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RENEWABLE ENERGY SYSTEMS INSTALLED IN ASIA:

CURRENT SUCCESSES AND THE POTENTIAL FOR FUTURE WIDESPREAD DISSEMINATION

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ACRONYMS

AID	U.S. Agency for International Development
ARD	Associates in Rural Development, Inc.
ASEAN	Association of Southeast Asian Nations
ADBN	Agricultural Development Bank of Nepal
ATU	Appropriate Technology Unit (Nepal)
ADB	Asian Development Bank (Philippines)
BED	Bureau of Energy Development (Philippines)
BHEL	Bharat Heavy Electricals Limited (India)
CEL	Central Electronics Limited (India)
CSU	Colorado State University
DNES	Department of Non-Conventional Energy Sources (India)
EGAT	Electrical Generation Authority of Thailand
ERDC	Energy Research Development Center (Philippines)
FSDC	Farm Systems Development Corporation (Philippines)
GEMCOR	Gasifier Equipment Manufacturing Corporation
GOI	Government of India
GOP	Government of the Philippines
GOT	Government of Thailand
IIS	India Institute of Science
ISA	Integrated Services Association (Philippines)
JPL	Jet Propulsion Laboratory, NASA
KSIC	Karnataka Silk Industries Corporation (India)
MHS	Ministry of Human Settlements (Philippines)
NEA	National Energy Administration (Nepal)
NGO	non-governmental organization
OCD	Office of Capital Development (AID)
PEA	Provincial Electrical Authority (Thailand)
PNOC	Philippine National Oil Company
PV	photovoltaic
RCUP	Resource Conservation and Utilization Project (Nepal)
RECAST	Research Center for Applied Science and Technology (Nepal)
RET	renewable energy technology
TISTR	Thailand Institute of Scientific and Telchnological Research
TRP	Technologies for the Rural Poor project (AID)

PREFACE

The following paper reports data and observations gathered by the author in the Philippines, Thailand, Nepal and India during the period October 16 through December 20, 1984. This data collection and analysis consultancy was undertaken by Associates in Rural Development, Inc. (ARD), of Burlington, Vermont, in response to a request by the Office of Energy, Forestry and Environment of the Bureau for Asia, U.S. Agency for International Development (AID), under AID contract number PDC-1406-I-06-2167-00.

This material is designed to provide background information to AID mission energy officers within the Asian region on the field experience in other countries with the testing and operation of renewable energy technologies. This report has been specifically designed to assist the AID energy officers during their review meeting to be held in Los Banos, Philippines, in April 1985.

Numerous individuals in the four countries visited provided valuable support and assistance in gathering the information reported here. I would particularly like to thank Mr. Richard Stevenson of AID Manila, Mr. Dan Jantzen of Bikash Enterprises in Kathmandu, Mr. Mintara of AID Bangkok, Jr. R. K. Berry of AID New Delhi, and Dr. G. D. Sootha of the Indian Department of Non-Conventional Energy Sources (DNES) for their help in scheduling meetings, selecting sites to visit, and providing the background information that is so hard to gather during a short in-country stay.

Portions of this report, including the life-cycle costing and comparative economic analysis of the Indian renewable energy technologies, were developed by Mr. Richard McGowan, ARD's senior engineer, as part of our joint evaluation of the Technologies for the Rural Poor project. Information on Philippine gasifiers was gleaned from the early draft of the evaluation of that AID-sponsored project, which is currently underway by another ARD team, led by Dr. George Burrill. These new data enabled me to update estimates of profitability and trade-offs between diesel and charcoal fuels and to incorporate additional Philippine field survey information.

Valuable comments on earlier drafts were received from Dr. Robert Ichord and Mr. Robert Archer of the AID Bureau for Asia, as well as from Mr. McGowan. These comments have been incorporated in this final report and, hopefully, have contributed measurably to its utility for AID energy officers in the Asian region.

Lastly, I would like to thank the support staff at ARD, who dealt with numerous revisions in the face of many other demands on their time. In particular, I would like to thank Sally Ballin for shepherding this report through the production process and contributing greatly to its final readibility.

EXECUTIVE SUMMARY

The U.S. Agency for International Development (AID) has supported the development, field-testing, and limited dissemination of a number of renewable energy technologies (RETs) in Asia in the past 10 years, as well as the creation of high-quality, indigenous centers of RET design and adaptation. A number of these technologies supported by AID have proven to be durable, reliable, and socially acceptable to local users. More importantly, they have demonstrated in field trials that they are economically attractive to potential users because of the income they generate, the fossil fuels or scarce fuelwood they displace, or the unique services they provide that are otherwise unavailable.

It was found that the success of these technologies is due in part to three environmental factors: the skilled manpower pool of trained scientists, technicians and mechanics available in the developing countries of Asia; the sophistication of the Asian private sector for producing high-quality prototype and production models of various RETs; and the commitment of the Asian governments to reducing fossil fuel imports through RET promotion and energy conservation. In addition, the successful AID-sponsored RETs had five common characteristics:

- high value attached to system output by potential users;
- participation by end-users in system adaptation or construction;
- high-quality local resource base;
- compatibility with existing local fabricating facilities;
- relatively low cost when compared with other methods available for doing the same work.

