TECHNOLOGIES FOR THE RURAL POOR PROJECT:

FINDINGS AND RECOMMENDATIONS OF AID/DNES EVALUATION TEAM

Prepared for:

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and

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PREFACE

The following report is the result of a cooperative effort between consultants from Associates in Rural Development (ARD), Inc., Burlington, Vermont, USA, and senior staff from the Department of Non-Conventional Energy Sources (DNES), New Delhi, India. Given the tight time constraints for the completion of the site visits and draft report, the analysis that follows would not have been possible without the active assistance and support of a number of individuals and organizations. The Office of Project Design and Portfolio Management of the U.S. Agency for International Development (AID) in New Delhi provided facilities for the ARD consultants during their stay, as well as logistical support and arrangements for the field site visits. Mr. R. K. Berry was very helpful in setting up visits with key researchers and took care of a myriad of logistical details, while providing much of the background historical material on the progress of each subproject. Mr. Robert Nachtrieb gave the team free rein of his facilities and made all of his staff available on a minute's notice for consultations and questions. He provided valuable historical perspective on the evolution of the project and served as a sounding board for the evaluation team's preliminary recommendations and conclusions. The AID/New Delhi Mission also provided extraordinary support services, including word processing and reproduction, for the first draft of this report.

The evaluation team would also like to thank the numerous members of the DNES staff in New Delhi for their assistance in the collection of data and historical information on each of the project subcomponents. Similarly, this evaluation would have been impossible without the assistance and courtesy provided by the staff of the following Indian scientific institutions: the Indian Institute of Science, Bangalore; Bharat Heavy Electricals Limited, Hyderabad; the Central Electronics Laboratory, Sahibabad; Annamalai University, Annamalainagar; and Roorkee University, Roorkee. Each of these institutions graciously welcomed the U.S.-Indian evaluation team, provided field visits and documentation of subproject problems and progress, and discussed freely the collaboration with their U.S. counterparts.

Lastly, the team would like to thank the support staff at ARD, who cheerfully dealt with numerous revisions and contributed to the readability of the final product. In particular, we would like to thank Laurie Gee for her expert assistance in the preparation of this final document.

ACRONYMS

AHEC	Alternate Hydro Energy Centre
AID	U.S. Agency for International Development
ARD	Associates in Rural Development, Inc.
AU	Annamalai University
BHEL	Bharat Heavy Electrical Limited
BU	Boston University
CEL	Central Electronics Limited
CSU	Colorado State University
DAS	data acquisition system
DNES	Indian Department of Non-Conventional Energy Sources
DOE	U.S. Department of Energy
EMC	equilibrium moisture content
ERDA	U.S. Energy Research and Development Administration
GOI	Government of India
IIS	Indian Institute of Science
JPL	U.S. Jet Propulsion Laboratory
KSIC	Karnataka Silk Industries Corporation
KVIC	Khadi Village Industries Corporation
LCC	life-cycle cost
MOE	Indian Ministry of Education
NASA	U.S. National Aeronautics and Space Administration
NPV	net present value
PI	principal investigator
PV	photovoltaics
RET	renewable energy technology
Rs.	rupees
TRP	Technologies for the Rural Poor
UH	University of Houston
UV	ultraviolet

EXECUTIVE SUMMARY

The evaluation team found that the Technologies for the Rural Poor (TRP) Project resulted in significant technology transfer between U.S. and Indian scientific and academic institutions in the area of renewable energy utilization. Long-term institutional relationships were established which will facilitate future technology development and information transfer. In addition, the TRP project assisted significantly in the establishment of Indian centers of excellence in several areas of renewable energy research and utilization. The quality of the technical research performed was high, and the technologies developed were technically sound, with high performance characteristics.

The project seemed to have suffered from a divergence between its initial conception, that of scientific exchange and scholarly research, and its stated purpose, which was to develop technologies for the rural poor. A number of the technologies that emerged from this project were scientifically interesting, but too expensive and too complex for remote site operation and maintenance. The complexity of several of the projects, combined with shifting research priorities in the United States, led to serious project implementation delays. Only one of the four subproject components had been completed at the time of the evaluation team visits. The other three projects will require an additional three to 12 months just to complete the installation of the technologies at the field-testing sites, plus six to 12 months of monitoring and data collection to determine the performance of the complete systems under field conditions and their economic feasibility.

The evaluation team found that one of the technologies, the solar rice drying systems developed by Annamalai and Colorado State Universities, appeared to be ready for a widespread testing and dissemination program. The evaluation of the cost-effectiveness of the other technologies will have to await the results from the field-testing and data collection.

The evaluation team recommended that all of the subprojects be extended to allow for the final procurement of all needed equipment, system assembly and debugging, and six to 12 months of field-testing. It also recommended that the U.S. Agency for International Development (AID) and the Indian Department of Non-Conventional Energy Sources (DNES) fund follow-up economic analysis of each technology, after the field-testing is completed, to determine if broader demonstration or commercialization is warranted.

The evaluation team recommended that AID and DNES consider three follow-up activities:

- utilization of solar energy and biomass waste in agricultural drying: testing of 10 to 20 industrial solar dryers, as well as additional technology modifications to examine the utility of a solar dryer that can use rice husks as an auxiliary heat source;

- integrated rural development projects to couple with planned remote micro-hydro installations: working with local communities to develop income-producing or social service electrical loads that could be coupled to forthcoming micro-hydro installations to increase load factors and stimulate rural development;

- wind monitoring systems for agricultural and community water supply: working with the Government of India (GOI) to set up a national wind monitoring network, as well as testing a small number of wind water-pumpers for provision of drinking and irrigation water.

1.0 INTRODUCTION

The following report is an evaluation of the Technologies for the Rural Poor Project (USAID 386-0465) in India. This report contains the findings, recommendations and suggestions for follow-on activities of a joint U.S.-India team, based on interviews, field visits, and analysis of documentary information conducted between November 25, 1984, and December 20, 1984. The team had the opportunity to visit the sites of all four of the project subcomponents, to examine the systems developed, and to discuss at length with the Indian participants the problems encountered, the current status of the subcomponents, and the plans underway to complete the proposed research and development as well as to commercialize the various renewable energy technologies (RETs).

As requested by the U.S. Agency for International Development (AID) and the Indian Department of Non-Conventional Energy Sources (DNES), the evaluation team focused its limited time and resources on what the individual subcomponent projects have accomplished relative to their original objectives and those of the overall project. Considerable attention was also paid to the lessons to be learned from the constraints encountered to timely project completion (since only one of the components is operational thus far), the collaborative relationship established, and management problems of a joint U.S.-Indian scientific technology development program. An effort was made to assess the utility of the technologies developed to future Indian development, with particular emphasis on rural areas. Lastly, the evaluation team provided several suggestions for new initiatives, based on the work undertaken in the Technologies for the Rural Poor (TRP) Project, that will assist in the further development, dissemination and commercialization of renewable energy systems appropriate to Indian rural development in the period 1985-1990.

2.0 BACKGROUND

2.1 Project Development

In the early 1970s, Indo-U.S. diplomatic relations reached a low point since Indian independence, with the phase-out of the AID program and a drastic reduction in the U.S. presence in New Delhi. In 1974, as an initial step in reversing this unfortunate development, the two countries agreed to establish a Joint Commission for Indo-U.S. Cooperation, which included among its components a Subcommission on Scientific and Technological (S&T) Cooperation. Subsequently, the S&T subcommission identified energy and natural resources as one of its priority areas, with an emphasis on RETs. As one of the first steps in the revival of the AID program in India in 1978, a project fostering joint scientific cooperation among U.S. and Indian researchers in the area of solar energy was developed and approved.

2.2 Selection of Individual Subcomponents

Under the auspices of the Subcommission on Scientific and Technological Cooperation, discussions on possible collaboration on solar energy research topics began between U.S. and India researchers in 1976 and 1977. Proposals were developed and submitted to the U.S. Energy Research and Development Administration (ERDA--now the Department of Energy or DOE). ERDA/DOE provided the technical review of the proposals, selecting the U.S. Jet Propulsion Laboratory (JPL)/Bharat Heavy Electrical, Ltd. (BHEL) dish concentrator system, the Indian Institute of Science (IIS) Bangalore/University of Houston (UH) trough collectors, and the Annamalai University (AU)/Colorado State University (CSU) solar drying systems as being technically interesting and worthwhile. The collaborative work between CSU and Roorkee University on micro-hydro electronic controllers appeared later in the project development process. ERDA/DOE did not have the funds available to pay for the U.S. dollar costs of the proposed research. At that point, the chief ERDA/DOE manager of the project selection process moved to AID/Washington to work on the growing AID energy portfolio, and this provided additional impetus to AID's involvement in funding and supporting the proposed subcomponents. It should be noted, however, that they were initially screened and selected on their technical merit and interest, rather than on their applicability to the rural poor (a criterion which was later added when AID/New Delhi decided to fund the overall Energy for the Rural Poor Project). The subcomponents were designed as research projects, and several of them remained that despite the changing environment in AID and in India.

It is important to remember that this project, as well as the similar renewable energy projects that were launched simultaneously in Thailand, Indonesia, and the Philippines, was based on a strong assumption that the international price of crude oil would continue to rise to over US$40 (1979 dollars) per barrel. There was also strong U.S. Congressional and administrative pressure to develop foreign assistance projects centering on solar energy technologies, in order to reduce consumption of firewood and other biomass fuels and to reduce the dependency of developing countries on imported fossil fuels.

2.3 Initial Delays and Problems in Implementation

It took nearly two years for the individual components of the TRP project to receive approval after the project agreement was signed on August 26, 1978. A Government of India (GOI) committee had to be set up to review the various proposals, and its procedures had to be approved by AID. This did not occur until January 1979. AID/New Delhi informally rejected most of the initial subproject submissions as being too small, not collaborative in nature, or not promoting technology transfer. At AID's urging, the GOI's Department of Science and Technology developed more sharply focused guidelines for subproject selection. This led to the revision and resubmission of some of the larger proposals, such as the Salojipally village energy system, the IIS Bangalore/UH collaboration, and the AU/CSU solar drying collaboration. Finally, the Salojipally proposal was approved on June 12, 1980, with the others approved in December 1980. These delays were crucial for subsequent implementation of certain subcomponents, in large part because of the de-emphasis on RETs that took place with the arrival of the new U.S. administration in January 1981.

2.4 Emphasis on Indo-U.S. Technical Collaboration over Delivery of Services and AID Technical Monitoring

Based on the correspondence examined at AID/New Delhi and on discussions with the Indian principal investigators, the TRP project was seen by AID and the scientists involved primarily as a program of scientific exchange and collaboration. While the criterion of providing technologies appropriate to the rural poor has been added at AID's insistence, it did not seem central to either the subsequent technology development or to AID/New Delhi's oversight of each of the subprojects. Moreover, AID/New Delhi never had a technically trained energy officer during the course of the project, but rather a project officer assigned to make certain that work was done on time. When problems arose and budgets began to rise due to unforeseen problems, as is bound to happen in technology development projects, there was no scientific expertise in the mission to pass judgment on proposed solutions. The mission seems to have felt that such decisions are best left to the scientists involved, although the project officers did intercede effectively on certain of the subprojects to block gratuitous travel and unnecessary principal investigator expenses.

2.5 The Evaluation Schedule Versus the Implementation Schedule

One of the major problems confronting the evaluation team was that only one of the subprojects (the AU/CSU solar drying collaboration) was completed. In the other cases, the field-testing had not yet begun as of mid-December 1984, and was not scheduled to commence until sometime after the evaluation was completed. This was a constant problem, since it was impossible to comment on the technical performance and economic viability of a system that had only been tested in the laboratory. While the causes for the delays vary from subproject to subproject, the evaluation team found it necessary to place reduced emphasis on areas such as economic analysis, since the stream of benefits had not yet been measured, all the capital costs had not yet been incurred, and no information was available on recurrent operating costs.

2.6 Evaluation Requirements

The evaluation team was asked by AID/New Delhi to examine each of the four project subcomponents to "determine the:

(a) soundness of criteria used to select various subprojects;

(b) attainment of subproject objectives and overall project objectives;

(c) constraints that may have inhibited attainment of objectives and actions that could have been taken to overcome constraints;

(d) effectiveness of U.S. technology transfer;

(e) management effectiveness of CASE/DNES/AID;

(f) relevance of technologies selected, i.e., is it a technology that can be replicated without donor technical/financial assistance? Is it appropriate for the targeted beneficiary population? Does an adequate maintenance capability exist?

(g) relevance/effectiveness of study tours. Was U.S. technical assistance satisfactory? Could project have done with more or less?

(h) Will collaborative ties established exist beyond the life of the project?

(i) Was procurement of equipment timely and selection of equipment appropriate?"

In addition, the evaluation team was asked to provide suggestions on what follow-on activities should be pursued. These were to include the development of draft project proposals which could later be developed into project identification documents for use by AID/New Delhi staff.

3.0 OVERALL PROJECT ACCOMPLISHMENTS

3.1 Fulfillment of Project Objectives

- Technology Transfer and U.S.-Indian Collaboration: The cooperation between U.S. and Indian counterparts in the TRP project has resulted in both genuine transfer of technical skills and the formation of several long-term institutional relationships that should facilitate future cooperation in the same scientific areas.

- Institution-Building: The TRP project has measurably assisted in the formation of several Indian centers of topical excellence that would not have existed without this project. This is particularly true for the industrial solar drying work at AU and the high-temperature solar thermal design capability at BHEL.

- Development of Technology Directly Applicable to the Rural Poor: It is impossible to estimate the ultimate applicability of the technologies developed in all of the subcomponents except the AU/CSU solar drying work, since no working prototypes have been field-tested yet, and no economic feasibility and social acceptability studies have been done. Several of the technologies appear to be too complex and expensive for remote site operation and maintenance, and appear to have been selected for their scientific interest rather than for their relevance to rural development.

3.2 Current Status

- Completion of Project Tasks and Technology Testing: All of the subcomponents, with the exception of the solar drying development, are seriously behind schedule. In most cases, field-testing will not begin until April-June 1985, and results from field monitoring will not be available until the summer of 1986.

- Procurement Problems: Several of the subcomponents are having great difficulty getting delivery of specialized, custom-fabricated parts ordered in the United States, and the testing of the technologies will be dependent on the delivery and satisfactory performance of these components.

- Additional Funding: Several of the U.S. collaborators are requesting additional funding for continuation of the work. Such additional funds should be granted only in one or two instances, and then only for specific, standardized, technical assistance work or procurement of U.S. equipment.

3.3 Project Design

- Subcomponent Selection: Several of the subcomponents funded under this project have only a tenuous connection with cost-effective rural development and appear to have been selected because they were expensive and involved very experimental techniques. The criteria that were suggested in the project paper for subproject selection, although quite adequate, should have been more rigorously applied to guard against the selection of what should have been perceived as inappropriate technologies. Economic, social and technical feasibility studies, when performed at all, were frequently inadequate. Some criteria were completely ignored (for instance, although it was stated in the project paper that particular attention should be paid to including professional women in project selection and implementation, of all the project personnel met by the evaluation team at all four projects, none was a woman).

- Choice of Collaborators: The selection of universities and national laboratories as U.S. collaborators probably increased unnecessarily the emphasis on high performance and reduced the emphasis on the commercial viability of the prototypes developed. In at least one case, the choice of an inexperienced U.S. collaborator materially hampered the progress of the Indian scientists.

3.4 Project Management

- Trained Project Monitors: The absence of an experienced, technically trained AID energy officer or personal services contractor supervising the four subcomponents of the TRP project was a major problem. This meant that several basic research activities that should have been abandoned early on as being economically unfeasible were allowed to continue and consume valuable project resources.

- Narrow Focus on Project Objectives: There was a lack of direction from AID and DNES, during the periodic reviews and annual evaluations, to force the researchers to defend activities undertaken that were academically interesting but irrelevant to the development and testing of the technologies and to the overall project objectives.

- Timeliness of Task Completion: Several of the U.S. counterpart organizations were very slow in executing the activities to which they had agreed. While there is evidence that pressure was brought to bear upon them by AID staff to speed up these activities (particularly procurement), it appeared to have little impact. These delays in turn slowed other technology development and testing work in India.

3.5 Technology Readiness

- Commercial Status: Of the technologies developed under the TRP project, the small-scale and industrial solar drying systems appear to be ready for a broad-based demonstration and commercialization effort, involving both potential users and potential commercial fabricators. Until the other field trials are complete, it is impossible to estimate whether there is a demand in India for the other technologies, such as line-focus solar collectors and micro-hydro hybrid systems. The dish collectors still appear to be too complex and expensive for commercial operation.

- Applicability to Remote Site Operation and Maintenance: Virtually all of the systems developed under this project have been optimized for technical performance, rather than for ease of installation and operation and low maintenance requirements. Additional production engineering, based on field trial results, will be required before remote site performance can be assured.

4.0 AU/CSU SOLAR DRYING SYSTEMS FOR AGRICULTURAL PRODUCE

4.1 Subproject Description

Annamalai University in Tamil Nadu State and Colorado State University mounted a collaborative effort to address a very specific need for the rural poor in India, drying agricultural produce, especially paddy (rice). In southern India, drying of freshly harvested rice is required during two seasons, after the May/June harvest and then again after the October/November harvest. The favorable climate after the first harvest allows for easy drying using traditional methods (described below). However, the second drying is difficult due to the less than favorable solar radiation levels and frequent rains of the late fall.

By tradition, in southern India rice is dried twice, once after harvest, then after parboiling. During parboiling, rice is soaked in water for four hours, then steam-heated for 10 minutes. This sets the bran into the grain, increasing the nutritional value of the rice. Parboiled rice also stores longer after being re-dried.

The traditional method of drying rice, used both by small farmers and rice mills, is to spread the harvested grain out on a flat surface, usually the ground, where natural solar drying will occur. The rice is turned frequently to ensure uniform drying. While rice mills normally have interior courtyards for drying, small farmers, who frequently lack sufficient drying space, simply spread their harvest on a nearby road for drying. It is damaged by vehicles, ravaged by birds, occasionally soaked by rain, and becomes contaminated by dirt and vehicle exhaust. The low quality of the grain results in a lower price if sold, and decreased nutritional value if eaten by the growers.

CSU and AU had both worked on agricultural solar drying technologies in the past. In their collaborative effort for this project, they pursued two parallel approaches to the drying problem. AU was primarily interested in developing a low-cost portable dryer which could be used by groups of farmers in rotation, first drying crops in one village, then being disassembled, transported to another village, and reassembled for further use. The primary design criteria were portability, proper capacity for the user audience (small village farmers), use of locally available materials for construction, and overall cost-effectiveness. The aim was to save money, time, and make better use of scarce available space for small farmers.

