temperature faster than the type mentioned earlier.

Higher concentrations than the surfaces previously discussed can provide is needed for high temperature work, solar engines, etc. For this purpose, the geometry has to be more perfect. Fig. 26 shows such a mirror of rather high quality giving high degrees of concentration, with the ultimate reached in the solar furnace, Fig. 27.

## Solar Furnace

This solar furnace, with a 5 foot diameter mirror, can produce concentration ratios of almost 25,000 and temperatures of up to 7000 F.

Solar furnaces can be used for research where high temperatures and extremely pure, uncontaminated heat is needed. Materials can be enclosed in glass containers or plastic containers, surrounded by vacuum or any desired atmosphere and heated under very closely controlled conditions. Since the solar energy can be concentrated onto a very small region it is not necessary for the support of the sample to be able to withstand very high temperatures nor is it necessary for the glass or plastic container to be high-temperature resistent since the energy as it goes through this material is not yet concentrated to a high degree. See Fig. 28.

The furnace has been used to produce extremely high purity materials, to grow crystals of high temperature materials, Fig. 29, crystals non-existing in nature, to extract water from rocks and moisture-containing soils (work which may be of great importance when a Lunar station is going to be set up since many experts believe that the solar furnace will be an important tool on the moon), and it may be possible to produce materials on location instead of hauling them from the earth to the moon. We received a citation from the Air Force for this work, etc.

## Mechanical Power

One of the largest programs in our laboratory is the conversion of solar energy into mechanical power. This is done by steam engines (one of them shown in Fig. 30) supplied with steam from the large cylindrical parabolic concentrator, Fig. 31. The combination shown will give about one quarter horse power, limited only by the concentrator and quantity of steam delivered by it.

A working model of a steam power plant is shown in Fig. 32, with the absorber and boiler shown from the front in Fig. 18, and the engine driving a generator and lighting up a small light bulb. The steam engine with a different type of absorber is also shown in Fig. 33. The small square boiler in this case must be used with the concentrators shown in Fig. 21. Other combinations and designs are possible and will work equally well, if designed properly.

We believe, however, that hot air engines have a much greater promise than steam engines for fractional horsepower requirements. They are safer, quiet and need only a source of heat, any source. These engines can be operated off solar energy during the day and, if power is needed during the night, by other sources of heat such as wood, coal, oil; or they can be operated by the heat produced from the burning of waste products such as trash, cow dung, etc.

## Closed Cycle Hot Air Engines

There are two basic types of hot air engines. The closed cycle type encloses a certain amount of air which can be pushed back and forth by a plunger between hot and cold surfaces. When the air is in contact with the hot surfaces it is heated and thus increases the pressure in the engine and when in contact with the cold surfaces it is cooled, thus decreasing the pressure in the engine. A power piston is pushed down when the pressure in the engine is high and returns due to flywheel action when the pressure is low. So every down stroke is a power stroke. With proper timing of the power piston and the plunger, considerable amounts of energy can be produced.

These engines are inherrently slow-speed engines — a few hundred revolutions per minute — since it takes time to heat and cool the air. The heat transfer can be improved by either pressurizing the engine or filling it with gases such as hydrogen or helium. Also, a large surface regenerator will increase the performance of such engines but they become more complicated and much more expensive by such additions and refinements.

Fig. 34 shows a quarter horsepower engine with the displacer cylinder in horizontal position on top and the power-cylinder directly underneath in vertical position. The blackened end of the displacement cylinder is heated and the other end cooled, in this case by a water jacket. Fig. 35 shows such an engine dis-assembled. The basic unit for this engine is a lawn mower engine but the engine itself is much simpler and less expensive since it does not require any valves, carburator or electrical system.

Another engine is shown in Fig. 36 in operation with a radiation shield around the hot end of the displacer cylinder. The concentrated solar energy can clearly be seen heating the end of the displacement cylinder. A five foot mirror is used with this engine which has to be moved about every 15 minutes to keep the energy concentrated on the engine. This movement is rather small and could be automated. Enough heat capacity is built into this engine so that if small clouds pass over the sun the engine will operate through the short intervals of shading.

These engines are not self starting and, after the engine surfaces are heated, must be given a push but will then take off on their own. This should be no handicap if compared with the attention a team of bullocks requires. A single man can operate a bank of these small engines, adjusting the mirrors periodically. In addition, no further land is needed as in the case when animals are used to raise the food they need.