AID-sponsored RETs were examined in Nepal, India, Thailand and the Philippines, including visits to field sites where units were being operated by purchasers or professional operators. Of the technologies examined, four have the potential for or have already begun widespread dissemination:

- micro-hydro units in Thailand--locally produced systems that are installed and operated by local villagers at a low cost per delivered kilowatt;
- micro-hydro mills in Nepal--locally produced units that are sold to local entrepreneurs as multipurpose power units for operating grain grinders, rice dehullers and mustard oil expellers;
- biogas plants in Nepal--small-scale, locally designed

units that are being sold to households and entrepreneurs throughout Nepal to provide lighting and cooking fuel, and increasingly to power engines for running grain grinding mills and other rural industries;

- photovoltaic systems in India--small-scale systems for the provision of village lighting, TV and radio, and irrigation for high value crops.

Several of these technologies--especially the Nepalese micro-hydro mills and the Thai micro-hydroelectric systems--are already the systems of choice for consumers, if the resource base is available locally. Adoption of these successful technologies is often limited as much by access to credit and the availability of installation crews as by the acceptance of the technology itself.

In addition, the AID-supported RETs were found to have near-term possibilities for widespread dissemination or transfer to other interested Asian countries. These are:

- solar rice dryers in India;

- biomass gasifiers in the Philippines and Thailand;

- rice husk pyrolysis systems in Thailand; and

- wind water pumpers in the Philippines and Thailand.

It was also found that the various AID-sponsored renewable energy projects had significantly increased the institutional capabilities of the Asian countries visited for this assessment. The indigenous energy development and energy conservation programs of several of the key countries now have an internal dynamic of their own that will provide additional benefits from the use of RETs in the next decade. Core staffs of skilled system designers and installers have been created, partly through AID-funded training, and these energy specialists will now assist in the direction of future programs within the Asian region.

1.0 INTRODUCTION

Over the past decade, the U.S. Agency for International Development (AID) has provided funding and technical assistance for the development, testing and dissemination of a variety of alternative energy technologies in Asia. A number of these AID-sponsored projects are now complete or nearing completion, producing energy systems that have undergone a complete technology development and delivery process. This report is an assessment of the technical, economic and social performance of seven* of these renewable energy technologies (RETs), selected by the AID/Asia/EFE as representative of the progress and potential of such systems in Asia.

Field site visits were made to the Philippines, Thailand, Nepal and India to examine these seven AID-sponsored RET systems. They were evaluated according to a number of specific criteria, including: the value attached to the system output by prospective users; the quality and availability of the local resource base; the participation by end-users in system adaptation and/or construction; compatibility with local fabricating facilities; and cost relative to other currently available technologies that perform the same work.

Part I provides the results of this field evaluation. Section 2 examines the four AID-sponsored RETs selected as being ready for or already undergoing widespread dissemination, according to the pre-established criteria. These systems are: micro hydroelectric installations in Thailand; micro-hydro mills in Nepal; biogas plants in Nepal; and solar rice dryers in India. The current status of each technology is briefly described, along with the role that AID has played in its development. Section 2 also assesses for each system its potential impact in its country of origin and its applicability to the other nations of Asia. Several other technologies that have good near-term possibilities for widespread dissemination but are still encountering economic, technical or institutional difficulties are also briefly discussed in section 2. Part I then closes with an outline of several recent, interesting Asian RET developments not sponsored by AID but having implications for future AID energy programs.

Part II presents case studies for the seven renewable energy systems examined in the Philippines, Thailand, Nepal and India. For each country and each technology, the host-country context, site selection process, and the technology/system selection and

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*The seven systems examined are: biomass gasifiers and wind water pumpers in the Philippines; micro hydroelectric generators in Thailand; biogas plants and micro-hydro mills in Nepal; and solar rice dryers and solar concentrating collectors in India.

design process are presented, along with any information on the involvement of local and private-sector participants. The technical monitoring and data collection system is explained for each technology. The economic, technical and social performance of each system in its country context are then analyzed, along with the comparative economic performance of the unit versus grid electricity and/or stand-alone diesel generators. Lastly, the potential widespread replication of each of the seven technology/end-use application pairings is examined, both for the country of origin and for the other nations in Asia.

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PART I

The Impact of the AID Renewable Energy Technology Program

2.0 AID-SUPPORTED RENEWABLE ENERGY TECHNOLOGY DEVELOPMENT AND TESTING IN ASIA

Over the past decade, AID has provided more than 100 million dollars to help the nations of Asia develop, modify and install a wide range of alternative energy technologies. The impetus for this activity was partially an agreement among the major OECD donor nations, as articulated at the Bonn summit in 1978, to give substantial emphasis within bilateral foreign assistance programs to testing and installation of renewable energy systems. In addition, Congress reinforced this policy direction through section 119 of the Foreign Assistance Act of 1978 which required that AID emphasize RETs whenever possible within the broader AID foreign assistance mandate. Thirdly, there was the perception by both Asian leaders and AID energy analysts that the price of fossil fuels would continue to rise, with $40 per barrel being a standard planning figure used in project development in the 1979-81 period. AID's Asia Bureau and the individual country missions responded with two groups of renewable energy projects. The first set was launched between 1977 and 1979 and included: the Technologies for the Rural Poor Project in India (1978); the Appropriate Technology Project in Indonesia (not reviewed during this field assessment); the Philippines Non-Conventional Energy Development Project (1978); and the Thailand Renewable and Non-Conventional Energy Project (1979). Most of these projects are now completed or are near completion. More recently, the AID Asia Bureau has launched a second set of renewable energy initiatives, including the Pakistan Energy Planning and Development Project, the Philippines Rural Energy Project, the Indonesian Puspitek Research and Development Center, and the Second ASEAN Cooperative Program in Energy.