Units owned individually by small farmers might only be used for 30 days per year if only paddy drying is done. One way of making the units more cost-effective is to dramatically increase the amount of time each unit is used, or its capacity factor. Portability would provide for serial use by many farmers, both for freshly harvested as well as parboiled rice. Parboiled rice can be dried at other than harvest time. If the units could be used to dry other agricultural produce, such as groundnuts (peanuts), maize or chilis, this would further increase their capacity factor, and hence their cost-effectiveness.

Concurrently, larger units were developed for use by local rice mills which can process an average of 10 tons of paddy per day when several of the units are used in parallel. Advantages of a solar drying unit to a rice mill include faster, more uniform drying, fewer losses to birds, lower labor costs (no labor for turning the rice is required), and higher quality output. Since open ground is a costly commodity, the increased drying capacity per unit area from solar drying is another benefit to large users such as rice mills as well as small farmers.

The CSU efforts focused primarily on a stationary unit mounted on the roof of a small building which can be used for grain storage, shelter, or other purposes. Reflecting the economic differences between the two sites, the CSU unit used more expensive materials (e.g., glass collectors rather than plastic) to avoid the higher costs of U.S. labor if frequent replacement of plastic glazing were required. The AU design used low-cost plastic collectors because low-cost, semi-skilled labor required for the increased maintenance was locally available.

4.2 Progress to Date

Both universities have completed all major tasks for the project. Cost-effective solar dryers have been developed, tested, and are currently being demonstrated to target audiences, as well as to interested government officials and researchers, prior to their expected commercialization.

AU designed, built and tested nearly a dozen solar drying units before arriving at three units which they hope to commercialize. The simplest of these will be used by the poorest farmers, and consist principally of sheets of plastic. The inexpensive unit has three types. The first is simply a sheet of black polythene (polyethylene) plastic laid on flat ground. This serves a dual purpose of absorbing additional solar radiation, as well as reducing the amount of contaminants (dirt, surface water, etc.) in the rice. This is only slightly more thermally efficient than ground drying. One kilogram of paddy per square foot of plastic can be dried over a normally sunny eight-hour day at an efficiency of about 10 percent. Efficiency is the ratio of the minimum energy required to evaporate the water out of a one-square-foot layer of rice divided by the solar radiation incident upon that same square foot.

The second type of unit uses two pieces of plastic. The layer of black polythene is used as described above. A three-inch layer of rice husks is placed on top, with a second piece of polythene on top of the husks. The upper layer of polythene was later replaced by rexin (rubberized cotton) cloth for much greater durability. This arrangement provides an insulating layer between the rice and the ground, reducing downward heat losses. About 1.5 kg per square foot of plastic can be dried per day at 15 percent efficiency. The third type of simple dryer has the same polythene insulated ground cover as the second, but a piece of ultraviolet (UV) treated translucent polythene on a bamboo frame is placed three inches above the rice to be dried. UV-treated polythene lasts much longer than regular polythene when continually exposed to sunlight. This dryer can produce two kilograms per square foot per day at greater than 20 percent efficiency.

For all of the above units, manual stirring of the rice is required every 20 to 30 minutes. The polythene-on-bamboo frame can be removed easily to do this. The polythene can also be used in all cases for quick rain protection. Since the cost of the plastic is only Rs. 0.60 per square foot (rexin is Rs. 3 per square foot but lasts about 50 times as long), these dryers are well within the range of the average farmer.

The next type of unit is much more costly, yet is capable of much higher yields than the models previously discussed. This intermediate-sized unit uses the same basic design as the simple units, black polythene base, three inches of rice husk insulation, rexin cloth on top. On top of the rexin cloth are placed flat, rectangular pieces of galvanized sheet metal with many small holes punched in them and painted black. This serves as the primary solar radiation absorber. Small mild steel trusses support the translucent UV-resistant polythene cover as a gable roof above the absorber. Bamboo strips between the plastic and steel protect the polythene from melting on the steel trusses. The overhanging sides of the plastic cover are covered with earth to prevent air coming in except at the gable end. There is no rice in the collector unit per se. Rather, a circulation fan sucks air through the collector, where it is heated by solar radiation. The hot air is then blown into a raised 2.4m x 1.5m x 0.6m rectangluar bin and forced up through a grate upon which the rice is piled. The 4.5m x 12m collector provides enough hot air to dry 250 kg of rice in three hours on a sunny day. This is nearly double (3.6 kg per square foot per day) the output of an equivalent-sized, simple plastic dryer with translucent cover. Its efficiency is 30 percent. The rice must be manually stirred in this unit as well.

Since this intermediate-sized dryer can dry much more rice than one typical small farmer would normally have, it was designed to be portable for use at many sites. It can be taken apart by two people in three hours, and reassembly takes seven hours. It costs Rs. 7380 to manufacture.

The third and largest dryer was designed for use at rice mills. The collector unit is essentially the same as the one just described, except that its dimensions are larger, 30.5m long and 4.5m wide. The drying unit through which the solar heated air is blown is considerably different. A vertical column recirculating dryer is used, essentially two concentric wire mesh cylinders. Grain is loaded into a hopper at the top, then runs down into the six-inch space between the wire mesh, making in effect a hollow cylinder of rice supported by the wire mesh. Grain falls out the bottom and into a funnel which channels the grain into an elevator which carries the grain back to the top of the vertical column for another run through. Hot air from the collector is blown through a diffuser and into the center of the grain cylinder. It is then forced out through the falling grain, drying it.

The automatic recirculation allows for very uniform drying. The efficiency approaches 40 percent. The dryer has an output of 1.75 tons of rice per day. It has been installed at the Tamil Nadu Civil Supplies Corporation rice mill in Chidabaram, near AU, and is currently undergoing extensive field-testing.

The CSU unit was developed as a stationary unit using higher cost yet more durable materials than the AU dryer. The slightly more efficient (42 percent) unit has a capacity of one ton in less than one day and uses motor-driven mechanical stirring devices. The collector is 40 square meters of roof-mounted tempered glass and aluminum absorber solar air heaters. A fan is used to move hot air through the collectors and into the grain drying bed, where grain is piled about two feet deep. After passing through the grain, the cooler humid air is exhausted to the outside.

The fan was initially electrically driven, but later a three-horsepower natural gas engine was used, since access to reliable electricity is not likely in a rural Indian setting. The waste heat from the engine is used to further heat the air from the collectors, thereby increasing the unit's overall efficiency. Total cost of the dryer is $4630 on a one-off basis. Production runs would likely reduce costs considerably.

4.3 Attainment of Subproject and Overall Project Objectives

The subproject had four primary objectives:

- assessment of drying demands for agricultural products, including current practice and climatic factors;
- use of this assessment by CSU to apply and modify current U.S. crop drying technology, in conjunction with AU, to meet rural Indian needs;
- construction of prototype units in India and the United States using CSU-generated design specifications and methods; and
- a field monitoring program during the third year of the project to measure the effectiveness of the system prototypes.

AU also added a further objective in later reports of providing rural employment in the manufacturing of the dryers developed during the project.

The primary responsibilities of CSU were the assessment of proper materials and construction methods (this was essentially completed by September 1981); computer optimization of various designs from the perspective of thermal performance; and the selection, procurement and experimental methodology of the monitoring instrumentation (most of the instrumentation was brought over during Mr. Smith's (the CSU principal investigator) first visit to AU in February 1983). AU scientists were then instructed in its operation and maintenance.

AU performed the agricultural drying demand assessment during the initial months of the project. This information was used by CSU to do initial system sizing and design using its computer model and the basic dryer design. As was detailed in section 4.2, a number of different dryer designs have been developed and tested by both CSU and AU, with AU deciding on the three portable systems described previously, and CSU's effort focused primarily on the stationary, more durable model.

The field monitoring program has been an integral part of the design/development process at AU. As each model was developed, field tests were conducted, and feedback from farmers on ease of use, effectiveness of design and suggestions for further modifications were taken into account.

Through a series of demonstrations and seminars, AU is conducting a public awareness campaign as a precursor to its commercialization efforts. The designs that have evolved are manufacturable out of mostly locally available materials (the translucent UV-treated polythene is presently being procured from the United States) and with indigenous manufacturing capabilities.

4.4 Constraints to Timely Subproject Completion

This subproject was completed on time and under budget. In that sense, it was unique among the subprojects reviewed. There were several minor problems which did cause some delay. There was an unusually high turnover of the technical support staff (not the principal investigators) at AU. This was because the project was by definition of limited duration. Therefore, as permanent positions arose in other projects at AU, staff transferred out of the CSU/AU subproject.

Very frequent power outages caused almost daily delays in the production of the units. Testing programs were somewhat slowed due to unusual weather conditions in Tamil Nadu State. The drought of 1982 made it difficult for the University to get parboiled rice samples because of very low rice production. The excessive rains following the drought resulted in poor operating conditions (cool temperatures, low solar radiation levels) and impassable roads to villages where the units were being tested.

There were some minor difficulties in obtaining certain materials for the collectors, such as UV-treated translucent polythene. Although this is manufactured in India, the supply is erratic, the quality control poor, and the film is actually more expensive than U.S.-manufactured material. The U.S. material has thus been used for most of the collector covers manufactured thus far.

The computer-based data acquisition system experienced some difficulty in clearing customs. Delays in obtaining several documents (NMI and MOE certificates) required by the GOI for avoidance of customs duties were a problem shared by all the subprojects evaluated.

AU was having some difficulties due to a lack of financing for the extension work necessary to the overall dissemination/commercialization effort. It is hoped that this will be remedied by DNES contributions after the subproject evaluation is made available.

4.5 Procurement Problems

The few procurement problems have been mentioned in previous sections. The majority of U.S. procurements consisted of instrumentation for data acquisition during performance tests of the drying units. As of August 1984, AU had received virtually all of this equipment, except for two instruments for which GOI clearances were being obtained. As mentioned above, Mr. Smith of CSU had brought much of the equipment with him on his first visit to AU. Principal investigators on other subprojects would have done well to do likewise.

4.6 Management Effectiveness of U.S. and Indian Institutions

The effectiveness of the management on the part of both the U.S. and Indian institutions is attested to by the fact that the project fulfilled its objectives within the time and budget constraints originally agreed upon. It must be borne in mind that this was, conceptually and practically speaking, by far the simplest of the four subprojects in the TRP project.

The pre-design energy survey was carried out prior to committing resources to any particular design. Design and procurement decisions were essentially completed in the first year of the project (April 1981 to May 1982). Prototype performance testing proceeded in an orderly fashion throughout the project, as each design was laboratory and field-tested (using farmers' inputs) to provide design criteria for succeeding designs.

Project funds were not used extensively for travel. Although useful and rewarding trips were made by members of both institutions, these trips were well planned and well focused to accomplish specific technical (as opposed to managerial) tasks.

4.7 Effectiveness of U.S. to India Technology Transfer

Unlike the other three subprojects, this project did not involve a sizeable infusion of U.S. technology to the Indian counterpart organizations. AU had done as much work in low-cost solar drying as had CSU, if not more. Transfer of U.S. technology was principally in two areas, data acquisition systems (DAS) instrumentation and computer modeling.

The DAS was based on a Hewlett-Packard HP-85 computer and HP-3497A data acquisition module. These were used to record the test variables being measured. The sensors were also manufactured in the United States: pyroheliometers (measures direct solar radiation); pyranometers (total solar radiation); thermocouples to measure ambient, dryer interior air, and paddy temperatures; air flow measuring devices, etc. The AU investigators were trained in the use of this equipment and have used it to successfully monitor and evaluate their dryers. This DAS can be used in widely diverse projects in the future as well.

The computer programs used by CSU to optimize design parameters of the dryers provided useful information to AU, but the programs themselves, which were written on mainframe Control Data Corporation machines, cannot be used directly by AU because the computer hardware is not available in India.

4.8 Relevance of the AU/CSU Solar Dryer Development

4.8.1 Production and Installation by Indian Institutions

Due to the careful consideration given to the choice of materials and construction techniques during the design phase, these dryers are replicable without requiring any further technical assistance. They can be manufactured in rural areas using semi-skilled labor and easily available materials (except UV-treated polythene, which could be purchased in bulk by a group of manufacturers). Groups ranging from small farmers to rice mills to government agricultural researchers have requested plans and assistance in building their own units.

4.8.2 Remote Site Operation and Maintenance

Components made of local materials, even though their performance characteristics might be less than ideal, are easily replaced and maintained by farmers. The adaptation of biogas-fired engines (rather than diesel or petrol, as used at present) would serve to make the units that much more independent of the vagaries of fossil fuel supply and price.

The units require little skill in assembly and disassembly for use at multiple sites. Capacity factors of up to 80 percent are possible, assuming that about 20 percent of the time is spent in transport and assembly. Multiple-site use might generate some management difficulties, however, if the units are jointly owned. Time allocation and use priority will likely cause problems, at least initially. A single owner could allocate use more easily. Site selection would be more critical for the stationary units. They would have to be in a high-use area such as a rice mill, or available to villages with diverse cropping patterns so that use schedules could be maximized throughout the year.

4.8.3 The Rural Poor

The rural poor have much to gain by the use of the lower priced dryers developed during the project. The very low costs, the use of mostly locally available materials, and the low levels of technical skills required place the small-scale dryers within the reach of many small farmers.

Solar drying, if performed carefully, increases the value of rice by providing a more uniformly high-quality product, free from broken grains and contaminants. The temperature regulation of the solar dryers allows for better retention of nutrients and flavor. Small units can be constructed by individual farmers, and the larger units encourage cooperative ventures. Discussions with farmers who were taking part in the field-testing programs left the evaluation team with very favorable impressions of the commercial potential of the units.

4.9 Relevance of Collaborative Effort and Study Tours

According to AU researchers, their U.S. counterparts at CSU provided all the technical assistance that was required for successful completion of the project. Collaborative ties between the two institutions, as well as between AU and the other individuals and institutions visited on the U.S. trips, will likely prove to be of benefit to all parties. The AU scientists visited 11 institutions where research was being conducted on solar drying techniques and closely related topics such as biogas engines. During the four-week visit, system designs were finalized with CSU and procurement issues were settled.

Because of AU's extensive experience in solar drying, CSU researchers also benefited from the association. Papers were delivered by both parties at international technical conferences in Europe and Australia, where the interim results of the project were shared with other scientists involved in related research.

AU scientists said that they were quite satisfied with the cooperation they had received from CSU. They did say, however, that in future research efforts they would further exploit the contacts made in their travels to work more closely with those who had more specific experience in paddy drying in tropical climates.

4.10 Economic Viability of the Technologies Under Development

The economic analysis of the dryers developed by AU/CSU is not as clear cut as the analyses of other subproject technologies given in this report. This is because the traditional alternatives to the use of solar dryers do not have easily quantifiable costs against which the measurable cost of the solar dryers can be compared.

Drying increases the value of rice sold to a rice mill by a small farmer. For a rice equilibrium moisture content (EMC) of 18 percent (18 percent by weight), the standard government fixed rate of Rs. 137 per kg is paid by the rice mill to the farmer. If the rice is dried by the farmer down to the 12 percent EMC which is necessary for long-term storage, no incremental benefit is paid by the rice mill. Drying down this far would only be directly beneficial to the farmer if the rice is used for personal consumption, or for storing the rice for sale at a later date when prices are higher. If the rice to be sold has a 19 percent EMC, the price is Rs. 3.5 less per kilo (Rs. 133.5/kg). At 20 percent EMC, the price drops to Rs. 131 per kg. Above 21 percent EMC, the rice is refused by the mill.

Thus the farmer has no direct economic incentive to dry rice below 18 percent EMC if it is intended for sale to a rice mill. However, the rice mill will then have to dry it down to 12 percent before it can be stored, and the price of the final dried rice must include this cost. Since solar drying increases the efficiency of ground use required for rice processing, this too should be incorporated into the aggregate benefits of solar drying, but this savings is again difficult to quantify.

A very detailed economic analysis of the AU dryers is given in AU's "Report of Indo-U.S. Collaborative Project on Optimisation of Solar Drying Systems for Agricultural Produce." The cost of drying a ton of paddy per day based on a 20-year amortization period is calculated as Rs. 16 for the 1.75 tons/day industrial or rice mill sized dryers. This is then compared to Rs. 21 per ton per day by traditional methods. Although one can certainly argue with the assumptions used to calculate the cost of drying rice by the traditional method (no cost is assigned to the land on which the dryers would be built, the major component in the cost for the traditional drying method), the fact remains that the cost of the large solar dryers, when amortized over a long period, represents a small incremental cost expenditure in processing. This, added to the fact that the largely unbroken rice from the solar dryers (as opposed to the broken grains resulting from road drying) commands an additional Rs. 10 per ton, leads the evaluation team to believe that there is tremendous potential for these dryers. They are relatively cost-effective even when prototype costs are used for comparison to traditional methods. If these units continue to generate the interest they have thus far among small- and large-scale farmers, government research personnel and private grain-drying mills, the cost of the units will no doubt drop somewhat, even when overhead and profit are included in the selling price.

Since the CSU dryer price is considerably higher than that of the AU dryer, reflecting the more expensive and durable materials used, the two systems cannot be directly compared until more data are gathered on the long-term durability of each system. Certainly the frequency of parts replacement for the AU dryer will be greater than that for the CSU dryer. However, the high initial cost of the CSU dryer makes it unlikely that a dryer of this design would gain widespread acceptance in India without heavy subsidies.

4.11 Summary of the Utility and Importance of the Solar Dryer Effort

This subproject more than any other directly addressed one facet of the energy needs of the rural poor, providing them with practical, cost-effective, user-maintainable technology which will have a favorable impact on their lives. The researchers have made more effective use of locally available energy and material resources. The various sized units address the needs of their target audiences.

The most telling confirmation of the worth of their efforts is the high level of interest in the drying units generated on the part of small farmers, grain mill operators, and a wide range of researchers in the field.

5.0 BHEL/CEL/JPL SALOJIPALLY INTEGRATED VILLAGE ENERGY SYSTEM

5.1 Subproject Description

This subproject was conceived as an applied research and development program which would develop "decentralized energy systems utilizing non-conventional energy sources." From its initiation, it was planned to be an integrated village energy system, using a variety of renewable energy systems to produce electricity and shaft power for small communities isolated from the national electrical grid. The main technical thrust of the project was the design, development, installation and testing of point-focus, two-axis tracking parabolic dish collectors, which produce medium-temperature steam that could be converted into electricity for various village applications. In addition, the design called for the side-by-side comparative testing of U.S. and Indian photovoltaic (PV) cells for electrical generation, and the installation of a community-scale biogas plant for the powering of a direct-coupled drinking water pump.