Fig. 37 shows another one of the closed cycle hot air engines in operation and in Fig. 38 it is pumping water out of a ditch. The mirror shown with this engine is actually much better than needed but was used since it was available. It is an old mirror from the solar furnace which has been polished so many times that the reflecting surface is no longer very good. For engine operation the concentrator only has to be good enough to provide a spot of concentration of the size of the displacement cylinder of the engine, about 3½ inches in diameter for the engine shown.

A ½ horsepower engine, closed cycle, is shown in Fig. 39, which is designed to be used with solar energy and can be used directly without modification to burn wood, coal, or liquid fuels. If used with solar energy it is only necessary to open the big door shown and to concentrate the solar energy upon the end of the displacer cylinder inside the furnace box.

## Open Cycle Hot Air Engines

The other type of hot air engine, the open cycle type, takes atmospheric air, compresses it, then heats it again by solar energy or other means and then expands the air and exhausts it into the open.

These engines have the advantage that the heating of the air and the speed of the engine are independent and so these engines can be made to run at much higher speed. This higher speed makes it possible to reduce the weight per unit power output but the engines so far built by us do not have as high conversion efficiency as the closed cycle engines. Fig. 40 shows one of these engines.

Both these types of hot air engines, but especially the closed cycle type, can be built without special equipment and with only the simplest types of machine tools. The timing for best performance is rather critical and should be adjusted carefully. Another critical parameter of the closed cycle engine is the clearance volume.

Our work was concentrated on fractional horsepower engines of the portable type which could be used for irrigation or to drive small machinery.

## Solar Pump

There are other solar devices which can convert solar energy into mechanical energy but they are of less importance.

Fig. 41 shows a solar pump model, in this case made out of glass so that its operation can be observed. It has only two check valves and otherwise no moving parts. A boiler is connected by a straight and a U-shaped tube to a chamber with check valves at the inlet and outlet. The liquid in the boiler is vaporized, pushing liquid out of the system and, when the vapor reaches the bottom of the U tube, it suddenly streams into the other chamber filled with cold liquid where the steam rapidly condenses. While the steam is produced, the top check valve is open and liquid is pushed out. When the vapor condenses, the top check valve closes due to the vacuum produced and the bottom check valve opens, letting in more new liquid to be transported. This pulsating action can be smoothed into steady flow if an air chamber is provided past the top check valve.

## Solar Turbine

Another method of converting solar energy into mechanical energy is by means of a turbine, a model of which is shown in Fig. 42. A vertical chamber with a turbine wheel in it is filled with a volatile liquid to just above the turbine wheel. The collecting surface has a cover with a small hole in the bottom of the chamber. The liquid will drain through this hole into the space below, will come in contact with the hot surface below and vaporize. The vapor will stream upward, forming a jet which, in turn, drives the turbine wheel. When leaving the turbine wheel it will come in contact with the cold surfaces of the upper part of the vertical chamber and condense, running down the walls and repeating the cycle.

For some applications it is more convenient to separate the steam generator from the turbine and the condenser.

## Solar-Gravity Motor

Shifting of weights from one side to the other on a wheel or seesaw can do work. Fig. 42 shows a motor where a number of spheres, two at a time, are connected by tube and mounted on a wheel. The sun shining on one side will vaporize the liquid and the vapor streaming to the other side will condense. If properly designed, continuous motion can be obtained which can be used to pump water or do other useful work. The conversion efficiency and power output are rather small but may be sufficient for certain tasks.

## Solar Reciprocating Engine

Fig. 44 shows another device for the conversion of solar energy into mechanical energy. It consists essentially of a column of water with bellows at the top. The system is completely purged of air. The end of the tube is heated by concentrating solar energy upon it or any other concentrated source of heat. This will vaporize the water on the end of the tube and force the column of water to the right, as shown in the picture. With vapor now in contact with the hot surface, the heat transfer is suddenly decreased tremendously and so the cooling effects are now greater than the heating and the vapor condenses, letting the column of water return to the left until it touches the hot end and the cycle repeats. Cooling of the lower end of the column of water will improve the performance. The moving column will make the end of the bellows move back and forth. This reciprocating motion can be coupled to a flywheel and transformed into rotary motion. This very simple little device is quite noisy, sounding like a small gasoline engine and can, by adjusting the pressure on the end of the bellows be made to run at different speeds, several hundred cycles per minute if desired.

## Conversion to Electricity

If electricity is desired as the form of energy to be used it can be produced by converting solar energy into mechanical energy and then driving a conventional electric generator. More conveniently, the solar energy can be converted directly into electricity by one of the many solid state devices normally referred to as solar cells. Through the space program, great strides have been made in the photogalvanic conversion field utilizing silicon as the most common material. Two photogalvanic converters are shown, Figs. 45 and 46.