The range of technologies in these AID-sponsored programs has been exceptionally broad, in keeping with the array of physical and manpower resources, current energy consumption patterns, and national development plans of the countries that make up the Asian community. An incomplete but instructive list of technologies that AID has helped develop in Asia includes: solar water heaters; solar crop dryers; solar line-focus and point-focus concentrators; anaerobic digesters; biomass gasifiers; biomass pyrolysis units; biomass direct combustion units; wind water pumpers; micro and mini hydroelectric generators; low-cost cookstoves; and agricultural waste-fired process heat boilers. Countries cooperating actively with AID on RET development have also benefited from major manpower training and institutional development programs that are normally a central part of the energy research and development pro ects. AID has supported at least one large RET program (and in many cases two or three) in Thailand, the Philippines, Indonesia, India, Bangladesh, Nepal, and Pakistan. Through the umbrella of the Association of Southeast Asian Nations (ASEAN), AID provides technical assistance on RETs and energy conservation to Singapore and Malaysia.

Many of these programs have now been underway for a number of years. Skilled and experienced staffs have been created in energy development and research institutions that AID helped to build. The national programs in key countries, such as India, Thailand, and the Philippines, have taken on lives of their own, independent of AID funding. National centers of excellence in research for various aspects of the renewable technologies have been established, and some countries have begun major subsidy or tax credit programs as a "demand-pull" strategy for commercialization of key RETs. For example, India's Department of Non-Conventional Energy Sources (DNES) funded 138 separate RET research programs in 1984. DNES is also administering a number of national subsidy programs, including one to provide subsidies of 50 to 100 percent to purchasers of improved cooking stoves. Current plans are for subsidies for 500,000 stoves during the two years ending in late 1985.

In the following sections, we will examine a select number of the AID-supported programs in the Philippines, Thailand, Nepal, and India. The effort will be to examine each technology in its economic, social, and institutional context, so that common factors leading to successful widespread use of renewable energy technologies can be isolated and examined. In addition, the potential application of the technology development and adaptation process (and the technologies themselves) to other countries will be examined. AID has helped develop a number of highly useful RET systems that are now being commercialized, and these mature RET systems may well have a major potential for other countries with similar energy needs and resource bases.

2.1 The Asian Context

RET development has three natural advantages in the Asian setting: a large pool of skilled manpower in both the research and manufacturing sector; sophisticated and vibrant private sectors that can both build and maintain virtually any type of RET equipment; and a government commitment to reduce imports of fossil fuels in the near future through aggressive national energy conservation and production programs. We will briefly consider the implications of each of these factors before turning to an examination of the resource bases that can be exploited for renewable energy production.

2.1.1 Skilled Manpower Pool

All four of the countries being examined in this study have high levels of basic literacy, universal education (usually through the 6th or 12th grade), world-calibre technical universities, and major government-funded energy research and development centers. This large pool of trained scientists, technicians and mechanics has two reinforcing positive impacts on the rapid development of renewable energy technologies. First, technologies are often conceived and designed locally, rather than initially imported. With a pre-existing reservoir of skilled engineers, most of the countries of Asia have been able to absorb training funded by AID through U.S. institutions in renewable energy system design and sizing and immediately moved to system fabrication and testing. In certain cases, such as the Philippine gasifier program and the Thai small-scale hydroelectric program, the local systems evolved ahead of any U.S.-based counterparts, partly due to the excellent local resource base and partly because of strong local political support.

Equally important, there is a strong reservoir of mechanical skills throughout many Asian rural market centers and even in smaller villages. Farmers are familiar with machinery and how to repair it. There are nearby car, truck, tractor and pump repair services. Some spare parts are available on the local market or through local distributors. While the local skill levels are still much lower than would be found in rural areas of the United States or Canada, they are quite advanced compared with those found in the rural areas of the rest of the developing world. Relatively complex technologies, such as solar concentrating collector systems, biomass gasifiers coupled to diesels, or micro-hydro driven mills can be field-tested and introduced to local users with little difficulty, provided that enough initial training is provided and that major emphasis is laid on preventative maintenance, stockpiling of spare parts, and system troubleshooting. Familiarity with existing machinery makes it easier for Asian rural villagers to accept and operate new RETs.

2.1.2 Private-Sector Sophistication

In the four countries visited for this study, there are strong machinery fabrication and production sectors. Even Nepal, which is considerably less advanced than the other three countries, is able to produce whole RET systems, using some imported components. Thailand and India have very advanced manufacturing sectors, currently producing commodities ranging from computers to large-scale electrical substations. Contractors are able to do sophisticated machining and fabrication work, to world-standard tolerances, from blueprints to final simulation tests. For example, both India and Thailand have existing private manufacturing facilities that produce a variety of high-performance Pelton and Francis turbines.