The subproject was a joint development effort of Bharat Heavy Electricals Limited (BHEL), a large Indian parastatal firm which produces equipment used in central power generation and transmission; Central Electronics Limited (CEL), a GOI research and development group that works on the design and fabrication of a variety of electronic components and subsystems; and the U.S. Jet Propulsion Laboratory (JPL), a national laboratory of the U.S. National Aeronautics and Space Administration (NASA). In 1978, at the time of the initial subproject design, JPL was a leading center for the DOE program for both the design and testing of high-temperature solar thermal systems and for several components of the U.S. national PV development program. Therefore, JPL was a natural counterpart both for BHEL (point-focus solar thermal collectors) and for CEL (design and installation of PV-powered lighting and pumping systems). At the time of project initiation, BHEL had no experience in the design or fabrication of point-focus dish systems, while CEL was just beginning to design and test its own PV modules on a very limited basis.

Almost from its inception, this subcomponent became focused on a single poor community, Salojipally, located 110 kilometers from the BHEL Research and Development Center in Hyderbad. All the technology testing was to be done at the generating site that BHEL set up on government land adjoining the Salojipally community. The concept underlying this approach was that electricity would be provided as soon as possible to the villagers, and they would provide a user's perspective to the researchers that would help to focus the development of an integrated village energy system, to later be replicated in other isolated locations.

5.2 Progress to Date

Like all of the other subcomponents, the BHEL/CEL/JPL cooperative effort did not start officially until November 1980, over two years after the project had been approved and funded by both governments. This delay was particularly crucial for this subproject, because of a major de-emphasis on solar dish technology in the DOE research program by the time that the initial subproject design meetings had begun. This and other problems that led to the successive delays in project completion will be explored in detail in section 5.4 below.

Two separate PV electrical generating systems are installed and operating satisfactorily. The first, a 200-watt PV array powering a community television and radio, as well as four small fluorescent tube lamps, has been operating continuously without problem since February 1982. The second PV system, a 7.3-kW(e) array comprised of both India (CEL) and U.S. (Photowatt) cells, has been installed and operating since November 1983. It powers a distributed lighting system of 30 street lights, which have been operated for a year, and one irrigation pump that has been operated since March 1984. A second PV irrigation pump has been operated for one planting season, and a third large irrigation pump should have been installed before the end of 1984. The output of each PV system is run through a battery bank, which then provides power in the evening hours. The street lighting system is operated by an automatic timer, which turns the lighting on at dusk and off late in the evening.

In addition, a 60-cubic-meter floating dome-type biogas plant has been in use since November 1982, providing drinking water to the village from a 30-meter borehole via a biogas-powered jet pump and eight distributed community taps. BHEL successfully modified an existing Indian-made single-cylinder, 4.5-kW(e) diesel engine-generator set to burn biogas by adding a spark plug and making modifications in the fuel delivery system. The biogas-fueled engine currently burns an 80/20 percent mixture of biogas and diesel, although it can run successfully on a 100 percent biogas mixture. The biogas unit, however, has been greatly underutilized because there is an inadequate supply of animal dung in the village. As a result, the digester is only loaded weekly, rather than daily, using purchased dung that must be trucked from a market town five kilometers away, rather than dung provided by the Salojipally villagers.

5.3 Attainment of Subproject and Overall Project Objectives

The Salojipally project objective, according to the BHEL/CEL/JPL revised proposal of February 1980, was "to design, develop, and install systems for the efficient utilization of solar energy in Indian villages, emphasizing the provision of electrical energy." It is not clear how one is supposed to judge whether or not the technologies developed and installed are "efficient" or appropriate to Indian villages. From the initial design stage, as reported in the Second BHEL/CEL/JPL Conference Report of February 20, 1982, the maximum overall efficiency of the steam-to-electricity conversion process can only be 13 percent. This does not include the losses in the concentration process itself (maximum 90 percent efficiency), in the receiver (85 percent), in the battery storage (75 percent), or in the transmission of the electricity. This calculation also neglects the substantial parasitic loads required for the operation of the 12 tracking motors, a number of circulating pumps, the four computers and other auxiliary units that make up the control system--even a small air conditioner required in certain months to keep the computers at optimal operating temperature. By contrast, the overall fuel-to-electricity efficiency of small [<25 kW(e)] off-the-shelf diesel generator sets is 10 to 15 percent, without any parasitic loads or battery storage requirements. Much of the low efficiency of the solar generator is ascribed by the BHEL project team to the use of the steam engine, which was available but not efficient, rather than a Sterling engine, which was in the original system design. Sterling engines have a 30-40 percent heat-to-electricity conversion efficiency, but are not available for installation at the focus of a parabolic dish. Substitution of six small Sterling engines for the one existing steam engine could double or possibly triple the electrical output of the existing six BHEL dish collectors, but the evaluation team found no evidence that any such units could be obtained in the near future without considerable expenditure on prototype development and testing. Likewise, the PV system has a maximum average efficiency of solar energy conversion of 10 percent, which is further decreased to about 7.5 percent by the use of battery storage for night-time operation of the loads such as street lighting, television, radio, etc.

However, the PV system looks highly desirable, as compared with the solar thermal dish/steam engine combination, when we look at the project objective of having the systems operate "in Indian villages." PV systems for electrical generation, for all their high capital equipment cost and low efficiency, have no moving parts. They require very little maintenance other than a periodic washing of the modules and checking of the battery electrolyte levels.

Since there are no recurrent fuel costs, their life-cycle cost can be competitive with diesel generation where solar radiation levels are high. While the fabrication of PV cells require sophisticated and expensive facilities, the installation and use of PV systems as a source of electricity requires very little training or expertise.

In contrast, it is hard to imagine the BHEL/CEL/JPL systems being operated in a remote location without a team of trained engineers in residence. A more inappropriate technology for a remote site occupied by uneducated villagers is hard to imagine. Each of the dishes must be tracked constantly to an accuracy of 0.1 degrees. The system output is high-temperature steam, running through imported, flexible steel, high-pressure lines. The steam is converted in an engine that is unknown virtually anywhere in the world, much less to a rural mechanic. If the coolant circulating pumps fail for more than four minutes, the receiver will melt from the concentrated solar radiation unless the dish can be "defocused" (the focal point of the mirrors is moved off the target). This requires knowing how to activate the rapid movement portion of the computerized tracking system. If a sudden storm (particularly a hail storm or cyclone) appears which could potentially damage the mirrors, the unit must be stowed downward. Afterwards, checks must be made to ensure that high winds or other forces have not moved any of the 325 mirror facets out of position.

Perhaps the clearest indication of the problems that a Salojipally-type system will face in other locations is to be seen in the biogas unit, which currently works intermittently. This is a very simple technology, being widely used in remote villages in India, Nepal and China for the production of gas and fertilizer. The Salojipally villagers are not yet convinced that the effluent is a better fertilizer than the original dung, which they value as a fuel as well as a soil conditioner. It would have fallen into complete disuse if the BHEL staff had not agreed to supply dung purchased from a nearby cattle market and deliver it by truck to Salojipally. If a power system is to be actively accepted and maintained by a village community, the community must perceive that the system provides immediate and tangible benefits, while demanding inputs within the range of skills possessed by the villagers. Even a simple unit must meet these criteria to gain acceptance.

Examined from the broader perspective of the overall project, the Salojipally project has succeeded in some areas and not in others. It has definitely increased the technical skills of the Indian participants at BHEL and CEL, which appear to have already been formidable at the start of the project. It has also forged personal and professional linkages between Indian and U.S. institutions in the areas of solar thermal and PV power generation, although the reordered priorities of NASA/JPL make it unlikely that JPL staff would be available for active participation in future collaborative programs in terrestrial-based activities. However, the Salojipally project, as currently designed, does not appear to be a prototype for future village-level installations. It is too complex, too expensive, too demanding of scarce highly skilled labor. Many crucial system components are either imported or custom fabricated. Even if the simpler sun sensor tracker is substituted for the computerized "memory" tracker, and if a high-efficiency set of Sterling engines can be substituted for the current steam engine, the overall system will still be too costly and difficult to maintain in a remote area. As such, it fails to meet the most important objective of the overall Energy for the Rural Poor project, namely to make a "significant contribution toward upgrading the living standards and productivity of India's rural population." While the final configuration of interlocked power systems will provide irrigation and drinking water pumping, lighting, television, and radio for this village, it will never be a part of this or any other village, any more than a distant nuclear power plant will be a part of upgrading the skills and life of the village. The electricity provided by the energy center and the shaft power will be useful and valuable, but could be provided more easily and inexpensively by a variety of commercially available and easily maintainable technologies.

5.4 <u>Constraints to Timely Subproject Completion</u>

A number of technical, bureaucratic, and cost-related factors have delayed the design, fabrication, installation, and testing of the solar thermal portion of the Salojipally project. While initially designed as part of the work in 1974-76 of the Joint Commission for Indo-U.S. Cooperation, the overall TRP umbrella project was not formally approved until 1978, and the revised BHEL/CEL/JPL cooperative effort did not start officially until November 1980. This delay was detrimental to all the subprojects, but particularly affected the Salojipally component because of the major de-emphasis on solar dish technology which took place within DOE's Research and Development Program between 1976 and the completion of the Salojipally design work in February 1982. JPL was no longer operating a major solar thermal program, and by mid-1984 had shipped their large dishes to Sandia Laboratories. The JPL scientists who had previously been involved with concentrators had been assigned to other research programs as well. Components which were under development by various DOE/JPL contractors were never commercialized or rose sharply in price as the U.S. domestic program shrank in size. Had there been an AID technical officer who was aware of current developments in U.S. energy research programs, which de-emphasized the importance of the solar dish technology, the proposal would likely not have been accepted. However, the solar dish program appeared to have acquired a momentum of its own, which carried it forward despite all the technical problems.

For instance, in the November 1982 JPL Task Plan, it was mentioned that two JPL engineers were to visit the BHEL facility to assist in the testing of the first prototype solar thermal modules, consisting of the concentrator, receiver, steam engine, generator and control systems. Presumably, the experience gained from testing this prototype would be used to modify the design before the six dishes were assembled and installed at Salojipally. However, due to delays in equipment procurement, this prototype was never built. Thus, any design faults that occur will now occur in all six of the concentrators being installed at Salojipally.

The design of the dish and receiver system took a great deal of time and effort on the part of both the BHEL and JPL staff, raising the overall cost and delaying the writing of specifications and solicitation of contractor bids. Other technical problems arose because components (drive systems, receivers, tracking programs) had to be custom fabricated or less expensive units substituted for the originally specified units because of escalations in price. While none of the individual problems were insuperable by themselves, they created a cumulative effect that was quite serious. The fabrication of the receivers has been particularly troublesome. The shaping of the tubing within the receiver coils and the spiral welding (braizing) could not be done in India. After considerable delay, JPL was able to get the receivers fabricated, but they failed the JPL acceptance tests and are currently being refabricated. In mid-December 1982, receipt of the receiver coils by BHEL was scheduled for April 1983. By November 1983, they were scheduled for delivery to India by February 1984. As of December 1, 1984, the receivers were supposed to be shipped from the United States no later than December 15, 1984. Latest estimates are that the coils will be ready for shipping by the end of February 1985.

Bureaucratic process has had a considerable role in the long gestation of the Salojipally project. The chief delay was between the signing of the Project Agreement (August 26, 1978) and the actual approval of the subcomponents (Salojipally was the first to be approved on June 12, 1980). The delays affecting the whole TRP project are outlined in section 2.3 above. There appears to have been high-level interest in the Salojipally subcomponent in both the Indian and U.S. governments, which might explain why it was approved without change despite all the objections raised by the anonymous outside reviewer in the appendix to the original project paper.

After the Salojipally project was at last approved, it became caught up in an AID review of Science & Technology projects. Between November 1981 and May 1982, AID put a freeze on any further procurement by JPL until AID determined whether the sophisticated research and development project was appropriate for rural village settings. The evaluation team finds that many of the objections to the Salojipally subproject raised by senior AID/Washington and AID/New Delhi staff at that time--its high cost relative to its delivery of useful energy, its complexity, the small number of local beneficiaries--are still valid today. However, AID eventually accepted a series of JPL projections for drastically lower future costs and the procurement hold was released. In May 1982, JPL was permitted to begin procurement again, but all these delays had already led to increased costs of labor, materials and fabrication. Getting additional funding required contract revisions between JPL and AID, during which JPL staff were not able to devote their full energies to the project. The BHEL/DNES discussion on additional funding appears to have been much more expeditious and did not slow project progress.

The possibility of cost overruns by the U.S. contractor, JPL, were raised as early as July 1982, and the discussions with AID for an additional $98,500 and then finally $153,000 began in October 1982. Getting approval for this supplemental funding, primarily for JPL staff salaries, appears to have taken a great deal of the JPL project manager's time between the period October 1982 and May 1984, and certainly delayed some of the required procurements (particularly the tracking and power controls as well as the servo drive systems) until the funding was finally released.

5.5 Procurement Problems

Some of the procurement difficulties have already been noted in section 5.4 and will not be repeated in detail here. In general, three problems were encountered: required components were not available commercially and had to be custom fabricated; U.S. and particularly Indian subcontractors were building their first prototypes from engineering drawings and ran into unexpected delays; and cost escalations required substitution of different components or additional supplemental funding. An example of each type of problem might be illustrative of the kinds of difficulties that are encountered in a complex technology design and development exercise. The steel support structure (which holds the dish and mirrors) was constructed in India to BHEL specifications. It was the first time such a system had been built by this fabricator, and it took 10 months instead of the scheduled six. Similarly, the completion of the steam storage tank and condenser was delayed by the Indian supplier for four months. The firm that built the receiver coil in the U.S. did not intially meet the exacting requirements of the engineering design and had to remanufacture the units. Thirdly, the tracking and drive mechanisms originally specified (and for which the rest of the system was tailored) proved to be too expensive by the time procurement was initiated. The process had to be started over again, with a substantial loss in time and effort expended.

The Salojipally project's solar dish component was at the leading edge of the state of the art in solar thermal engineering, so many of the delays should have been anticipated. However, it is not clear why it took so long to purchase and install such off-the-shelf items as the U.S. PV arrays. These are stock items, and even with a competitive tender JPL should have been able to ship them within three to six months. They were not received in India until early 1983, over two years after the signing of the subproject PASA agreement between NASA and AID, and were not installed until November 1983. In telex traffic to India, JPL noted a module testing program that was estimated to cost $49,000 and take nearly four months. JPL tested each panel and sent engineering staff to the manufacturing plant. This seems unnecessary for warrantied, off-the-shelf units and undoubtedly contributed to the increase in JPL labor costs. Given the normally very low percentage of defective panels, it would have been much less expensive to simply ship extras and discard any defective panels encountered during installation in the field. Also, it was the AID/New Delhi staff who discovered, during a routine visit in May 1983, that the U.S.-made PV modules were still sitting in storage and had not been installed as scheduled in April 1983. Apparently, poor coordination between CEL and BHEL was partly responsible for these delays. Similarly, the large array of CEL panels was not installed at the site until November 1983, partly because CEL had to develop and test the lamps, pumps, etc., which were to use the PV-produced power.

5.6 Management Effectiveness of the U.S. and Indian Institutions

The Salojipally Village Project has been a major undertaking from its design to the logistical problems of shipping and assembling components built by nearly a dozen subcontractors in two countries. The management of BHEL, CEL and JPL are to be commended for how much they have been able to accomplish. To the outside observer, JPL appears to have had more problems in meeting both cost and time objectives, despite a heavy expenditure on management time and senior engineering talent. JPL management appears to have incurred large manpower costs for relatively simple tasks (such as PV system testing and procurement), manpower that might have been shifted to the more complex solar thermal design and fabrication problems.

The evaluation team is particularly puzzled by the use of scarce U.S. travel funds for trips to India by the U.S. project manager rather than by his technical staff. Four JPL technical staff and the project manager visited India for a series of meetings in February 1982. Of the six JPL visits since that time, four were by the JPL project manager. While there were numerous procurement and funding problems, it would seem to have been more appropriate for the solar thermal design or controls specialists to have been working with Indian counterparts during these periods. In the forthcoming six months (December 1984-May 1985), the BHEL technical staff may require detailed assistance from JPL in debugging the control system or for optimal system balancing once the receivers and steam engine are installed, but the evaluation team sees little need for additional senior management collaboration.

The evaluation team also notes that several planned activities that might have helped correct the course of the technology selection and development process were never undertaken. The overall project paper stated that technical feasibility, and soundness of technical, financial, social, economic and environmental considerations of projects were to be ensured through the project selection criteria, GOI screening process, and AID project concurrence mechanism. Requisite analyses for successful application of these criteria did not, however, occur. The failure to have a thorough socioeconomic review done, although it was repeatedly promised, was a serious omission. The AID/New Delhi staff is to be commended for their frequent raising of this issue with their GOI counterparts (including offering to pay for the study) but it was never undertaken. It might have provided information, particularly on the benefits and costs of the solar thermal unit, that would have been valuable to the GOI/AID management in determining whether to complete this component.

5.7 Effectiveness of U.S. to India Technology Transfer

The collaboration between the JPL and BHEL solar thermal scientists was very close, particularly in the system design stages. JPL engineers had been instrumental in the U.S. development and testing of the system that was selected for the Salojipally installation, and they were able to transfer the knowledge that had gone into the design decisions directly to the BHEL engineering team. The Indian team now feels confident that they could design similar systems from start to finish, to include overall system specifications, the computer programming of the tracking mechanism, the creation of the facets, and the various energy conversion devices. In addition, the JPL/BHEL collaboration resulted in the direct transfer of a number of U.S. subsystems, such as the receiver coils and drive mechanisms, which can now serve as prototypes for future Indian fabrication if there is continued demand.

The U.S. to India technology transfer was much less important in the areas of PV systems and the biogas engine-generator set. CEL, which developed the electrical subsystems as well as the portion of the solar cells made in India, appears to have done most of the required experimentation on its own. Also, the system design work was much simpler than that required for the solar thermal components, and most of the subsystems are commercially available throughout India. The biogas plant is basically an indigenous Indian system that required little or no technology transfer from the United States.

5.8 Relevance of the BHEL/CEL/JPL Salojipally Integrated Village Energy System

5.8.1 Production and Installation by Indian Institutions

The BHEL and CEL technical staff participated fully in the design of the Salojipally solar thermal and PV subsystems. Indian subcontractors did much of the fabrication work, with the exception of the steam engines, the receiver coils and control systems. BHEL management feels confident that all of the components of a next unit, to include Sterling engines and the receiver coils, could be built in India (or purchased commercially by international tender).

The CEL PV systems and the BHEL biogas units are basically Indian units, both in design and fabrication. While more development work will need to be done to increase the efficiency of the PV-powered water pumps (which are very inefficient compared to other commercially available PV pumping systems, based on the preliminary data supplied to the evaluation team), CEL has the skills and determination to carry out this work. The biogas engine is a simple modification of a commercial Indian model, and is powered by the same type of digester that the Khadi Village Industries Corporation (KVIC) has been building in India for well over 15 years.