Thermoelectric conversion has also been investigated in our laboratory, using certain semiconductor materials as super thermocouples, as well as thermionic conversion, but not a great deal of effort was spent in these areas.

## Sewage Treatment

Another project of interest is application of solar energy to sewage treatment. One phase of this work provided solar heating for sewage digesters. By heating these digesters and controlling the temperature for optimum efficiency, considerably more sewage can be

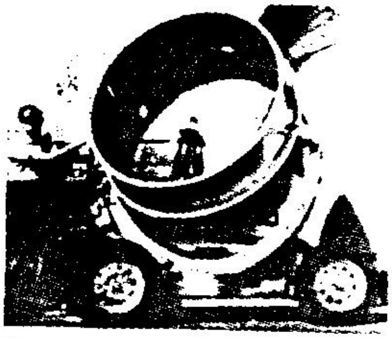

Fig. 27. 5-foot solar furnace.

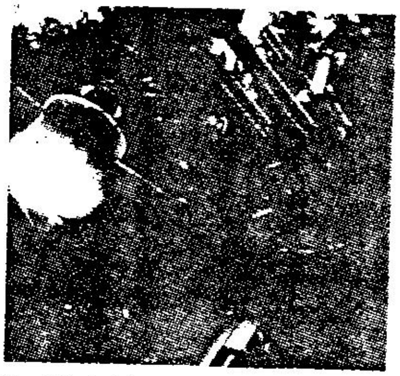

Fig. 28. Calcium oxide target irradiated in solar furnace.

Fig. 29. Calcium oxide crystal.

Fig. 30. Small steam engine.

Fig. 31. Steam engine operated by solar energy (¼ horsepower).

Fig. 32. Solar steam power plant (see also Fig. 18).

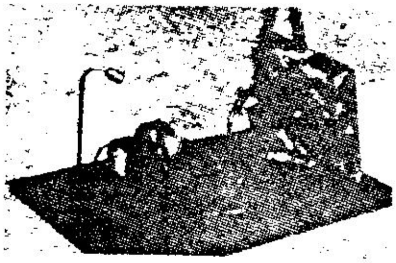

Fig. 33. Solar steam power plant (see also Fig. 21).

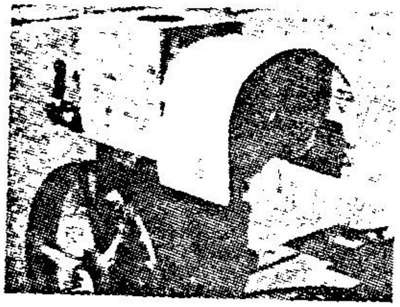

Fig. 34. ¼ horsepower closed cycle hot air engine.

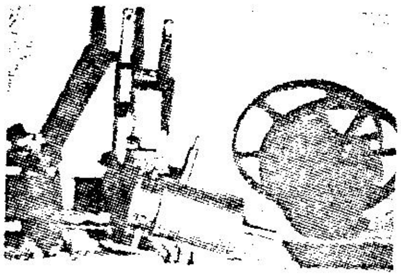

Fig. 35. Dis-assembled closed cycle hot air engine.

Fig. 36. Hot air engine operated by solar energy.

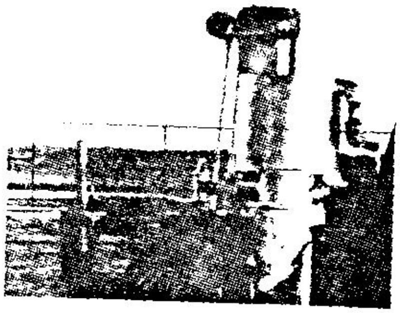

Fig. 37. 1/3-horsepower closed cycle hot air engine.

Fig. 38. Pumping water with solar energy.

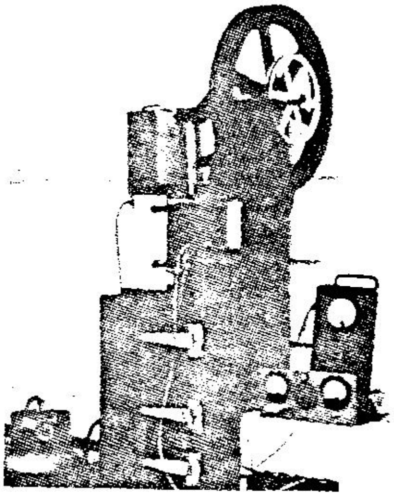

Fig. 39. ½-horsepower closed cycle hot air engine.