Not only is it relatively simple to get prototype RET units built locally, but local manufacturers have the facilities to build systems in commercial quantities if they feel that the demand warrants the tooling and set-up costs. Private-sector firms have even taken the initiative to design and test prototype

RETs for direct private sales. One Thai machine shop, for example, designed and built several successful prototype gasifiers, using only sketches and photographs provided by a visitor. One Indian machine shop set up an assembly line for metal stove production, using blueprints provided by a nearby research facility. Because these fabricating firms already possess various metal forming, shaping, bending, casting, drilling and polishing equipment, they can readily undertake new assignments such as building RETs from scratch.

In certain sectors in Asia, the skills available in the private or parastatal sectors are very advanced. In designing the ribs for solar trough concentrating collectors, for example, scientists at the Indian Institute of Science were able to have the drilling or nibbling of the metal done by numerically controlled drilling machines. Similarly, researchers in many countries in Asia can have custom circuit boards or logic circuits built by local firms for control boards or data acquisition units. This level of sophistication means that the RET designer is not limited by the resources at his or her disposal, but only by what appears to be economically and mechanically feasible. This fact alone makes the design process far different from that in Africa, where the shortage of many materials and skills shapes the entire technology design and adaptation process.

2.1.3 Government Commitment to Reducing Fossil Fuel Imports

In India, Nepal, Thailand, and the Philippines, limiting the use of imported oil, coal, and natural gas are major national priorities. All have launched major programs to increase production of domestic fossil fuels (principally natural gas and coal), increase hydroelectrical power generation, increase use of non-conventional fuels, and conserve energy in the government and industrial sectors. Since renewable energy projects are strongly backed by their respective governments, they have access to scarce local investment funds. AID funds are matched by local commitments not just of labor but of materials, facilities, and senior scientific talent. Local industries and parastatals cooperate readily with demonstration projects, partly because of the high visibility and national emphasis on RETs. High-quality scientists are attracted to the national RET programs, which leads to a higher quality technology development, testing and adaptation process. As much as any other factor, it is the consistent national commitments of the Asian countries cooperating with AID on RETs that has led to much of the progress outlined in the sections that follow.

2.2 The Market-Readiness of RETs in Asia

Market-readiness of any set of technologies can be determined only by using two different sets of criteria:

- the cost-competitiveness of the systems versus current technologies for providing the same work, and

- the reliability, durability, and commercial availability of the units.

Using either set of criteria, renewable energy technologies have a bright future in most of Asia.

Energy, led by liquid fossil fuels and electricity, has grown dramatically more expensive over the past decade, partly due to escalations in the price of petroleum and partly due to government initiatives to remove energy price subsidies (especially for diesel fuel, kerosene and electricity). At the same time, most Asian governments have made strong commitments to providing electrical services to most of their major villages by the end of the decade. Because of the low initial load factors in rural areas, the cost of extending existing electrical grids for each kilowatt of consumption is often exceedingly high. Where the local load is relatively small and located more than a few kilometers from the existing power grid, RETs such as mirco-hydroelectric systems may be the low-cost option for the provision of electricity. Similarly, RETs may be an inexpensive solution for the provision of small increments of shaft power for water-lifting at remote sites, as has already been proved by the market acceptance of systems such as the Nepali biogas-powered grinding mills and small wind pumpers in the Philippines and Thailand. In most of Asia, unlike other parts of the developing world, renewable resources such as flowing water, solar insolation and biomass fuels are relatively abundant, although they may not be readily found at any given proposed installation.

The question of proven field performance, reliability and durability are very much specific to a given country and technology. As can be seen from a number of the case studies in Part II, many of the technologies that have been central to the USAID-sponsored RET testing and transfer project have demonstrated good field performance, with little or no unexpected downtime so long as the routine maintenance requirements are carried out. Photovoltaic systems, wind water pumpers and micro-hydro units in particular are now commercial products, sold by a variety of indigenous and foreign firms on a turnkey basis. Mirco-hydroelectric and hydro mills are produced in several of the Asian countries visited for this study (Nepal, Thailand and India) and are already being exported to other countries on a trial basis. Thousands of biogas plants have been successfully installed in a number of Asian countries, but the designs are still evolving in an effort to reduce costs or increase gas output per unit volume. Biomass gasifiers are also still being modified, both to meet newly identified markets for industrial process heat and to resolve operating problems encountered to the broad-based technology dissemination programs in the Philippines.

Solar thermal systems are commercial in most of the Asian countries for residential and commercial water heating, but still are in the field-testing and demonstration stages for agricultural process heat and power-generation applications.

2.3 AID-Supported RETs Ready for or Undergoing Widespread Dissemination

Of the technologies examined in the course of the field work for this study, we have selected four as examples of successful technology development. All four are ready for widespread commercial use, and two (Nepalese micro-hydro and biogas units) are already in commercial production. While the units vary widely in complexity and cost, all of these systems share a number of common characteristics which can be summarized in the following five points:

- high value attached to system output -- in every instance, local users are either now paying for a similar service or are willing to expend time and resources to get the end product produced by this RET;
- participation by end-users in system adaptation or construction -- the individuals or firms that are potential users of this RET played important roles in the design and adaptation of the original prototypes to make them more useful and acceptable;
- good local resource base -- all the successful Asian RET units draw upon a strong local physical resource (falling water, sunshine), and indeed may be a modern, efficient adaptation of a traditional way of using that resource base;
- compatibility with existing local fabricating facilities -- all of the most successful RETs developed with AID assistance are built or can be built with local skills, using production techniques which are well known to local artisans and entrepreneurs;
- relatively inexpensive when compared with other methods available for doing the same work -- the most successful RETs either displace an expensive common fuel (kerosene or diesel) or provide a service such as electricity at a lower cost than the commercially available alternatives.