5.8.2 Remote Site Operation and Maintenance

A truly integrated renewable energy production system is designed such that when the driving force behind one component is not available (solar radiation for PV, for example), a second component (such as wind for a wind turbine generator) becomes the primary producer. Two components which both rely on solar radiation, for instance, are not going to do much good when the sun does not shine for a long period. The Salojipally energy package is not an integrated system but a number of discrete technologies and electrical loads that happen to be located in the same place. Since this is the case, the end-use devices will be dealt with first, then the individual power production and storage units. None of the electrically powered devices installed at Salojipally--lamps, television, radio and irrigation pumps--pose any major problems for use and maintenance, as long as adequate spare parts are provided or can be purchased locally. Likewise, the two separate PV systems are operating satisfactorily, although the use of such a large bank of batteries, as is installed at Salojipally, is a potentially serious maintenance problem at more remote sites. This is due to the need to monitor electrolyte levels of replacement cells and to the fact that batteries are normally the only major cost component of a PV system which requires replacement over a 20-year system lifetime. Biogas units are operating successfully in remote areas of India, Nepal and China, but the Salojipally unit, because of its large size and use of floating steel gasholder, would probably not be constructed except where materials could be brought in by truck. Instead, the Chinese dome-type unit would be preferable, as long as an adequate supply of dung is available (and some individual derives enough direct benefit to provide motivation to gather the dung daily).

Finally, there are the Salojipally solar thermal dishes, steam engine, and all the associated controls, motors and pumps. Even the designers admitted this system was totally inappropriate for a rural setting. Few trained engineers could step in and operate this system without a long training period, so one would hardly expect a rural villager to be able to undertake the task. Since the system requires a substantial amount of auxiliary power to start up the unit and to activate the motors, pumps, and computers, one wonders if it wouldn't be simpler and cheaper to switch on the back-up unit and feed that power directly to the village without running it through the solar thermal and control loops first.

5.8.3 The Rural Poor

The Salojipally project provides an integrated set of services, such as street lighting, pumping of drinking and irrigation water, and entertainment, that are valued by people all over the world. However, it is extremely doubtful that the Salojipally set of energy systems is the optimal or even an acceptable way of providing these services to the rural poor. All the members of the evaluation team were struck by the fact that the energy center was not even peripherally a part of the village life. It could have been located 500 kilometers away, instead of 200 meters from the village. There was little interaction with the villagers in determining the priority of services to be offered, although irrigation pumping was a strongly felt need. Individual house lights were not provided, only street lights, because they are easier to install and provide a constant load. Except for irrigation pumping, no power was provided for income generating activities such as grinding, dehulling, and milling, partly because the benefits would accrue to only one or two individuals. Moreover, the irrigation pumping only benefits four farmers, and no one is certain how many more farmers will be aided by the addition of the larger third pump.

Electricity has the potential for drastically altering the lives of the rural poor. It can give them light, entertainment, new appliances and new opportunity to earn income. But an electrical plant that is much more difficult to maintain and far more costly than a diesel generator set, and that requires three trained engineers in residence, is not the solution.

5.9 Relevance of the Collaborative Effort and Study Tours

By all accounts, the collaborative work was extremely beneficial for the BHEL and CEL staff. The JPL specialists provided detailed assistance and suggestions in a whole range of areas, from fabrication of the mirror facets to design of the receiver coils. The collaborative work undertaken through lengthy conferences, as well as during the visits of various Indian professionals to the U.S., was judged to be very valuable.

5.10 Economic Viability of the Technologies Under Development

An effort was made by the evaluation team to determine for each subproject the real cost of building a similar system once the research and development costs are omitted. Perhaps the best way to express this figure is: What would be the per unit cost of building each of the next three units now that the design and fabrication problems have been solved?

For the Salojipally project, the main interest on the part of all parties concerned is to determine the cost of the solar parabolic dish complex, along with its control system and power generation module. Since all six dishes feed a single steam engine, the costs will be given for a set of six dishes. All costs are given in rupees (dollar costs converted at 12 rupees/dollar and marked by an asterisk).

Foundation construction (including labor)	Rs.	125,000
Steel structures (bases & framework)		630,000
Mirror facets (2000 total)*		88,000
Foam glass (for mirror backing)*		108,000
Labor for facet production		20,000
Drive mechanisms*		1,037,000
Receivers*		288,000
Control system*		587,000
Control valves*		204,000
Steam storage, condenser & condenser tank		182,000
Steam engines (two--one for spare)*		154,000
Condenser pump & water supply*		3,480
Chemicals used for mirror production*		121,500
Supervisory labor		10,000
Miscellaneous		25,000
TOTAL	Rs.	3,573,680
or Equivalent	$	297,806

Thus, the costs per installed kilowatt are:

at 12 kW(e) rated output (the minimum figure)--$24,800
at 22 kW(e) rated output (the maximum figure)--$13,500

These figures do not include any costs for operation and maintenance. This system will require two or three resident engineers, at least for the first year of operation. There will also be additional costs for the auxiliary power (diesel, biogas or PV) required to start the system in the morning, until it is generating enough electricity to power itself (the cut-in output is about three kW(e) of steam engine output).

These figures are quite high. In contrast, a medium-scale coal-fired plant costs $800-1500/installed kilowatt (excluding recurrent fuel costs), a micro-hydro unit $1000-4000/installed kilowatt, and a PV unit $10,000-15,000/installed kilowatt. CEL is quoting $8,000 per kilowatt to the purchasers of its Indian-made PV systems, but there are a number of hidden subsidies in the CEL program, so the figure of $15,000 seems more realistic for commercial Indian production. In addition, because of the much greater simplicity of a PV generation system, and greatly reduced costs of parts replacement (principally due to the need for battery replacement every five to 10 years), the long-term recurrent costs of the PV system would likely be much less than those for the solar thermal electric generator in its current configuration.

Under the best of circumstances, the present design of six dishes and a single steam engine is not economical. BHEL staff maintain that a set of six Sterling engines would increase the system output by 200 to 240 percent. Unfortunately, there are no cost figures for the six engines, since they are not commercially available. It is assumed that they would cost a minimum of Rs. 1,000,000, but would eliminate the need for the steam engine, the steam storage, condenser, tank, control valves, etc. If the net price increase was Rs. 500,000, then the cost would rise to about Rs. 4,000,000 or $335,000, but the cost per kilowatt would drop due to the 200 percent increase in power to $6,750 to $12,400 per installed kilowatt. Even at this cost, the solar thermal system is only barely competitive with PV when we add in the parasitic losses and labor requirements, and is certainly more difficult to operate and maintain.

5.11 Summary of the Utility and Importance of the Salojipally Integrated Village Energy System

The BHEL staff have gained tremendously, in terms of experience in the design and fabrication of solar thermal dish systems, by participating in the Salojipally project. They are justly proud of what they have accomplished, although it is too early to tell if the entire unit will function as planned when it is complete. But, even if it does, the evaluation team does not foresee a major role in India for such a system, and certainly not in rural areas. It appears to be too costly and complex even for the generation of industrial process steam, although this application has not yet been tested. The PV units are still expensive, but may find acceptance for small loads in remote areas. The biogas-powered water pump, despite the problems of dung availability at this site, may be the one unit with a major future in India. The biogas engine developed by BHEL could also be used to drive small machines for the cottage industry, as has been done successfully in Nepal.

The salient points concerning the likely impact of this project can be summarized as follows:

- the project is unlikely to gain widespread acceptance due to its cost and complexity;

- both of the collaborating institutions have gained significant relevant experience in the design and manufacture of the hardware; and

- the project as completed thus far represents state-of-the-art research in solar thermal engineering, but final conclusions about the usefulness of the equipment (at _other_ than remote rural sites) must await the completion of installation and initial performance monitoring.

6.0 IIS/UH LINE-FOCUSING SOLAR CONCENTRATING COLLECTORS

6.1 Subproject Description

The goal of the project was to develop a cost-effective, parabolic solar collector capable of generating medium-temperature steam for use in a silk making plant in Mysore. The collector is a single-axis tracker; i.e., the collectors are oriented with the long axis north-south so that a sun-seeking sensor and servo-motor drive mechanism will move the collectors to follow the sun in its east-to-west path throughout the day. Direct-beam solar radiation is focused on a coolant water pipe inside a glass tube mounted along the focal axis of the parabolic trough. As water is pumped through the pipe it is heated and delivered to a flash boiler. The steam then goes into the auxiliary coal-fired boiler system which supplies the remainder of the steam required for use in the silk printing section. The solar industrial process heat system was designed to provide approximately one-third of the steam required for the silk printing process (80 kg/hr of 150^{o}C steam). The originally proposed system was to have provided 250 kg of steam per hour. Rs. 1,400,000 was requested for this design, but since only Rs. 800,000 was awarded, the system size was reduced to provide only 80 kg of steam per hour. The flash boiler unit was sized to accommodate the larger steam production, and the full contingent of collectors will be added as additional funds become available.

The project is a joint effort between the Indian Institute of Science (IIS) in Bangalore and the University of Houston (UH) Department of Mechanical Engineering. The University of Houston was to provide the technical expertise necessary for the computer design and simulation studies to size the system and its components, as well as to facilitate procurement of U.S.-manufactured components such as the flexible glass mirrors and the tracking mechanism which were not available in India. The IIS investigators had originally requested the assistance of the University of Arizona in the project because of their extensive experience in the field. However, UH was chosen by AID representatives as the final U.S. counterpart organization. UH has done some work with concentrating collector tracking mechanisms, as well as with computer simulation models of concentrating collector-absorber heat transfer phenomena. The IIS had worked on selective surface coatings for solar collectors, parabolic point-focusing dish collectors, and prototype linear-focusing concentrators which were to be the subject of this project.

6.2 Progress to Date

Because of the overall project delay which moved the subproject starting date back to December 1980, preliminary contacts between the counterpart organizations did not take place until May 1981. These delays were discussed in section 4.0 above. The U.S. principal investigator (PI) first spent one month in India, then the Indian PI spent three months touring U.S. research sites which were working on concentrating collectors. Other IIS personnel followed soon thereafter to complete their review of current U.S. linear concentrator technology. Collector and system design work on both the IIS and UH sides began soon thereafter.

As of mid-December 1984, when the evaluation team visited, all of the design and much of the procurement process had been completed. Three different prototype collectors had been constructed and installed on the roof of IIS for comparative technical evaluation. The selective surface coating (high-radiation absorptivity and low emissivity, which allows for greater heat absorption yet less re-radiation heat loss) and application techniques had been developed by IIS through the production stage. Absorptivity- and emissivity-measuring instruments had been developed at IIS. Collector support structures had been developed, tested, and were in production for the demonstration array. Work on instrumentation for the array is progressing, and procurement has begun. While manually operated controls will be used initially, work is progressing on an automatic programmable controller. This will be ready near the end of 1985. A locally manufacturable sun-tracking mechanism is under development. This will eliminate the need for U.S.-manufactured controllers, should its development prove successful.

While construction and procurement of the demonstration system components such as collectors, piping, flash boiler, valves and instruments are underway, work had just begun on the actual installation at the Karnataka Silk Industries Corporation (KSIC) plant in Mysore. Only the concrete collector supports had been poured. While all components of the collectors have been received by the IIS group, none of the parabolic collectors have been either assembled or installed at the KSIC site.

6.3 Attainment of Subproject and Overall Project Objectives

According to the initial subproject proposal, which was slightly modified by combining both the development and the demonstration/commercialization phases into a single concurrent effort, the main project objective was the development, testing, demonstration and commercialization of a cost-effective, high-efficiency solar collector capable of generating medium-temperature process steam appropriate for small-/intermediate-scale industries in rural India. The project was to address technical issues from the perspective of the appropriateness of the technology chosen; that is, making use of indigenous materials and technical skills to develop a cost-effective solution to the energy supply problem. The overall project objective, as stated in the project paper, was to increase Indo-U.S. collaboration in the testing and application of science and technology to India's rural development efforts. The project goal in contributing to rural development was to particularly address the needs of the rural poor, and is to be measured by whether or not the various technologies result in increased real incomes of rural people. The subprojects were to be selected based on technical, economic/financial, and social criteria of appropriateness in addressing the subproject goal.

The IIS/UH subproject has successfully addressed certain of the overall project goals, particularly the increase in Indo-U.S. collaboration in the testing and application of science and technology. The trips made by IIS scientists to the United States furthered their technical skills and knowledge of state-of-the-art research, particularly in the area of selective coatings. However, since much of the U.S. effort regarding line-focusing collectors has ceased due to lack of funding, the benefits to U.S. researchers at this point have not been significant. The development by UH of the computer design program for parabolic collector systems (which essentially combined several programs developed by Sandia National Laboratory and UH into a more user-friendly format) is an advance, useful both to U.S. and Indian scientists. However, this Fortran program, which was to be used in the design process of the KSIC system, was received by the IIS investigators in December 1984. Since it was not designed for the IIS computers and since its documentation is scanty, it will require several months of concerted effort to render it into a more useful form. Because the KSIC system has been designed for two years and has entered the construction phase, it is unlikely that this computer program will receive much attention by IIS personnel in the near future.

The objectives of the subproject vary somewhat depending on what source is taken as definitive. In the original project proposal, 13 tasks were outlined, all of which were directly concerned with concentrating parabolic collectors for the purpose of intermediate-temperature steam generation. These were the following: structural design of the collectors and mounting hardware; reflective surface research for the flexible glass mirrors; selective coating studies for the absorber tubes; calibration and standardization instruments for the selective coating;

receiver development; construction of a prototype single-axis tracking collector; development of a non-tracking prototype collector; establishment of a test facility for performance evaluation of the various systems; optical analysis; thermal performance analysis; heat transfer studies; computer simulation of system performance; and finally, information exchange between the Indian and U.S. counterparts. With the exception of the non-tracking component, which was later dropped after being judged impractical, the remainder of the technical objectives were all concerned with developing a collector which could produce industrial process steam.

The objectives of the project as listed by the IIS in their annual and occasional status reports essentially concur with those listed in the original project paper. The U.S. counterpart organization, UH, issued a similar series of semi-annual and annual reports during project implementation. In these reports, the project objectives were divided into somewhat different categories: linear focusing collectors; selective coatings; non-tracking concentrating collectors; thermal system design; flat-plate thermosyphon system design; materials evaluation and degradation; air heater technology assessment; equipment specification; and literature surveys.

Note that there are several objectives in the UH list which do not occur in the original AID project paper. These are concerned with the development of flat-plate thermosyphon systems, air heaters, and materials evaluation and degradation. Thermosyphon collectors are normally used for low-temperature (50-85°C), low-demand domestic hot water heating loads. They are neither high-efficiency nor medium-temperature (100-300°C) devices. They are not designed for producing industrial process steam. Air heaters are similarly unsuitable for producing steam. When contacted, the UH principal investigator commented that these components had been contained in the original 1978 proposal, when there were two Indian counterpart institutions. He said that he never received a scope of work other than the original proposal and so proceeded with this work even though there was no Indian institution to which the work could be transferred. He noted that AID/New Delhi was interested in and encouraged the thermosyphon work.

Thermosyphon collectors were first mentioned in the May-December 1981 Semi-Annual Report from UH, where it was noted that "Although no activity was planned for this time period related directly to this project, activity has been underway as part of another project in this area." Work on the thermosyphon system computer modeling was delayed until 1983, when experiments were performed to obtain data to use for program validation (fine-tuning the computer simulation based on actual experimental results). The experiments and validation were completed during 1984 and a report was to be issued after June 1984. This report had not been received by IIS as of December 1984.

The evaluation team feels that this point should be investigated further. It appears the AID funds and contractor time were spent on any activity which was not in the project paper, did not contribute to the Indian work, and did not have anything to do with the primary project objective.

According to the UH status reports, no work was performed on the air heater technology until the July-December 1982 period, at which point consideration of the technology as a design alternative was dropped. Since the solar system was designed to complement the existing steam generating system of the KSIC plant, and air heaters (which do not produce steam) would have required an entirely separate distribution system, one wonders why air heaters were considered in the first place. The UH principal investigator commented that this work was originally included to support the interest of IIS in tobacco drying, which was subsequently tested using non-AID funding.

Materials evaluation and degradation studies were presumably to be undertaken prior to choosing reflector and absorber materials for the concentrating collectors. The test facility UH was to use was not available due to building maintenance problems. Investigators from IIS were to be exposed to current U.S. research in this field during their visits to the United States. In the July-December 1982 report, it is stated that this activity would be dropped due to a lack of facilities. After this, although each succeeding report stated that no work had been done under this category, the January-June 1984 report simply stated that the work had been completed for the prototype development, with no further elaboration. Note that the prototype development by the IIS had already been completed by this time.

The subproject objectives which directly pertained to the primary technical development focus of the subproject, concentrating solar collectors for steam generation, have been achieved with varying degrees of success. Although all design and development has essentially taken place (albeit behind schedule), installation is well behind schedule. Reasons for this are discussed in the following sections.

6.4 Constraints to Timely Subproject Completion

The IIS/Bangalore subproject was delayed, along with all other project components, due to funding delays for the period 1978 to December 1980, when grant awards were finally made. The detailed description of these delays was given previously in the section on the BHEL/JPL project at Salojipally. There were several other delays that prevented the installation and testing of the solar concentrator system by the anticipated project completion date. Probably the most significant obstacles were lengthy procurement delays, particularly (but not exclusively) of U.S.-made equipment. Procurement problems will be dealt with separately in the next section.

Throughout the project, unreasonably optimistic estimates were made of the time required to complete the various subtasks. In May 1982, the AID Project Evaluation Summary stated that the subproject was moving according to schedule and that there were no inordinate problems with or constraints on timely completion of tasks undertaken. In September of the same year, AID personnel again visited the project and discussed with IIS the duty exemption and customs clearance certificates from GOI. Waiting for GOI concurrence on "Not Manufactured in India" (NMI) certificates and Ministry of Education (MOE) certificates stating that the equipment was required for research purposes further delayed procurement in the United States.

In June 1983, AID evaluators recommended that procurement must be accelerated to allow scheduled project completion, since it was unlikely that AID would extend the project assistance completion date (PACD, December 31, 1984). In August 1984, AID personnel again visited Bangalore and were informed that all procurement matters had been settled with UH, up to the full amount of the equipment allocation. The equipment not already received by IIS was to have arrived by the end of September. It had not yet arrived when the evaluation team arrived in early December.

IIS informed AID that all domestic equipment had been ordered and was expected to be installed at KSIC by November 1984. Since the evaluation team was scheduled to visit in late November, IIS was asked to try to have the system operational by the end of October, and to supply AID with brief biweekly status reports. Although IIS agreed to this, no reports were sent, nor had any of the equipment been installed by the time of the evaluation team's visit.