Each of the individual technologies will be examined in depth in the country case studies contained in Part II. Therefore, the remainder of this section will outline in brief the current status of each of the most successful of the Asian RETs examined, its potential impact within the country, and its possibile utility in other AID-supported developing nations.

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2.3.1 Micro Hydroelectric Units in Thailand

Since 1979, the National Energy Administration (NEA) of the government of Thailand has launched an ambitious program for the development and installation of locally manufactured micro [0-100 kW(e)] and mini [100-6,000 kW(e)] hydroelectric power systems. The mini-hydro units were designed to be stand-alone village power systems, while the micro-hydro units were normally to be grid-interconnected. Starting with a 7 kW(e) unit in cross-flow turbine, NEA installed 15 locally built cross-flow and micro Pelton turbines by October of 1984, had 10 more units under construction, and has 20 pending requests for systems that it hopes to install by the end of 1986. AID provided grant funding for four of these installations under the Renewable and Non-Conventional Energy Project and one under the Mae Chaen Watershed Development Project. Under a project just initiated, AID is also providing technical assistance and loan funding for several larger installations under the Micro/Mini Hydroelectric Project.

The NEA micro-hydro program is part of a national effort by the government of Thailand to extend electrical services to most of the major villages in the country by 1988. NEA has targeted those villages that have access to good stream flows but are too remote to qualify for grid extension by the Provincial Electricity Authority. NEA initially started out with streamflow data and meteorological data (it has historical data for 100 streamflow and 150 meteorological stations), village-level demographic data, and transportation maps to locate villages of interest. Site visits and preliminary layouts were done to find the sites with the highest benefit/cost ratios. For each prospective site, an analysis is done of the estimated cost of the micro-hydro unit vs. grid extension and installation of stand-alone diesel, to make certain that the micro-hydro system is the least costly approach.

The NEA micro-hydro program has been a success from virtually any point of view. The systems installed have provided small increments of power at a low cost per installed kilowatt ($1000-$4300 per kW) in very difficult and inaccessible sites. The systems have proven to be relatively trouble free in operation and simple to install (generally four to five months is sufficient for system installation of the penstock, headrace, power house, turbine, and distribution network, including household hookups).

One way that NEA has managed to keep its cost low has been to insist on a major contribution of labor and materials from the local village in order to receive the turbine. The villagers form an association to manage the installation (and subsequent collection of electricity fees) and are responsible for all the installation work. NEA provides one engineer to supervise the major hardware components and the system design. The villagers do all of the site preparation (building flumes, digging channels for the penstocks, building the power house, stringing the electrical lines) in exchange for an equity share in the finished power station. It is clear that the electricity is highly valued by the villagers. They not only provide all of this labor (10,500 person-days in the case of one 20 kW(e) unit with a 55-meter head) as well as all the local building materials, but they also collect a charge of 8.5 to 10 cents (U.S.)/kilowatt from all the participating village users.

The NEA has been careful to develop a system that is first and foremost inexpensive and reliable. At the same time, they have sought to minimize the number of imported parts, with the ultimate objective of producing in-country an array of commercial small-power units. NEA developed in-house, based on a design from the Intermediate Technology Development Group, a low-cost electronic controller to replace the hydraulic or electro-hydraulic governors traditionally used in hydroelectric installations. NEA also provided technical assistance to several Thai manufacturers to enable them to successfully fabricate high-quality cross-flow and Pelton turbines.

It is expected that the NEA small-scale hydroelectric program will have a major impact on the development of the rural areas of northwestern and southern Thailand. There is an estimated 200 mW(e) of sites that are suitable for development only by micro-hydro and that are remote from planned grid extension programs. If the NEA is able to install the 50 units that it has targeted for the period 1982-1986, it will provide electricity services to 25,000-40,000 villagers at a cost of between $250 and $400 per person. In addition, the mini-hydro program now underway is expected to install six larger units--two over 1 mW(e), but mostly in the 200-400 kW(e) range--while building a capacity within the Thai private sector to build complete units up to 500 kW(e). It is also possible that the Thai private sector will begin to export one or more of these models to interested buyers in Southeast Asia, if NEA decides to allow them to export the NEA electronic governor/speed controller.

The NEA micro hydroelectric technology, along with its concurrent village involvement program, has a wide application throughout those portions of the developing world with year-round streams with heads over 10 meters. The technology is simple and rugged, and could be built by private firms throughout Asia or Latin America with a modest amount of metal machining or casting expertise. Companies that are already in the pump fabrication business are ideal candidates for turbine manufacture. Involving the village in the construction of the system and in the collection of the stream of revenues from the electricity sales both lowers the installed cost and reduces the administrative problems that often plague rural electrification programs. The cooperative also insures that the system is properly maintained and operated. Lastly, the village cooperative can serve as a nexus for other development activities. Since the cooperative generates a small revenue stream for the village, it can be used to promote other village improvements (schools, health clinics, etc).