IIS now predicts that commissioning will occur about April 1, 1985. This estimate was given before the unavailability of the Winsmith gearbox was known (see section 6.5 below). Since the monsoon starts in May, if installation is not completed well before then, system performance tests will not begin until the monsoon is over in October.

All of these delays have had the cumulative effect of reducing the real equipment procurement budget. Prices of virtually all system components had risen considerably over initial estimates made in the project proposal. This is part of the reason that the size of the installation was reduced from 80 collectors (200 square meters) to 30 collectors (75 square meters). Salary costs of the investigators increased similarly.

Another cause for the delay in accomplishing the primary project objective becomes obvious when the initial subproject objectives are compared with the list of accomplishments by both IIS and UH. Reviewing the list of equipment purchased by IIS (with Indian funds), approximately 10 percent of the equipment costs involved air collectors and solar water heaters, which had no apparent connection to the steam generating project. While there is no cost breakdown on time spent on peripheral tasks, it is not difficult to imagine that a significant amount of the researchers' time was spent on them, thereby reducing the amount of time spent on the primary objective. Reading the status reports for the project, one is struck by the very slow pace of prototype fabrication. The specifications had been developed by January 1983, and by June 1983 drawings from Hindustan Aeronautics had been received by CMTI for fabrication of ribs and holding plates. Yet no actual collectors, except the prototype, have been constructed.

6.5 Procurement Problems

As stated above, much of the delay in the execution of the project was due to lengthy procurement. For example, the tracking system for each of the six banks of five collectors requires a 10,000:1 gearbox which is not manufacturable in India at this time. They were therefore ordered from a U.S. manufacturer, Winsmith. The first order to Winsmith was sent between July and December 1983. In December 1984, IIS received word from UH that they had been unable to set timely delivery of the Winsmith devices, which were the last major procurement items not yet received, and had cancelled the order. While UH had ordered substitute devices from another U.S. manufacturer, it will likely result in a further delay of several months.

The Honeywell tracking system, which was to drive the Winsmith gearbox, met with a similar fate. Although the units had been commercially available in the United States during the early part of the IIS/UH project, the units were not available when ordered. This was due to the significant reduction in funding for the DOE parabolic collector program, which was the principal buyer of the Honeywell trackers. Thus, another procurement source for the tracker had to be sought. Industrial Solar Technology of Denver agreed to supply the units, but they were not in production. The units therefore had to be custom manufactured, increasing both the price and the delay before delivery at IIS. Since the cost of trackers for 30 collectors was Rs. 180,000, this cost increase was a significant factor in the decision to reduce the array from 80 to 30 collectors.

The flash boiler was ordered from BHEL after bids were received from several manufacturers. Although BHEL said the unit would be delivered for installation at KSIC in six months, after 10 months it had not arrived. Since this is the major retrofit component in the steam delivery system, installation of that system has been delayed considerably. Of the 200 square meters of flexible glass mirrors originally ordered, 10 arrived damaged. Since cracked mirrors dramatically reduce collector performance, and the mirrors were purchased from a European supplier, the evaluation team expressed concern about the durability and replaceability in a rural setting. IIS has ordered 100 square meters of mirrors as spare parts in addition to the initial order.

These and other similar procurement problems point out the difficulties in dealing with system components which are not commercially available, particularly those which have to be purchased from foreign sources. In addition to design and manufacturing delays, customs and shipping compound the problem further. The evaluation team felt that any efforts made which help to localize the procurement process would be extremely desirable. Even if, for example, the desired accuracy or reliability of the locally manufactured equipment were less than that which could be obtained from a foreign source, there would be distinct advantages to local procurement. Not only would this help to build an indigenous capability for manufacturing higher precision machinery, but it would reduce reliance on expensive foreign-made products with normally long procurement times. All other things being equal, this would more than make up for a few percent of lost efficiency.

6.6 Management Effectiveness of the U.S. and Indian Institutions

There are two U.S. and one Indian institutions involved in the project whose management effectiveness must be examined: the University of Houston, AID, and IIS. In the project paper, a matrix of appropriate technology characteristics was given which was used to evaluate the various projects submitted for funding. These were chosen to allow people with little technical background to compare the proposals on their relative merits. As finally developed, the IIS/UH system falls short on most of these criteria of "appropriateness." This project has high capital costs (Rs. 1,238,000 for the reduced-size system); has several critical components which are not locally available; creates few jobs because it is capital-, not labor-intensive; is hardly affordable by small farmers or even groups of small farmers; and cannot be understood, controlled or maintained by villagers who do not have a high level of education. Moreover, the overall system or even its components cannot be produced in a village or even in a small metalworking shop. The current design is inflexible and not particularly adaptable to altered circumstances (not many village or cottage industry tasks require the use of steam). Practical plans for construction would have few takers because of their complexity. Looking at these selection criteria, the evaluation team is still somewhat puzzled as to why such a proposal was chosen by AID in the first place, despite the obvious experience and quality of the Indian research team.

Turning to the project principals' responsibilities, the execution of the project was hindered by extensive delays. Procurement problems were discussed earlier.

The time and effort spent by UH on objectives which were not in the subproject paper approved by AID (e.g., thermosyphon collector modeling) no doubt took time, effort and funds away from the primary objective. As a result, the computer system design program which was to have been used to develop the KSIC system was only received by IIS in December 1984, during the evaluation team's visit--two years after the actual design was completed.

The evaluation team recognizes that two phases, planned to last five years, have been collapsed into one three-year program. Nevertheless, time objectives repeatedly went unmet, with the net result that installation of the KSIC system has barely begun. Due to the further procurement delay for the gearboxes, the system is not likely to be completed by the latest reported completion date of April 1985.

These considerations should not cloud the fact that a very concerted research and development effort has taken place, and that Indian scientists (if not the rural poor) have benefited greatly from the project. The logistical requirements of obtaining highly specialized equipment from widely diverse suppliers are nearly complete, a monumental task in itself. The project might well have benefited from at least a rough estimate of the economic and financial costs of the proposed system before devoting such effort to it. This is standard practice in most engineering projects, and a question arises as to why there was so little focus on the practical benefits which might accrue from the project.

6.7 Effectiveness of U.S. to India Technology Transfer

There were several areas in which technology transfer to Indian scientists was very successful. The four topics which presented the most serious technical challenges were:

- structural design of the low-cost lightweight collector mounting system to account both for survival wind loading and for sufficient stiffness so that precise focus would be maintained under ordinarily encountered wind conditions;
- development of a proper reflecting surface so that maximum radiation would be reflected to the absorber surface;
- development of high-absorptivity yet low-emissivity absorber coating to allow for maximum radiation heat transfer to the coolant; and
- a reasonably priced, yet accurate and reliable tracking mechanism.

The higher the temperature at which the energy is delivered, the higher the collector concentration ratio must be and the more precise the optics of both the concentrator and orientation system must be. Images of linear parabolic concentrators can become enlarged (not as tightly focused) if the cross-section of the collector is not perfectly parabolic. If there are cracks in the collector reflecting surface, this will similarly distort the image, thereby reducing the solar radiation on the absorber surface (the steam tube) and reducing the temperature of the steam, reducing its usefulness.

A stiffened rib structure was developed in coordination with Hindustan Aeronautics Limited which satisfactorily met the structural requirements for the collector mounts. These structures are now being produced at IIS for the demonstration system at KSIC. Prototypes of the stiffened rib collector have been tested for stiffness and optimal performance using a laser-based test rig to determine optical error limits.

6.8 Relevance of the IIS/UH Line-Focusing Solar Collector

6.8.1 Production and Installation by Indian Institutions

The IIS/UH parabolic concentrator is a very sophisticated solar thermal concentrator. There are a substantial number of system components which are not manufacturable in India at this time. The flexible glass mirrors are imported from Europe. The tracking mechanisms were custom-manufactured in the United States. Several of the structural components had to be custom-manufactured in India. These systems are therefore not yet off-the-shelf technologies. While research work is continuing at IIS on the shadow band tracking systems, there are not yet any existing prototypes. Even if these are successfully developed, the 10,000:1 reduction ratio gearboxes are not available in India. There are no facilities at present which are capable of manufacturing the flexible glass mirrors.

Since installation of the demonstration system has barely begun, it is difficult to say what installation problems will be encountered. Given the high quality of technical work evidenced by IIS thus far, and the apparent competence and interest of KSIC engineers at the demonstration site, however, it is likely that technical problems will be overcome.

The very high capital costs of the system are another matter. Although KSIC is sufficiently interested in the project to invest Rs. 100,000 in the civil works required for the solar system, it is uncertain at this point whether other industries would be willing to finance the entire capital cost of such a system. Should this happen, however, IIS will have the technical capability to aid commercial vendors in the design, installation and operation of such systems.

6.8.2 Remote Site Operation and Maintenance

The complexity of the solar steam generator and the likely difficulty in procuring spare parts for it make it inappropriate for remote site operation, particularly if there are no qualified engineers and technicians to supervise daily operations. The medium-temperature steam output of the system is unlikely to be required at remote installations, unless it is used to drive a turbine to produce electricity. This, however, will add yet another expensive level of complexity to the overall system.

Since mirrors are much more likely to get damaged during transport to or during assembly at remote sites (not to mention children who are quite good at hitting a goat with a rock at 15 meters), the likelihood of the IIS system providing a reliable energy supply at such a site is further decreased.

6.8.3 The Rural Poor

Since only skilled or semi-skilled labor will be used in the manufacture and operation of these systems, income generation or other direct benefits will be unlikely to accrue to the rural poor. Only insofar as there might be employment generated by the use of a solar industrial process heat system in a nearby town would there be some benefits, direct or indirect.

6.9 Relevance of the Collaborative Effort and Study Tours

Although UH had had some experience in the design of parabolic concentrating collectors, IIS scientists felt that perhaps some other institution which was more directly involved in state-of-the-art research in such systems might have been more appropriate as a U.S. counterpart. Valuable exchanges did take place, however, particularly in the area of selective surface technology. A spinoff from this is that IIS has provided technical assistance to a local private-sector manufacturer of flat-plate solar collectors for domestic hot water heating. The process which was developed at IIS uses less toxic yet locally procurable chemicals, rather than the standard U.S. process. This allows IIS to coat the solar water heating collectors, providing considerably higher performance at low incremental cost.

IIS has also directly benefited by its experience in production engineering. The processes for manufacturing the structural supports for the collectors were developed in-house. These can be made available to private-sector firms for system construction if a demand arises.

One of UH's other principal responsibilities was to facilitate the visits of the Indian scientists to appropriate researchers and institutions in the United States. Reviewing the trip reports, wherein Dr. Thomas of IIS visited Houston on four occasions, Albuquerque on three, and Phoenix, Los Angeles, Denver and San Francisco twice each, one wonders if the trip might have been better prepared for. IIS personnel said that visits were not confirmed beforehand, necessitating return trips at a later date. However, UH staff felt that the frequent visit changes set up by the IIS staff, plus their insistence on visiting certain sites that were off limits to them (Sandia Lab, for example) led to many of these multiple visits.

6.10 Economic Viability of the Technologies Under Development

It is very difficult to do a precise economic analysis on the system because it has yet to be installed, and full system costs are not yet known. However, using the overall system cost estimates provided by IIS, approximate comparisons between the parabolic concentrating system and the principal alternatives, coal and oil, can be made. Cost estimates for a solar system capable of delivering 80 kg of steam per hour are given below. These are based on IIS estimates of what the system would cost in its next incarnation. No research and development costs are included in these figures.

Cost Estimates

I.	Collectors 30 Nos. @ Rs. 20,000	Rs. 600,000
II.	Steam generating system	140,000
III.	Pumps, electrical connections & valves	165,000
IV.	Water treatment plant/tanks	23,000
V.	Steam pipeline with insulation	70,000
VI.	Driving units	140,000
VII.	Civil works (e.g., control room, pump house)	100,000
	Total	Rs.1,238,000

To perform the analysis, the following assumptions were made:

1. Cost of coal equals Rs. 630/ton delivered (price to government agencies) or Rs. 1250/ton for private buyers. The KSIC plant pays the Rs. 630 price.

2. One ton of coal can provide 2700 kg steam.

3. The labor costs for running the solar system plus main boiler are approximately equal to labor costs of running just the main boiler. In any event, any cost increment would have a negligible impact on the overall system cost.

4. Since the solar system provides only one-third of the load, the main boiler will have to be run continuously, so savings in operation and maintenance costs for the main boiler system, except for the cost of the displaced coal, will be negligible.

5. Six-day work week, 52 weeks per year.

6. No shadow costs for foreign exchange have been used here, since it is uncertain at this point which of the components will be manufactured in India should mass production begin.

7. Shipping and installation costs have been included in the initial capital costs given for each system.

As an initial figure of merit, the simple payback period was calculated, assuming no discounting and no maintenance costs for the solar system (highly unlikely, given its complexity):

Cost of displaced coal per year =

$$\frac{80 \text{ kg steam/hour}}{2700 \text{ kg steam/ton of coal}} \times \text{cost/ton} \times \frac{8 \text{ hours}}{\text{day}} \times \frac{312 \text{ days}}{\text{year}}$$

= Rs. 46,592 @ Rs. 630/ton of coal
= Rs. 92,444 @ Rs. 1250/ton of coal

Simple payback period is then:

$$\frac{\text{Cost of system}}{\text{Cost of displaced coal}} = \frac{1,238,000}{\text{Cost of coal}} =$$

26.6 yrs. @ Rs. 630/ton
13.4 yrs. @ Rs. 1250/ton

To do a more precise analysis (given the constraints initially mentioned), a life-cycle cost comparison was made, using the assumptions listed above. The spreadsheet on the following page gives the details of the comparisons of the various solar, coal and oil options. The different types of systems and the assumptions made about each follow the spreadsheet.

COMPARATIVE ECONOMICS FOR STEAM GENERATION

	LINE FOCUSING SOLAR CONCENTRATORS							COAL-FIRED BOILERS					DIESEL-FIRED BOILERS			
SYSTEM:	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Amortization Period (years):	20	20	20	20	15	20	20	20	20	20	20	20	20	20	20	20
Hardware Lifetime(years):	10	10	10	10	10	10	10	20	20	20	20	20	20	20	20	20
Discount Rate:	12%	12%	12%	12%	12%	16%	8%	12%	12%	12%	12%	12%	12%	12%	12%	12%
Fuel Inflation Rate:	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	4%	6%	0%	2%	4%	6%
COSTS																
Initial Capital Cost	$103,167	$77,375	$51,834	$25,792	$77,375	$77,375	$77,375	$0	$0	$0	$0	$0	$0	$0	$0	$0
Shipping	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Installation	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Init.Cost	$103,167	$77,375	$51,834	$25,792	$77,375	$77,375	$77,375	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual O+M Costs	$2,063	$1,548	$1,037	$516	$1,548	$1,548	$1,548	$3,883	$7,704	$7,704	$7,704	$7,704	$10,594	$10,594	$10,594	$10,594
NPV of Annual O+M Costs	$15,412	$11,559	$7,743	$3,853	$10,540	$9,175	$15,194	$29,004	$57,545	$65,172	$74,426	$85,710	$79,131	$89,621	$102,345	$117,063
NPV of Replacement Parts Costs	$3,322	$2,491	$1,669	$830	$2,491	$1,754	$3,584	$0	$0	$0	$0	$0	$0	$0	$0	$0
Life Cycle Cost	$121,901	$91,425	$61,246	$30,475	$90,406	$88,304	$96,153	$29,004	$57,545	$65,172	$74,426	$85,710	$79,131	$89,621	$102,345	$117,063
BENEFITS																
Steam Generated (kg/year)	199,680	199,680	199,680	199,680	199,680	199,680	199,680	199,680	199,680	199,680	199,680	199,680	199,680	199,680	199,680	199,680
Value of Output @ $0.05/kg	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984	$9,984
NPV of Benefit Stream	$74,575	$74,575	$74,575	$74,575	$68,090	$59,194	$98,024	$74,575	$74,575	$74,575	$74,575	$74,575	$74,575	$74,575	$74,575	$74,575
Effective Cost of Steam ($/kg)	0.08	0.06	0.04	0.02	0.07	0.07	0.05	0.02	0.04	0.04	0.05	0.06	0.05	0.06	0.07	0.08
Benefit/Cost Ratio	0.61	0.82	1.22	2.45	0.75	0.67	1.02	2.57	1.30	1.14	1.00	0.87	0.94	0.83	0.73	0.63

Solar Concentrators:

A. The prototype system developed by IIS and UH using actual equipment costs, assuming a 12 percent discount rate and a zero real inflation rate. No shipping and installation costs are listed separately for any of the systems since these costs were already buried in the equipment cost figures given to the evaluation team. Annual operation and maintenance (O&M) costs are assumed to be a constant two percent of the capital cost, with no real inflation of parts or labor charges. Replacement part (broken mirrors, worn out drive mechanisms) costs are assumed to be 10 percent of the initial capital cost, and occur half way through the overall lifetime of the equipment.

B. Identical to System A, using 75 percent of the prototype cost as initial capital cost.

C. Identical to System A, using 50 percent of the prototype cost as intitial capital cost.

D. Identical to System A, using 25 percent of the prototype cost as initial capital cost.

E. Identical to System B, 15 year amortization period.

F. Identical to System B, 16 percent discount rate.

G. Identical to System B, eight percent discount rate.

Coal-Fired Boilers:

H. No capital costs are assigned to either the coal- or diesel-fired boilers. Since the solar concentrators are only intended to supply one-third of the steam demand, the backup coal- or diesel-fired boilers are common to all systems. Since these are relative comparisons of the different systems, costs which are common to all systems are not included in the calculations. The cost of coal, US$52.50/ton (Rs. 630/ton), is heavily subsidized and available only to government and parastatal organizations like KSIC. Rate of consumption per unit of steam output was from KSIC. Again, since any costs for boiler replacement parts are common to all systems, a zero value is assumed here.

I. Identical to System H, but using the nonsubsidized coal cost of US$104.17/ton (Rs. 1250/ton).

J. Identical to System I, but including a real fuel inflation rate of two percent per annum.

K. Identical to System I, but including a real fuel inflation rate of four percent per annum.

L. Identical to System I, but including a real fuel inflation rate of six percent per annum.

Diesel-Fired Boilers

M. Since no oil-fired boiler equipment costs were available to the evaluation team, it was assumed that coal and oil boiler equipment costs were equal. Diesel was used in the calculations for cost and calorific value since residual fuel oil (normally used in industrial boilers) cost was not available.* Fuel consumption rate was based on the assumption that combustion efficiency was equal for both coal and oil burners.

N. Identical to System M, but including a real fuel inflation rate of two percent per annum.

O. Identical to System M, but including a real fuel inflation rate of four percent per annum.

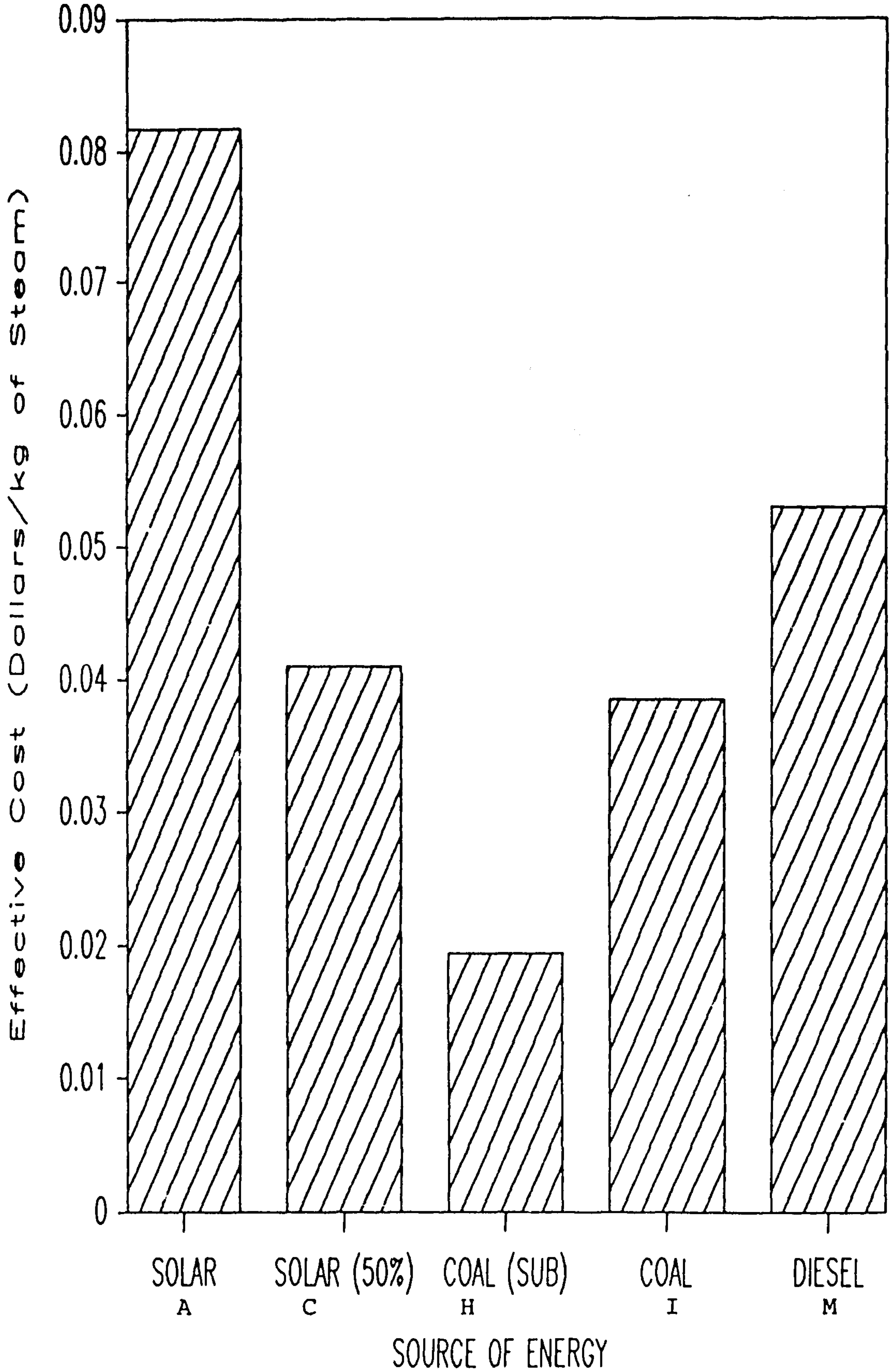
P. Identical to System M, but including a real fuel inflation rate of six percent per annum.

The value per unit of steam generated is an assumed $0.05/kg which represents an average value for the types of systems examined. The life-cycle cost (LCC) is directly proportional to this value, and it directly influences the benefit/cost ratio. However, calculating the "effective cost of steam" in the benefits section eliminates this assumption by calculating the "effective" cost at which the LCC equals the net present value (NPV) of the benefit stream (i.e., IRR=0). Thus, comparison of the effective cost of steam is a less assumption-laden basis of comparison of system merits. This cost is presented graphically on the following two pages. In the first graph, five points are graphed. These are the effective costs of steam generated by systems A, C, H, I and M--the prototype system, solar system at 50 percent of prototype cost, subsidized coal, unsubsidized coal, and retail diesel fuel. These are excerpted for quick comparison. The entire set of systems is graphed on the next page.

*As this report was going to press, the price of heavy fuel oil was determined to be $0.23/liter. Since the cost of diesel used in the calculations was $0.29/liter, oil-fired boiler costs would be 79 percent of the diesel costs shown here.

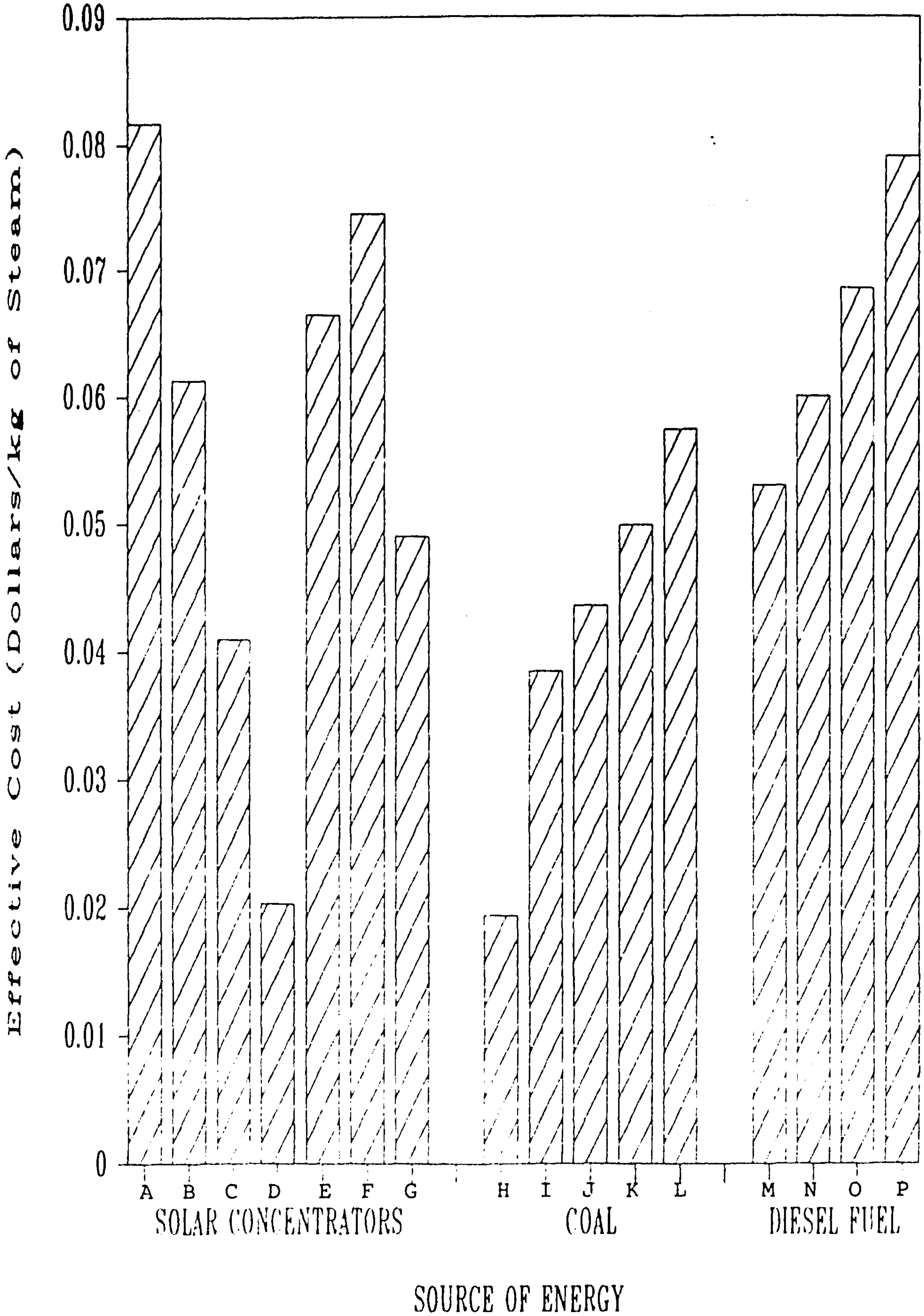
Current Cost Comparisons

Solar Concentrators, Coal and Oil



Comparison of Steam Generating Options

Solar Concentrators, Coal and Oil



The bars are grouped according to the source of energy, whether solar, coal or diesel fuel. The assumptions about amortization period, replacement hardware lifetime, discount and fuel inflation rates are given on the spreadsheet.

Generally speaking, the bar on the left side of each of the groups represen`s the current state of affairs. The solar concentrators are by far the most expensive option at present, generating steam for approximately $0.08/kg (an estimate since the system is not yet operational). Diesel is next at $0.05/kg, then coal (at its heavily subsidized price of Rs. 630/ton) at $0.02/kg. The solar system generating cost is based on the cost of the prototype system, but not including any research and development costs per se. However, if other systems are built, they will no doubt be less expensive. How much so is somewhat speculative at this point, but the graph gives some indication of what the costs would have to be for solar to become competitive with coal or oil.

Solar only becomes competitive with the present subsidized price of coal when system cost falls to about 25 percent of the prototype cost. Solar is competitive with unsubsidized coal when system cost falls to about 50 percent of the prototype cost. Since fuel cost inflation negligibly affects the LCC of the solar system, real fuel cost inflation favors use of the renewable energy option. Since oil steam generation is more costly than coal, the use of solar as an alternative to oil is more favorable than as an alternative to coal. However, solar system capital costs must nonetheless drop considerably below the prototype cost (approximately 60 percent thereof, a not unlikely scenario) before it truly assumes a competitive edge with respect to oil.

It was noted by AID/Washington reviewers of the initial draft of this report that portions of the silk industry in India are fueled by fuelwood, not coal. If this were the case, then the IIS/Bangalore solar concentrating system would displace approximately 150 tons of wet firewood, if wet wood is assumed to be 4300 BTUs/pound and local coal 9000 BTU/pound.

6.11 Summary of Utility and Importance of the Line-Focusing Solar Concentrating Collectors

Viewed as a research and development effort, the IIS/UH collaboration has resulted in some significant achievements in solar thermal technology development in India. Thus far, the most important aspect has been the considerable success achieved in the area of selective surface coatings for solar thermal collectors. The use of these coatings significantly enhances collector performance. Although they do represent an additional manufacturing expense, when used in many applications they can greatly increase system cost-effectiveness. The process developed by IIS is already being exploited commercially.

The design and fabrication expertise gained by IIS and its private-sector contractors will no doubt allow for considerable cost reductions, should further line-focusing collector systems be manufactured in India. However, the likelihood of this happening is conjectural at this point since the prototype system has not yet been installed, so performance and final cost data are not yet available for review. Given the system's cost estimates thus far and the relative complexity of the machinery, the evaluation team feels that widespread dissemination of this technology in rural areas or direct benefit to the rural poor in the near future is unlikely. The technology is more appropriate at an urban or suburban industrial site where requisite technical skills are available to ensure the proper operation and maintenance of the system. If further developments can reduce the overall solar system's LCC to approximately 50 percent of the prototype cost, it becomes competitive with the present unsubsidized cost of steam generation using coal.

7.0 AHEC/CSU/BU MICRO-HYDRO AND HYBRID SYSTEMS

7.1 Subproject Description

All stand-alone, AC-current, micro-hydro electricity-generating systems require some sort of governor to match the load with the power being generated. These devices can be either mechanical or electronic. Mechanical governors regulate the flow of water to the turbine which drives the generator. Reducing or diverting the water flow reduces the electrical output of the generator, and vice versa.

Electric controllers are of two types. When the load on the system is reduced (by shutting off the motor, for example), one type of governor reduces the field current in the generator, which reduces the generator output and wastes the hydraulic power being supplied to the turbine. The other electronic governor is a load diversion device. Of all mechanical and electronic governors, only a load diversion device permits the use of all the power generated by the system at any time. This is done by providing immediate switching to one or more secondary loads which are large enough to absorb any power delivered by the generator, but not currently being used by primary loads (such as lights or motors).

The underlying concept of this subproject was that low-cost, governorless micro hydroelectric installations would be installed at low-head and ultra low-head sites, using electronic load controllers to be developed jointly by the U.S. and Indian counterparts. The electrical output of the hydroelectric installations would be shifted automatically by the controller among loads of varying priority, enabling full utilization of the hydroelectric output 24 hours a day. This is particularly attractive to energy planners because the load factor in most rural locations is only 10 to 30 percent. A very low load factor such as this indicates that the system is being used very inefficiently, and that consequently the capital costs per unit of output increase significantly. In a stand-alone hydroelectric installation, the rest of the electricity produced would have to be dumped (into a dummy electric resistance load) since it could not be fed back into the main electrical grid.

The subproject was originally planned to be a joint collaborative effort between the Water Resources Development Center and now the newly created Alternative Hydro Energy Center (AHEC), University of Roorkee, and CSU. However, after one year the U.S. principal investigator, Professor Joel Dubow, and his chief research assistant, Rakesh Thapar, moved to positions at Boston University (BU), so the U.S. collaborator was changed in July 1983 to Boston University.

Roorkee University is one of the leading centers for civil engineering in India, with particular expertise in hydrology and structures of power generation and irrigation dams. For a number of years, CSU has had an active program of basic and applied research in civil engineering and hydrology, so the collaboration was a natural one. In 1978, prior to the start of the project, Roorkee University and CSU had signed a memorandum of understanding to conduct joint research, faculty exchanges, and technology development in hydrology, hydrogeology, fluvial hydraulics, water resources and water management, and earthquake engineering. Faculty exchanges conducted under this existing agreement had led to the proposal for joint research and development of electronically controlled micro hydroelectric units with a series of automatically switched primary and secondary loads.

As initially conceived, the subproject had several different activities, which were theoretically and practically discrete. One was the development and testing of a microcomputer-based controller which would not only switch the power produced by the micro-hydro unit among a series of loads, but would take over a variety of other unrelated functions, such as safety switching, overall system monitoring, etc. Furthermore, the controller would be able to switch among the loads according to a sophisticated priority system which could be subsequently field-modified by simple software changes. Second, very low-cost, low-head turbines were to be developed and tested. Third, a variety of "hybrid systems," meaning loads which could be powered by electricity and other renewable fuels and switched on and off automatically by the controller, were to be analyzed, purchased, and field-tested at several sites. Hybrid systems to be considered were a water hydrolysis unit, a biomass conversion and densification plant, a nitrogen fertilizer facility, and a food preservation system.

7.2 Progress to Date

The AHEC/CSU/BU subcomponent has accomplished a great deal since its inception in mid-1981, particularly in the development and testing of the hydroelectric systems and the proposed hybrid systems. At two of the three sites where the AID-supported controller is to be used, Manali and Jubbal, the civil works and site engineering are reportedly 90 percent and 85 percent complete (the evaluation team was unable to visit the sites because of their inaccessibility, the team's limited stay at Roorkee, and recent heavy snowfalls which made both airplane and ground travel difficult). The Roorkee University staff expect these sites to be complete within the next four months, provided that the electronic controllers and hybrid systems are available (see section 7.3 below). The third site, Kakroi, has had only site development work done thus far. One of the three experimental turbines (the Schneider engine) will not be ready until July 1985, so commissioning is not expected until December 1985.

The electronic controller is currently undergoing its third and hopefully last round of modification at BU. Initial deficiencies were found in the control functions, and additional safety functions were also added into the unit's software during the latest round of modifications. The final controller for the Manali site is scheduled to be ready for installation in the next several months. If it proves successful, the AHEC staff will build two additional controllers, based on this design, for the Jubbal and Kakroi sites.

Several potential hybrid loads have been acquired or developed by the AHEC and are now undergoing testing and development. These include a rice husk pyrolysis and briquetting unit, a three kW(e) electric arc nitrogen fertilizer unit (funded by the UN Development Programme and being field-tested at Maldeota), and several electrically assisted, upflow biomass gasification systems. The biomass gasification systems, along with some bench-scale biogas generators, are at a very early stage of development and will not be used in the initial test installations. AHEC plans to buy a commercially available water electrolysis unit for use at the Kakroi site, producing gaseous hydrogen and oxygen for local sale.

7.3 Attainment of Subproject and Overall Project Objectives

The AHEC/CSU/BU subproject had a very ambitious set of objectives, as already noted. These include the development of a low-cost, microcomputer-based controller and load management system for low-head hydro units; the integration of various electricity-using devices to "effectively utilize a substantial fraction of the energy generated by the hydro;" and the integration of "various energy sources synergistically and thereby improve the cost-effectiveness of each compared to what this cost-effectiveness would be if each system was used alone."

The controller is supposed to be ready by the time the rest of the Manali site is complete. U.S. computer-based equipment that will enable the AHEC staff to design and manufacture similar "intelligent" controllers had just arrived in Roorkee at the time of the evaluation team's visit, and will require several months of familiarization before the AHEC staff will be able to begin the task of developing the next generation of controllers. The integration of the end-use devices, by means of the automatic switching of loads by the load management circuits, has been tested in the AHEC laboratories with a series of electric resistance loads. It has not yet been field-tested. The evaluation team also visited a recent installation at Maldeota, where the Kettering nitrogen fertilizer unit is being run off a small micro-hydro unit, but this system is being controlled by a much simpler, early-prototype load management system that can just dump excess electricity to a single load (the nitrogen fertilizer plant). Also, the Maldeota system is connected to the main electrical grid. The evaluation team sees no technical reason why the load management system should not perform satisfactorily in the field initially, although the team is seriously concerned about the long-term durability and reliability of a microcomputer in a remote, inaccessible site when used continuously, 24 hours per day, 365 days per year. A simpler load controller such as that used at Maldeota, combined with some manually controlled load management, appears to be sufficient for all but the most complex rural sites.