2.3.2 Micro-Hydro Mills in Nepal

Prior to the early 1970s, Nepal had a tradition of wooden "ghattas" or water-driven grinding wheels. It is estimated that there are still 25,000 such small units in operation, using water carried through a wooden flume or channel to produce about one horsepower of shaft power to turn a large horizontal grinding stone. With the encouragement of a number of donors, including AID, Swiss Association for Technical Assistance, the United Mission to Nepal, and the Asian Development Bank, a number of small private entrepreneurs are now producing modern, efficient versions of the traditional design. These systems produce from 3 to 10 HP of shaft power, which is commonly used as a multi-purpose processing unit (MPPU). Various agricultural process devices can be attached singly or simultaneously to the power take-off. The most common package is a grain grinder, a rice huller, and a mustard oil expeller. A small electrical generator may be installed as well for use by the miller and his immediate neighbors.

The Nepalese modern water mill is largely a commercial venture. There are at least four producers of water turbines used for agricultural processing, with the largest one producing and installing 50 to 60 units per year. Virtually all of these units are financed under credit provided by the government's Agricultural Development Bank of Nepal (ADBN). The ADBN provides five- to seven-year loans, at 12 percent interest, to farmers or entrepreneurs interested in purchasing a turbine and the associated processing equipment. Generally, the total investment by the farmer is 50,000 to 75,000 Nepalese rupees (approximately US$2,800-$4,300). Because the units compete directly against high-cost diesel units, operating them is quite profitable, and the initial loan can generally be paid back in two to four years. While nationwide figures on installations are not kept, it is estimated that 100 to 200 units were installed in 1984, and the 1985 figures will be considerably higher.

AID was successful in accelerating the acceptance of the modern water mill in the western region of Nepal. Under the Rapti Zone Development Project, the technical staff funded by AID at the Appropriate Technology Unit (ATU) in Tulsipur worked with local farmers and the ADBN to speed the process of procuring and installing agricultural processing turbines. Between late 1981 and July 25, 1984, the ATU provided 71 feasibility studies for turbines and prepared designs and quotations on 51 of these sites. As of mid-1984, 25 units had been installed by the manufacturers, two were under construction, and 14 additional loan applications were being processed.

The micro-hydro milling program has been remarkably successful. The systems are being installed virtually without subsidy, other than the initial consulting services provided to the farmers prior to their agreeing to the installation and filing for the loan. Each installation creates a small village industry, generally provides agricultural processing services to local farmers for under the rate charged by nearby diesel mills, and reduces consumption of imported diesel fuel. The units are low in cost, locally made, and rugged in design. Because they are shaft-power units rather than electricity units, they do not require governors or elaborate water-control devices. The water that is used for the turbines is often diverted from an irrigation channel and is returned to irrigation below the water turbine installation.

The Nepalese water turbine program could be easily replicated in the mountainous regions of Thailand, India, and perhaps the Philippines. While the road and electricity infrastructure in these other countries is much better than in Nepal, the cost of agricultural processing is still high and the distances to be traveled to market are often great. Small turbines that could process three or more crops per year would be good investments for individual entrepreneurs, providing that reasonable credit is available through local agricultural development banks. The turbines are easily built and transported. The real uncertainty is whether there would be low-cost, small-scale grinding, milling and processing equipment that could be attached by belt to the turbines. Sites where good all-season water flows could be easily diverted to the mill would also have to be located, in order to keep down the investment cost of the overall installation.

One of the most attractive features of the Nepalese water mill is that it generates local income immediately, enabling the individual or community to repay the initial capital investment quickly. Unlike many rural electrification schemes, where the load factor is often only eight to 15 percent for the first five years of the installation, the water mill will be fully utilized for 12 to 16 hours per day as soon as the local operators are trained. The money received by the government from the repayment of the loan (which in the case of the ADBN includes market rates of interest) can be used to make additional loans, so that a one-time infusion of loan money becomes a revolving fund for the extension of credit to interested entrepreneurs and community organizations.

The role of the lender is crucial to the success of the Nepalese micro-hydro mill program. Because the active participation of the ADBN is crucial to the commercial success of the existing mill manufacturers and, indeed, their very existence, it can demand limited performance warranties as a condition of the loan. Because the ADBN has offices scattered throughout the rural parts of the country, it can promote the concept of the micro-hydro mill to progressive farmers and entrepreneurs, and then act as an intermediary between the farmer and the manufacturers to arrange satisfactory contract terms. Lastly, the ADBN has a vested interest (in the form of equity capital) in making certain that the mills are operating and producing a steady income stream for the owner. If there are operating problems, the ADBN can contact the manufacturer for technical assistance. If the owner is having managerial problems, the ADBN can provide limited small business assistance. However, little assistance of this type appears to be needed. As long as the mill is sited at a location with sufficient waterflow and a substantial production of grains within a one- to two-day walk, the economic return should be quite favorable.

2.3.3 Biogas Plants in Nepal

There are currently more than 1,400 biogas plants installed in Nepal, and 300 more units are expected to be installed in 1985. Like the micro-hydro mills discussed in section 2.2.2, most of these units are financed by the ADBN under loans to the individual users. AID has been active in promoting the use of this technology, both through the work of the technical staff of the ATU in Tulsipur under the Rapti Zone Development Project and through direct grants to community organizations in the Resource Conservation and Utilization Project (RCUP). The principal mechanism for the biogas plant installations has been the Biogas and Agricultural Equipment Development Company (more commonly known as the Gobar Gas Company). The Gobar Gas Company, jointly funded by the ADBN, the United Mission to Nepal, and the Nepal Fuel Corporation, installs 250 to 300 units per year through its 11 branch offices. While most of its initial installations were Indian-designed floating-metal gas holder, currently all of the smaller units are Chinese fixed-dome concrete units which are built on-site. The standard family-size units built by the Gobar Gas Company cost from 10,000 to 25,000 rupees each (US$600 to $1500), including installation and a seven-year performance warranty.

AID's technical and financial assistance has helped to lower the cost of new biogas plants being installed, as well as assist the Gobar Gas Company and the ADBN in popularizing the technology. The AID-sponsored ATU has developed and field-tested several low-cost digesters, and has encouraged local entrepreneurs to enter into commercial production to build and install them. The ATU's tunnel digester costs only 25 to 35 percent of the comparably sized Chinese dome system (primarily because of the elimination of the expensive imported cement) and has similar performance. Ten of these units have been installed thus far, and the Gobar Gas Company is considering adapting this design or another, slightly more expensive ATU design (a brick arch design) for widespread commercialization. In addition, the ATU staff, together with the ADBN and the Gobar Gas Company, promoted the biogas plant technology throughout the Rapti Zone. Eighty-eight small and medium-size plants were built by the Gobar Gas Company in the Rapti Zone as the result of ATU assistance and financing.

The Nepalese biogas plant is marginally commercial at the present time. While there is continued interest in the plants, and the systems are sold under ADBN financing, the Gobar Gas Company operates at a loss, due primarily to the expenses caused by its seven-year performance guarantee. While the units are promoted as a fuelwood substitute, they are most valued for the high quality of the light that the biogas lamps produce. The biogas lamps displace expensive imported kerosene directly, whereas cooking uses fuelwood which is often gathered rather than purchased. However, the economic viability of the biogas plant changes drastically if it is used to generate income. There have been 15 to 20 installations of biogas plants for the powering of agricultural processing mills. Like the micro-hydro mills, the biogas mill produces shaft power. The biogas is fed to a diesel engine, which operates on biogas/diesel mix. Grinding, milling, or oil expelling machines are attached to the diesel engine by belts. When the biogas is exhausted, the mill can continue to operate on 100 percent diesel fuel, if needed. For locations without a good micro-hydro capability, the biogas-powered mill is an excellent power source. It produces income for repaying the ADBN biogas plant loan, so that less wealthy farmers and entrepreneurs can qualify for the loans and increase their living standards. Based on the information received from several operators in the Pokhara region, the biogas plants pay for themselves through the reduction in diesel consumption and through the total displacement of kerosene for household and shop lighting.

The Nepalese biogas program is a major national effort. The Biogas and Agricultural Equipment Development Company has a large staff (approximately 140 full-time employees) and a dispersed set of field operations because of the difficulties of moving material and supplies over Nepal's very limited road system. Such a national program could be duplicated in other countries that have substantial rural animal populations, providing that low-cost designs are used and that ample credit is available for the purchasers. However, using the biogas plants as power sources, rather than just for cooking and lighting, will greatly broaden the appeal of the units. It would seem particularly appropriate in countries that already have large numbers of small stationary diesel engines used for applications such as water pumping, grinding, milling, rice dehulling, etc.

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2.3.4 Solar Rice Dryers in India

The drying of rice, both for grain and seed storage at the farm level and as part of the dehulling and grain milling process at commercial mills, has always been a major rural problem in India and other Southeast Asian countries. With the advent of double and triple cropping of miracle rices, the problem has become more pronounced, since now the drying of at least one crop has to be done at the beginning of the monsoon rains. The ground is wet, and intermittent showers greatly increase the chance of spoilage if the rice crop is spread out on the ground to dry. Rice retained for personal use or for seed grain by the farmer is normally dried to 12-14 percent, while rice sold to rice mills is dried only slightly (to 17-19 percent) on-farm. The rice mill then dries it to the desired moisture content for milling. In areas where parboiling is common, the rice is dried twice by the mill operator before dehulling.

With AID technical and financial assistance, Annamalai University has developed rice drying techniques for both small farmers and medium-scale (10 ton/day) rice mills. The 1.75 ton/day commercial-scale solar dryers have proven to be both technically successful, producing rice with the right moisture content within the time constraints of the participating rice mill, and also economically attractive. A one-HP blower and a large low-temperature mild steel, wood and polyethylene collector provides 45 to 55°C air to a vertical cylindrical dryer. Operated for 250 or more days per year in a typical southern Indian rice mill, the Annamalai University dryer will increase the market value of the rice being milled, save on labor costs and reduce the amount of land required for the drying facility.

The Annamalai University and local agricultural extension agents have also been working with Tamil Nadu farmers to develop very low-cost systems that will substitute directly for open air drying. Using black and clear polyethylene sheets and rice hulls for insulation, they were able to double the efficiency of open air drying, lower the drying time to less than a day, and provide protection to the rice from both the wet ground and from sudden rain showers.