The last subproject objective, that of integrating a variety of energy sources (hydroelectric power, solar energy, and bioenergy), has been somewhat de-emphasized as the project has progressed. While the hydroelectric energy will be used to drive motors required for the biomass pyrolysis process, the subproject is now more concerned with using electricity for a variety of end-use applications simultaneously, rather than using energy in a variety of forms simultaneously. The solar energy and alcohol production subsystems have been dropped as being uneconomical. One of the unstated but clear subproject objectives is to prove that an integrated set of electricity-using devices (the hybrid system), when combined with traditional intermittent rural electrification loads such as lighting, drinking water and irrigation water pumping, and small-scale industry, will produce very high load factors (65-90 percent were mentioned by AHEC participants). Instead of just dumping the excess electricity into a dummy load, it can be shunted into some useful service, or create employment. Conceptually, this is extremely attractive, since the surplus electricity is virtually free of cost and would otherwise be effectively wasted. The evaluation team is not convinced, however, that the applications packages selected by the AHEC (hydrolysis of water, water distillation, nitrogen fertilizer production, rice husk pyrolysis and briquetting, etc.) were the best choices for hybrid loads. The chief advantage of all of these units (except the pyrolysis system) is that they can be switched on and off instantly and with little or no operator intervention. However, the cost-effectiveness and rural utility of these particular systems, as opposed to more labor-intensive but traditional rural industries, is open to question. These points, and the larger question of the attainment of overall project objectives, will be discussed in the remainder of this section.

The overall project objectives of the TRP project can be summarized as follows: increase the capability of the Indian counterparts to conduct applied research and development; build institutional ties between U.S. and Indian counterparts working on similar problems; and develop technologies that will directly increase the income and quality of life of the Indian rural poor. The interaction between the Roorkee University and CSU/BU staff has certainly been close, partly due to family connections. The Roorkee University staff have received detailed training in microcircuit design and now have the equipment (Intel's Microprocessor Development System and Personal Development System) to design but not manufacture EPROMs (Erasable Programmable Read-Only Memories) and to tailor circuit boards and micro hydroelectric load management system software. The Roorkee University/AHEC staff feel that this capability will be extremely valuable as they move into the design of controllers for larger and more complex hybrid systems, such as will be used at the Kakroi site. The U.S.-Indian collaboration does not appear to have provided much technical assistance in the areas of micro-hydro system design or construction, partly because the Indian team was already eminently qualified in this area and partly because the U.S. principal investigators had never worked on micro-hydro systems prior to becoming collaborators with AHEC on this project.

There was close collaboration between the Roorkee University and CSU/BU staff throughout the project, due in part to the exchange of personnel. Rakesh Thapar, the son of the AHEC principal investigator, enrolled in graduate school at CSU in 1979, and became the principal research associate at CSU when the project was approved. He had previously done work at Roorkee University, as an undergraduate, on the design and development of micro hydroelectric controllers, so he provided a direct link between the two sets of principals and the two research programs. Mr. Thapar moved to BU with Professor Dubow in the fall of 1982, so this provided more continuity between the two U.S. institutions. Since Professor Thapar and his son visited back and forth during the course of the project, there was frequent cross fertilization of the research programs. However, it is not clear that BU was an ideal collaborating institution for this project, since the school has no laboratory facilities for the field-testing of the controller, and it seems doubtful that Roorkee University would have been as interested in giving up the collaboration with CSU, with its established hydrology expertise and water resources, if Rakesh Thapar had not also gone along to BU as a paid research associate. Unfortunately, Professor Thapar was at BU during the evaluation team's visit, so we were not able to discuss these points with him.

Finally, there is the question of whether the AHEC/CSU/BU subproject is contributing directly, in a cost-effective manner, to the betterment of the rural poor. The micro-hydro/hybrid system concept does have the potential for such a contribution. It can provide lighting, as well as energy for irrigation pumping, drinking water pumping, and power for a variety of small-scale industries (milling, drinking, etc.) as primary loads at remote sites. It will then dump the excess power into other electricity-intensive devices, such as the Kettering nitrogen fertilizer unit, which can yield a useful product for the rural farmer. However, the sites selected thus far will not allow for a real test of the concept. All have grid electricity available at the site or nearby, so these services are already being provided or can be obtained. It will be difficult to determine what impact the provision of the electric power and of the various electricity-using devices will have on the poorest sectors of the population. Also, attention of the AHEC/CSU/BU staff seems to have been focused much more on locating exotic, electricity-intensive technologies that can be used to consume large blocks of the excess electricity being generated (thereby testing the controller) rather than acquiring and installing technologies that are needed by the rural poor.

No effort seems to have been made at any site to work together with the local villagers to determine for which applications they require electricity, and what assistance they need to acquire electricity-using devices. Thus, while lighting, irrigation pumping, and cottage-industry motors are listed as primary loads, there is no indication that any local citizen has the investment capital or access to credit to buy such units. Instead, the attention has been on technologies that are appealing on the surface, but which pose large management problems or little direct benefit in rural areas. Hydrogen and oxygen production by electrolysis is the most obvious example. There is demand for both gases at the Kakroi site, but that is only because it is close to a coal-fired electrical generation plant (hydrogen is used for cooling the steam turbines of large thermal power plants) and to industrial areas requiring gaseous oxygen (for welding). These are hardly normal basic human needs in remote rural areas, nor are distilled water, industrial grade alcohol, or freeze-dried foods (all suggested as hybrid systems at various points in the project). Rural farmers need energy for grinding, rice dehulling, traction for plowing and harvesting, lighting and cooking. Much more attention should be paid to increasing the load factor by providing these services or others that villagers may need at specific sites (cold storage, school lighting, cooking, etc.) rather than just trying to increase the load factor for its own sake. While it is important, from a scientific point of view, to have a variety of electricity-consuming devices controlled by the microprocessors to see how well the control system adjusts as the loads change simultaneously, it is crucial that the devices provide services that people require and value, so that they will willingly maintain and operate the units after the research staff departs.

7.4 Constraints to Timely Subproject Completion

Like most of the other subprojects of the TRP project, the micro-hydro and hybrid systems component ran into a number of technical, managerial and financial problems to delay project completion beyond the anticipated December 1984 finish. Chief among these was the decision, announced in August 1982, of the U.S. principal investigator, Professor Joel Dubow, to accept a position as the chairman of the Electrical Engineering Department of Boston University. Rakesh Thapar, his graduate research associate and co-principal investigator, transferred to BU also. Throughout the fall and winter of 1982-83, considerable effort was expended in trying to determine how the U.S. work would continue: through CSU but with a subcontract to Professor Dubow, through a host-country contract, etc. Also, the funds allotted to the micro-hydro project under the TRP project had been exhausted, so additional funding for the second and third phases had to be provided under the separate Alternative Energy Project (386-0474). The result was that AID authorization was not completed until July 7th, 1983, and a retroactive host-country contract was then signed between Roorkee University and BU. Thus, all collaborative work ceased for nearly a year, although the controller design and software development at BU appeared to have continued during this funding lapse.

The lack of a test laboratory at BU was a serious problem, and calls into question why the program was transferred from CSU to BU. To check its logic sequences, reliability, etc., a micro-hydro controller has to be hooked up to a micro-hydro system for trials. A small micro-hydro test bed requires only a small area, 20 feet of piping, two pumps (one to simulate the water head and the other reversed to serve as the turbine), monitoring instruments, and a generator. AHEC even shipped an Indian generator to BU, so this expense was not required, but BU was unable to find both the required space and money. At the time of Professor Dubow's transfer to BU, there were plans for a new engineering building, complete with an energy engineering laboratory. Construction of the building was delayed, however, so there were no facilities for testing. Micro-computer work had to take place in a separate laboratory.

The controller had to be hand-carried to Roorkee University for testing in August 1983. A number of deficiencies were found, and it was sent back to Boston for further development. It was again carried from Boston to Roorkee and back in mid-1984, and is now undergoing final modifications. The delays entailed and the travel expenses of the BU team seem excessive to the evaluation team.

Like the other TRP subcomponents, the micro-hydro and hybrid system program ran into delays because of its use of prototype technologies as central components of the system. For example, by late 1982 it was decided to order a 100 kW(e) Schneider engine for the Kakroi site. The Lotte-Schneider engine is a recent development, and one full-scale prototype was undergoing testing in California at the time the decision was made to buy one. The system's developer had awarded a license to a Korean firm for Asian markets, so the procurement was to be done by BU with this supplier. This required a special waiver, since it was non-U.S. and non-Indian procurement, but the main problem was that the systems were not yet ready. Delivery isn't expected until July 1985. While the Kakroi site is a novel one (only a 1.5-meter head but a very high flow rate) and the Schneider engine is an exciting concept, its non-availability as a commercial product and its high initial cost (US$78,000) are major problems that should have received more attention by AID and DNES staff.

Some aspects of the projects that led to delays were unavoidable and expected. The sites at Manali and Jubbal are distant from Roorkee and have short construction seasons due to their elevation. Passes become blocked due to snowfall, and airplane flights into Manali are often cancelled during inclement weather. None of these were unexpected by the AHEC staff, who have done an excellent job in minimizing the impact of such setbacks on the overall project schedule.

7.5 Procurement Problems

The problems with the Schneider engine and other experimental systems have already been touched on and will not be repeated here. In general, pieces of key hardware arrived in India six to 12 months behind schedule, just as they did in the other TRP project components. Some of these problems may be attributable to the shift in procurement authority from CSU to BU, and others to unexpected difficulties in product development (e.g., the controller).

7.6 Management Effectiveness of the U.S. and Indian Institutions

The AHEC and Water Resources Development Centre staff seem to have done an outstanding job of coordinating a variety of civil construction, technology development and testing, and systems integration tasks. They are to be congratulated on the strides they have made in setting, staffing and running the new center (AHEC). With the cooperation of the state electricity boards, the irrigation authorities, and DNES, the Roorkee staff appears to have the construction of several micro-hydro sites well in hand.

It is difficult for the evaluation team to judge the CSU/BU management performance, since the team is not entirely certain what was done by them. The documentation provided by CSU was sketchy, and the pattern of actual expenditures and effort very different from the planned work. Six months into the work, in June 1982, CSU asked for a tripling of its budget (from US$429,000 to $1,282,000), including a 250 percent increase in the year already in progress. This request was turned down by AID in what appears to have been an excellent management decision. After examining the documentation provided by CSU and later by BU, the evaluation team concludes that very high manpower costs incurred by CSU were not for the computer or controller, since the memory demanded (4,000 bytes) and the overall system configuration can be provided in crude form by a programmable calculator (such as a HP-41) costing US$250. The problem was the very complex subroutines required for the total automation of the sample hybrid systems--the water electrolysis unit and the IIT biomass pyrolysis system. Integrating automated process controls (feeding the pyrolysis unit when it needs fuel, sending fuel gas through drying briquettes), safety features (pressure sensors in the H2 tanks, room "sniffers" for H2 buildup, high-pressure pump temperature) and system protection algorithms was a Herculean task, since they appeared to try to cover all contingencies. Such a complex process flow system may be appropriate in a 500-ton/hour steel rolling mill, but it seems unnecessary at a 100 kW(e) micro-hydro site. Workers being paid 20 to 30 rupees/day can read gauges, turn systems on and off, load hoppers, etc. All that is required of the controller is that it turns the power on and off, not continuously manage the load.

It appears that the magnitude of the computer programming challenge, rather than the need for a simple, sturdy control algorithm, was what drove the AHEC and thus the CSU/BU decision process. The complexity of the task may account for the large U.S. manpower investments between January 1 and September 1982. The evaluation team is not convinced such virtuoso programming was really needed for a developing-country application. The concept of using an existing process controller, originally discussed but finally disregarded in favor of the microcomputer, may be worth reconsidering in future installations.

AID/New Delhi and AID/Washington appear to have done a commendable job at keeping the escalating costs under control and keeping the researchers focused on the work at hand. Under AID pressure, the large proposed travel budgets ($60,000 for visits of Roorkee University staff to the United States) were trimmed, as were the requests for equipment to be used at CSU ($110,000 in 1982 alone).

7.7 Effectiveness of U.S. to India Technology Transfer

It is difficult to assess the value of the information and equipment transfer that has taken place, since the key items (the controllers) are still in the United States. The major capital investments (the Intel MDS and PDS and the Schneider engine) have either just arrived in Roorkee or are yet to be shipped. In addition, much of the learning of the sophisticated control strategies and writing of sophisticated software has been done by Rakesh Thapar. If he returns to Roorkee after finishing his doctoral work, then he will prove to be a valuable resource for controller design for larger systems.

7.8 Relevance of the AHEC/CSU/BU Micro-Hydro and Hybrid Systems

7.8.1 Production and Installation by Indian Institutions

Roorkee University staff feel they now have the tools to engage in controller design, as well as software development. The Intel MDS gives them the capacity to test circuit boards and to design microprocessors. Fabrication would still have to be done elsewhere, although they feel the Indian electronics industry can do such custom work under contract. The rest of the system, including the turbines (except for the Schneider engine), generators, relays, etc., are all of Indian manufacture. The hybrid system units are a mixture of Indian designs (the electrolysis unit) and imported units (the Kettering generator).

7.8.2 Remote Site Operation and Maintenance

The micro-hydro turbines and generators are simple and rugged, and should pose no problems for remote site operation. The pumps used as turbines are water lubricated, and only the power shaft bearings will need greasing. It would only be speculation to estimate the reliability and durability of the controller system (a microcomputer) of the various hybrid units since they have yet to be field-tested in their final configuration. The rice husk briquetter appears to be sturdy, but it will certainly need a staff of trained workers for its operation. The water hydrolysis unit will probably be used only at the Kakroi site, and it will require careful safety precautions and close supervision by trained staff ($H2$ is explosive and disperses quickly if there is a leak during the loading of the cylinders or during transport). Hydrogen and oxygen must be transported to a user in pressurized form. Hydrolysis will only be useful where there are good roads and a nearby industrial demand. The same is true for distilled water for industrial purposes, although it obviously can be used for drinking as well. Only a large unit (or a very large electrically assisted solar still) could produce an appreciable amount of water, such as is required for a village.

It is possible that the extra energy utilization provided by the controller/hybrid energy system may provide enough benefits to justify the additional cost and complexity. The one combination that appears to make sense is to dump all excess power into one system--a nitrogen fertilizer unit. This would couple nicely with other anticipated installations (irrigation pumps, for example). It is amenable to relatively automated operation and in effect becomes the dummy load. With this as the only hybrid system, however, the complex control logic becomes unnecessary.

7.8.3 The Rural Poor

Run-of-the-river, governorless micro-hydro installations can be a boon to the rural poor. Reduced civil works and lower capital costs (no governor) would make more remote sites economically feasible. But all this can be done with simple logic circuits already made by AHEC. The electricity will be useful only when it is converted into light, heat or work. The lighting will come once the transmission and distribution lines are installed, but process heat and shaft power will be installed only by those with access to credit and with technical know-how to operate the machines. It is this crucial phase--mobilization of resources and training--that will make the micro-hydro units relevant to the rural poor.

It is too early to say if the hybrid units will improve the lot of the rural poor, since none have been installed in rural areas without grid access. If the rice husk briquets turn out to be acceptable as a cooking fuel or as a displacement for wood being used as industrial process heat, then it may be a welcome addition to the rural village.

7.9 Relevance of the Collaborative Effort and Study Tours

Five of the Indian professionals from Roorkee University spent six to eight weeks at CSU or BU (mostly at BU). They felt the experience to be valuable and the U.S. counterparts helpful. Rakesh Thapar has also been directly involved full-time in the collaborative work with Professor Dubow, and there is an assumption that this acquired expertise will become available to India in the near future and has already been helpful.

7.10 Economic Viability of the Technologies Under Development

Micro hydroelectric generation is highly site specific. At an exceptionally favorable site, it is one of the least expensive power generation strategies, although the cost per kilowatt generated generally rises as one moves into smaller and smaller systems. There are five basic sets of costs to be considered: civil works (weirs, sand traps, diversionary canals, etc.); water delivery systems (penstocks or flumes); turbine/generator sets; control and/or governor sets; and power transmission and distribution costs. In general, sites with very favorable turbine-generator costs per kilowatt are those with high heads (over 50 meters). Because such heads are generally found only at very steep sites, there may be a trade-off in the cost of transmission (since the users of electricity are not normally found near such steep, fast-moving water sites). There are a number of other cost-related trade-offs. Lower efficiency turbines, such as those used by the AHEC using commercially available, mass-production water pumps as turbines, may be more economical because of their very low initial capital cost. Eliminating water storage saves greatly on the civil works, but necessitates an expensive governor or a sophisticated controller. There are a number of other such balances that have to be made.

For the current analysis, the site at Kakroi will be examined. There, AHEC is installing three 100 kW(e) units on an existing irrigation canal (West Yamuna canal). The site has a very high flowrate (400 cubic feet or 11 cubic meters per second), but a head of only 1.59 meters. This low head is normally considered much too low for power generation, but AHEC feels that the turbine generators being considered have the potential for cost-effective electric production. The costs for the whole 300 kW(e) installation are given below. (The dollar costs are converted at 12 rupees per dollar and marked with an asterisk.)

Civil Works (desilting tank, diversionary channels, etc.)	Rs.2,800,000
Schneider 100 kW(e) engine*	936,000
Voest Alpine low head turbine--100 kW(e)*	2,000,000
BHEL tube turbine--100 kW(e)	1,500,000
Control panel	400,000
Controller	50,000
TOTAL	Rs.7,686,000
or Equivalent	US$640,000

Additional Costs for the Hybrid Energy Systems:

60 kW(e) water hydrolysis unit	380,000
60 kW(e) nitrogen fertilizer system (20 units of 3 kW(e) each)	600,000
125 kW(e) rice husk briquetting plant	500,000
SUBTOTAL	Rs.1,480,000
or Equivalent	US$123,000

The cost per installed kilowatt of power is $2,133 (providing that all the systems perform at rated capacity throughout the year). If the hybrid system is added and the micro-hydro hybrid system combination is considered, then the overall system cost is $763,000, which is still quite reasonable for both a 300-kW(e) power system and a set of power-using technologies that generate a stream of benefits. Unfortunately, there are no firm figures for the value of the whole range of benefits. In particular, the commercial value for the H_2 and O_2 being produced (five cubic meters per day) has not been determined. While Roorkee University has found a local market for the rice husk briquettes at 0.70 rupees per kilogram, they do not know how much will be produced at Kakroi or how much can be sold at this price.

Some preliminary estimates of the value of the nitrogen fertilizer system can be made, based on its replacement of commercial urea fertilizer. Each 3-kW(e) Kettering unit produces 300 liters of nitrogen phosphate in 15 days, with a nitrogen concentration of 80 grams per liter. This means a nitrogen equivalent of 24 kilograms every 15 days. If we assume that urea is 46 percent nitrogen, then the 300 liters of solution displace 52 kilograms of urea. The price of urea is two rupees per kilogram, so the nitrogen phosphate should have a market value of approximately 104 rupees every 15 days or 2500 rupees per year. Twenty modules being run simultaneously would produce 20 x 2500 or 50,000 rupees of fertilizer per year. If we assume that one operator can operate 20 plants at 30 rupees per day, then the operating expenses will be 10,950 rupees plus the cost of the 4866 kilograms of phosphate rock that will be required to react with the nitric acid that is initially produced by the Kettering generator.

7.11 Summary of Utility and Importance of the Micro-Hydro and Hybrid Systems Subcomponent

Micro-hydro development projects have a great potential for spurring rural development in India. They can provide basic electrical services for remote villages that are too small or too distant from the existing grid to warrant the cost of stringing additional distribution lines. Since the current cost of additional incremental power lines is $2,000 per kilometer, small micro-hydro units that can provide power for $880-2,000 per installed kilowatt look (from a capital investment point of view, completely apart from the recurrent cost of energy purchased from the grid) very attractive for sites 10 or more kilometers from the grid. The problem with very small micro-hydro units is always minimizing or eliminating the civil works without producing unacceptable fluctuations in current. Also, the cost of governors for small units is quite high, as much as 30 percent of the total system cost. Therefore, the AHEC concept of governorless micro-hydro units can significantly reduce the cost per delivered kilowatt of electricity, providing that the controller that replaces the governor is low cost and reliable.

The concept of the hybrid systems using the excess power normally available at small-scale hydro sites (and indeed at all rural electrification sites) is also important and should be vigorously encouraged by DNES and AID. Without raising the capital cost of the hydroelectric system, additional services such as nitrogen fertilizer and cooking briquettes can be provided to local citizens.

However, the hybrid systems concept will only have major importance for rural areas if coupled with a program to develop significant electrical loads for income generation, education, health, and sanitation <u>before</u> the hydroelectric unit is installed. This will require a whole set of extension programs, small industry development efforts, credit facilities, and infrastructure being tested in collaboration with local villagers while the hydroelectric unit is being constructed. It also means a great deal more field research, again with the cooperation of local villagers and agricultural extension agents, to find hybrid systems that produce an output that will be economically viable. The objective should be to find technologies that produce an output of such value that the local sale of the produce will pay for the cost of purchasing and operating the hybrid system in three to five years. If these can be located, the micro-hydro/hybrid systems project will be able to make three distinct contributions: first, the basic electrical amenities of lighting and household appliances; second, the income generation provided by the electrically powered agricultural equipment and small-scale cottage industries; and third, the additional useful products that are created (and then locally sold) by the hybrid system operators. Such a program would not only provide power, but also a powerful motor for self-sustaining village development without further outside assistance.

The evaluation team would like to note that totally automated control of all of these components (amenities, income-generating equipment and hybrid systems) is neither necessary nor even necessarily desirable. Villagers can perform effective load management if it is in their interest. Such local planning and system management is routinely done by a local village committee in remote hydroelectric sites in Thailand and Nepal, for instance. Villagers decide, for example, that power will be provided for household lighting from 6:00PM to 12:00PM each evening and all day Sunday. The operator throws a master switch at that time, and power is provided. Similarly, the villagers agree that irrigation pumps are to be run from 8:00AM to 3:00PM each day. A switch is provided for this also. Small-scale industry can be scheduled in the periods when power is not being used by the priority loads, and any excess power can be automatically dumped into a useful dummy load (such as a nitrogen fertilizer plant). Such a simple system can be locally changed as circumstances change (lighting can be provided for holidays by shutting off all other loads) without reprogramming a computer. The system is transparent to the local user, not a black box provided by the government. It allows for local optimization, something at which local farmers are very skillful. Lastly, it allows for local control and participation. This is the type of sustainable development that AID and DNES should be supporting.

8.0 GENERAL RECOMMENDATIONS

8.1 Extension of Current Project Activities

- All of the project subcomponents should be extended for a time period which will allow for all planned procurement, system assembly and debugging, and six months to a year of field-testing. This will mean new completion dates that range from December 1985 to December 1986.

- U.S. collaborative assistance in the project extension period should be restricted to highly focused technical assistance, performance monitoring, and cost-reduction strategies by commercial producers.

- AID/DNES should jointly fund a careful economic analysis and market study of each technology system developed under the TRP project after a year of field-testing, to determine whether broader demonstration or commercialization is warranted.

8.2 Detailed Subcomponent Recommendations

8.2.1 AU/CSU Solar Dryer Subcomponent

- AID and DNES should jointly consider a follow-on, four-year proposal to modify, demonstrate and commercialize the industrial-scale solar rice dryer developed by AU.

- DNES should consider funding the development and testing of larger (three tone capacity) solar dryers, as well as solar dryers that have the capacity to use heat produced by the combustion of rice husks as an auxiliary heat source.

- AID should consider funding the installation of 10 demonstration solar drying units, distributed throughout the regions of India that consume large quantities of parboiled rice.

- AID should provide funding to allow AU to involve both commercial rice mill equipment firms and current solar fabrication companies in the design and construction of larger solar and solar/ biomass-fired dryer units.

- AU should receive funding to provide demonstrations to small-scale farmers of low-cost solar drying systems and to train teams of rural technologists to help disseminate the technologies.

8.2.2 <u>BHEL/CEL/JPL Salojipally Integrated Village Energy System</u>

- All remaining U.S. procurement and shipping should be completed as soon as possible.

- A maximum of four person-weeks of technical assistance should be supplied by JPL if required by BHEL for two remaining tasks: solar thermal subsystem testing and optimization; and overall system integration once all of the portions of the project are installed at Salojipally. Provision for the travel and per diem of these two specialists for two weeks each in India will also have to be made, either from the AID or DNES budgets.

- The provision of the additional JPL technical support should be made contingent upon AID or BHEL/CEL agreeing to provide one full year of monitoring data from the Salojipally site, to include the long-awaited socioeconomic study.

- A two-week study should be done by a competent Indian agricultural economist on the benefits accruing to the village from the provision of the irrigation water at the site. This economist should also be asked to provide detailed information on the cost of operating both the solar thermal and biogas plants, and to derive a cost per delivered liter of water from each unit.

- CEL should be asked to install monitoring equipment at the Salojipally site which will allow for a one-year comparative study of the two sets of PV modules installed at Salojipally. No comparative data have yet been collected, despite the mention of their necessity throughout the project documentation.

- A detailed analysis should be done, as originally requested by both DNES and AID, of the alternative costs of providing the same services at Salojipally by two means: diesel generator sets and extension of the existing grid to the site. These should be compared with an estimated life-cycle cost analysis of the solar thermal generator with the frequency of component replacement/repair based on the one year's operating experience. This study should be undertaken by an experienced Indian energy economist, with funding by DNES, AID, or both.

8.2.3 IIS/UH Line-Focus Solar Concentrator System

- The current contract should be given a no-cost extension until May 1985 to allow the Mysore Silk Industries installation to be completed and to allow for the collection of a year of data.

- The extension by both DNES and AID should be contingent upon an agreement to provide AID with the technical monitoring data in June 1985.

- Any follow-on funding for additional phases of this work should be directed by IIS. If a U.S. counterpart institution is required, it should be an organization with experience in the production and commercial installation of low-cost line-focus solar collectors.

- UH should be asked to provide a full accounting of its expenditures of project funds for the areas of thermosyphon water heating units, and air collector development.

- UH should be asked to provide full documentation to IIS and AID of the line-focus concentrating collector computer design model that was developed using project funds.

- An analysis of the economic feasibility of the solar steam generator at the Mysore silk factory should be undertaken by a competent Indian economist or industrial engineer once the system has been operating for six to nine months. This report should include a comparison with both oil- and coal-fired steam boilers.

8.2.4 AHEC/CSU/BU Micro-Hydro and Hybrid Systems

- The Roorkee/BU contract should be extended until November 1985 to allow for the completion of the Kakroi power plant, delivery of the Schneider engine, and the collection of a year's monitoring data.

- The granting of this extension should be contingent upon the provision of these performance monitoring data, to include the output and economic value of the various hybrid systems, by the end of December 1985.

- AID should consider funding a major program of integrated rural development to be conducted in conjunction with Roorkee University and one or more experienced Indian rural development and entrepreneurial development groups. This effort would be focused on two or three sites that have already been targeted by the GOI for micro-hydro installations, and would work on surveys of energy needs in those locations, financing and training for local industries or entrepreneurs, and extension programs for local farmers for irrigation management and financing, use of nitrogen fertilizer, etc.

8.3 Guidance for Future Applied Science and Technology Projects

The following general procedural recommendations are suggested as ways of avoiding some of the major difficulties which prevented timely completion of most of the TRP subprojects reviewed in this evaluation.

- Future AID-funded applied science projects should focus much more, during the design stages, on what technologies would be useful to meet national development priorities and what streams of costs and benefits would ensure commercial viability. To be useful development projects, scientific projects have to be needs driven rather than technology driven. They require a clear set of design criteria, including not only technical performance but also cost and reliability, that can only be provided by consulting directly with the intended user.

- AID should require that equipment being used in development projects be either available off-the-shelf in the U.S. from two or more vendors or be available for purchase in India. This will tend to eliminate prototypes still under development, which were major problems and causes for delay in the TRP project.

- AID should assign a qualified science and technology officer or experienced personal services contractor to any future U.S.-Indian collaborative project structured like the TRP project, and should consider having an outside technical review group perform an interim project evaluation. This would determine whether initial project objectives were being met, or whether they needed to be redefined in view of results obtained thus far.

8.4 Follow-On Activities

The following activities are suggested by the evaluation team as future subprojects which would further the original objectives of the TRP project, should additional funding become available.

8.4.1 Utilization of Solar Energy and Biomass Wastes In Agricultural Drying

Objectives:

- To test the acceptability and commercial viability of solar dryers (possibly with biomass combustion auxiliary) at small to medium-sized rice mills throughout India.
- To directly involve in the construction and placement of 10 to 20 prototype, three-ton-per-day dryers, Indian firms that have the interest and capability of selling turnkey dryer units directly to rice mills and to other agricultural processing plants.
- To develop and field-test a batch dryer that can successfully dry a number of different crops (rice, chilis, corn, etc.) in successive seasons.
- To develop and field-test a rice husk-fired cogeneration unit in one or more commercial mills. This system will not only produce the steam used for parboiling rice but will also produce electricity for plant operations.
- To experiment with small-scale biomass- or biogas-powered engines that can replace the electric blowers and bucket conveyors in the current AU/CSU 1.75-ton-per-day rice dryer and in the proposed three-ton-per-day model.

Key Institution: Annamalai University

Key U.S. Collaborator: Charles Smith

Project Duration: mid-1985 through mid-1989

Regional Foci:

- The commercialization of three-ton-per-day rice dryers would initially be focused on those states which currently favor parboiled rice, such as Tamil Nadu, Kerala, Andhra Pradesh and West Bengal.

- The development and field-testing of multipurpose dryers would take place in those states that have diversified cropping patterns (generally the northern and central regions).

8.4.2 Integrated Rural Development Projects to Couple with Planned Remote Micro-Hydro Installations

Objectives:

- To work directly with the communities being served by a micro-hydro installation to ensure local participation prior to the beginning of construction.

- To determine what direct development needs in the village can be served by the introduction of electricity, and what the community priorities are for services to be provided.

- To work with the community to schedule various community and private loads (irrigation pumps, mills, cottage industry motors) so as to determine the minimal power required at the site.

- To develop mechanisms for low-cost financing for the purchase of electrical devices desired by the community or by individual entrepreneurs.

- To work with the community to determine the hybrid loads that would be most desirable and most easily operated and maintained.

Key Institution: Alternate Hydro Energy Center, Roorkee University

Key Collaborator: An experienced private development firm or small-scale industry promotion group.

Project Duration: mid-1985 to mid-1990

Regional Foci:

- Remote micro-hydro installations are currently planned for the states which border the Himalayas: Uttar Pradesh, Himachal Pradesh, Kashmir, etc. The ultra low-head hydro installations, which are planned for various irrigation channels, will be spread throughout northern and central India.

8.4.3 Wind Monitoring System for Agricultural and Community Power System

Objectives:

- To provide the GOI with technical assistance and hardware for the creation of a national wind-monitoring network targeted specifically at irrigation and drinking water pumping with windmills.

- To locate five to 10 sites where installations of small to medium-size (up to seven-meter diameter rotor) wind water pumpers would provide cost-effective irrigation or drinking water.

- To provide comparative testing of Indian water pumpers in normal working conditions.

Key Institution: Wind Energy Center at the National Aeronautical Laboratory, Bangalore

Key U.S. Collaborators: Private U.S. energy instrumentation firms, energy system monitoring and development groups, and builders of commercially available U.S. wind water pumpers.

Project Duration: mid-1985 to December 1989

Regional Foci:

- The coastal regions of the southeastern and southwestern states (Tamil Nadu, Andhra Pradesh, Orissa, etc.) as well as selected sites in the northern foothills (Jammu, Kashmir and Himachal Pradesh) where the best wind regimes occur.

APPENDIX A

Individuals Contacted

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APPENDIX B

Sources Consulted

AID. Project Paper. India--Alternative Energy Resources Development (386-0474). June 29, 1982.

AID. Project Paper. India--Application of Science and Technology to Rural Development. May 5, 1978.

AU. Report of the Indo-U.S. Collaborative Project on Optimisation of Solar Drying Systems for Agricultural Produce. Funded by DNES and AID from 1-4-81 to 31-12-84.

BHEL. Development and Application of Decentralized Energy Systems Utilising Non-Conventional Energy Sources --Salojipally Project. Report prepared in connection with AID Evaluation Team visit, November 30-December 3, 1984. October 25, 1984.

BHEL. Development and Application of Decentralized Energy Systems Utilising Non-Conventional Energy Sources --Salojipally Project. Solar Thermal Power Plant System Analysis. July 15, 1981. BHEL Project No. DYN-80-240-83. JPL Task Plan No. 70-980.

BHEL; CEL. Development and Application of Decentralized Energy Systems Utilizing Non-Conventional Energy Sources. Project Proposal, February 1, 1980.

BHEL; CEL; JPL. Development and Application of Decentralised Energy Systems Utilising Non-Conventional Energy Sources--Salojipally Project. Project Management Review, December 11-16, 1982. JPL Task Plan No. 70-980; BHEL Project No. DYN-80-240-83.

BHEL; CEL; JPL. Development and Application of Decentralised Energy Systems Utilising Non-Conventional Energy Sources--Salojipally Project. Second Conference Report, February 20, 1982. JPL Task Plan No. 70-980B, BHEL Project No. DYN-80-240-83.

BHEL; CEL; JPL. Development and Application of Decentralised Energy Systems Utilising Non-Conventional Energy Sources--Salojipally Project. Second Project Management Review, November 5-15, 1983. JPL Task Plan No. 70-980B, BHEL Project No. DYN-80-240-83.

CSU. Optimization of Solar Drying for Agricultural Produce. AID Project No. 386-0465. CSU/Annamalai Subproject. Progress Report for the Period May 1 through November 30, 1983.

CSU. Optimization of Solar Drying for Agricultural Produce. AID Project No. 386-0465. CSU/Annamalai Subproject. Progress Report for the Period October 1, 1982-May 31, 1983.

DNES. Annual Report, 1983-84.

Guven, Halil M.; Bannerot, Richard B. Optical and Thermal Analysis of Parabolic Trough Solar Collectors for Technically Less Developed Countries. Technical Report 1. University of Houston. June 1984.

Guven, Halil M.; Bannerot, Richard B.; Mistree, Farrokh. A Comprehensive Computer-Based Method for Design of Parabolic Trough Solar Collectors for Technically Less Developed Countries. Technical Report 2. University of Houston. August 1984.

IIS. Medium Temperature, High Efficiency Tracking and Non-Tracking Solar Energy Collectors for Rural and Industrial Applications. Annual Report, May 1981 to April 1982.

IIS. Medium Temperature, High Efficiency Tracking and Non-Tracking Solar Energy Collectors for Rural and Industrial Applications. Progress Report, January 1984 to June 1984.

IIS. Project Status Report for the Visiting Evaluation Team (3-6 Dec. 84), Indo-U.S. Project, Medium Temperature High Efficiency Tracking Solar Energy Collectors for Rural and Industrial Applications.

JPL. Technologies for the Rural Poor--Development and Application of Decentralized Energy Systems. JPL Task Plan No. 70-980A. November 16, 1982.

Project Proposal for Support Under US AID Grant of $2 Million for the Technologies for the Rural Poor (Application of Science and Technology to Rural Development).

Quarterly Status Report as on September 30, 1984, Technologies for the Rural Poor (386-0465).

Salojipally Project Progress Report--May 4, 1984.

Smith, Charles C.; Muthuveersappan, V. R. Comparison of Portable and Stationary Crop Dryers for Developing Countries. Presented at International Meeting, Energy Savings in Drying Processes--Applications to Industry and Agriculture.

UH. Medium Temperature, High Efficiency Tracking and Non-Tracking Solar Energy Collectors for Rural and Industrial Application. Fifth Semi-Annual Report, July 1983 to December 1983.

UH. Medium Temperature, High Efficiency Tracking and Non-Tracking Solar Energy Collectors for Rural and Industrial Application. Fourth Semi-Annual Report, January 1983 to June 1983.

UH. Medium Temperature, High Efficiency Tracking and Non-Tracking Solar Energy Collectors for Rural and Industrial Application. Second Semi-Annual Report, January 1982 to June 1982.

UH. Medium Temperature, High Efficiency Tracking and Non-Tracking Solar Energy Collectors for Rural and Industrial Application. Semi-Annual Report, May 1981 to December 1981.

UH. Medium Temperature, High Efficiency Tracking and Non-Tracking Solar Energy Collectors for Rural and Industrial Application. Sixth Semi-Annual Report, January 1984 to June 1984.

UH. Medium Temperature, High Efficiency Tracking and Non-Tracking Solar Energy Collectors for Rural and Industrial Application. Third Semi-Annual Report, July 1982 to December 1982.

U.S. Govt. Memorandum. Project Evaluation Summary #82-4, Technologies for the Rural Poor (386-0465). May 7, 1982.

U.S. Govt. Memorandum. Project Evaluation Summary #83-4, Technologies for the Rural Poor (386-0465). August 9, 1983.

U.S. Govt. Memorandum. Trip Report Covering TRP Sub-Projects--CSU/AU, HU/IIS, NEI/NIN (Nutritional Blindness) and JPL/BHEL/CEL Salojipally Project During August 8 to 14, 1982. September 3, 1982.

Wu, Li-Yun; Bannerot, Richard B. An Experimental Investigation of the Effect of Water Removal and Replacement on the Thermal Stratification in a Horizontal Water Storage Tank. Technical Report 4. University of Houston. November 1984.