The Annamalai University designs have proven to be very successful. Based on the results of the pilot installation at a Tamil Nadu state-owned rice mill, the government of India is considering five or more additional installations in the other major rice-producing regions of the country. Building larger production models and equipping them with rice husk-fired auxiliary burners is also being explored.

The Indian industrial-scale solar rice dryer has great potential for widespread dissemination and commercial production in India and in other major rice-producing regions in Asia. India has over 300,000 rice mills, and countries such as Thailand have over 40,000 mills currently in operation. The vast majority of these mills are small, making them likely candidates for low-cost, medium-capacity drying systems. The solar rice mills can be easily adapted in size and output in order to match the scale of local operations, and can be installed in series for larger mills. The mill operators that have examined the pilot installations are eager to purchase one or more models. The questions that have yet to be answered are: Can the output of the system be increased by coupling it to a rice husk burner, and is this increased productivity worth the additional investment cost? Can the electrical or diesel-powered blower be replaced by a low-cost biogas or rice husk-fueled engine? Can the system be adapted for mass production either by firms that are currently supplying equipment to rice mills or by existing Indian renewable energy production groups?

It is too early to determine if the low-cost, small-farmer rice-drying techniques developed by Annamalai University staff will have widespread application in the rest of India and in Southeast Asia. It will depend on the efficiency of current open air drying methods, the crop losses from spoilage, insect infestation, birds, etc. The local cost and convenience of the simple polyethylene sheet dryers will be the most important factors in determining whether a given group of farmers adopts and adapts these new South Indian drying techniques.

2.4 AID-Supported RETs with Near-Term Possibilities for Widespread Dissemination or Transfer to Other Asian Countries

Over the past six years, AID has participated in the development and testing of a number of small energy systems which have proved reliable and effective, but which are not yet fully ready for commercialization. In some cases, the first systems are simply too expensive, largely due to one-time engineering costs or custom fabrications. In other cases, there were problems in system operation and maintenance which were partly institutional, rather than technological in nature. In one or two of these instances, the local resource base proved to be either insufficient or too expensive to support a major dissemination program, but the same technology might be readily applicable in other locations.

In the following section, we will describe in one or two paragraphs each of four RETs that may warrant further adaptation, testing and development to determine conclusively whether the technology can be broadly adopted on a commercial basis.

2.4.1 Biomass Gasifiers in the Philippines and Thailand

In the past year, there have been a number of negative reports by AID and Philippine government agencies on the field performance of the AID-financed GEMCOR charcoal gasifiers. A recent survey found that over 70 percent of the irrigation pumping gasifier sets were not operating. The major problems listed by the field investigation staffs are detailed in section 3.7.1. However, it is important to note that <u>only one of the key problems is technological in nature:</u> insufficient cooling and cleaning of the gas on early production models. The 1984 wet cleaning system has largely eliminated this problem. The other problems are due to sudden changes in relative fuel prices (a 300 to 400 percent rise in Philippine charcoal prices between 1981 and 1984), to poor matching of the gasifiers to the existing diesel engines, to inadequate training of operators, and to a chronic lack of spare parts and follow-up service. The shifting cost of charcoal is an exogenous variable that could not be predicted and is largely unique to the Philippines. Other Southeast Asian nations such as Thailand and Malaysia have not seen such radical price shifts in the same time period. The other problems are institutional, due to the speed with which the gasifier program was developed, poor quality control, and deteriorating Philippine national finances. The same technology, if transferred to other countries and carefully developed in a less frenzied program, appears to have a widespread applicability for remote power systems. This is particularly true if the technology could be run on fuels such as firewood and rice hulls, rather than charcoal, since the economic returns would be far better and the fuel supply would be subject to far less disruption.

2.4.2 Rice Husk Pyrolysis in Thailand

Rice husks are the major underutilized agricultural residue in most of South and Southeast Asia. Because of the high silica content of the rice husk, it has only limited application as an animal feed or as a soil conditioner. Larger rice mills use the husk as boiler fuel for power generation, but this still only consumes 20 to 25 percent of the husk produced by the milling. Small mills cannot afford the capital investment of the boiler, so they use diesel or electrically powered milling machines. As a result, rice husks have become a major disposal problem for small and large rice mills alike in Asia. In Thailand alone, nearly 40,000 mills generate 4,540,000 tons of rice husk per year, of which only 700,000 tons are used for fuel. AID provided support, through the Renewable Non-Conventional Energy Project, to the Thailand Institute of Scientific and Technological Research (TISTR) to develop a rice husk pyrolysis unit.

Demonstration units have been operated successfully at two local rice mills, and a number of mill operators have expressed interest in procuring similar systems to couple to existing diesel engine-generator sets. But the technology needs market-oriented adaptation and development before it can be broadly disseminated and commercially manufactured. The systems devised by the TISTR scientists are too complex and costly. Simpler and less expensive cleaning systems, along with an optimization of the product output for gas rather than char production would greatly enhance the range of commercial applications. With a small number of country-specific modifications, the technology would appear to be appropriate for other major rice-producing countries such as India, Nepal, and possibly the Philippines.

2.4.3 Wind Waterpumpers in the Philippines and Thailand

There are commercial producers of wind-powered water pumping machines in both Thailand and the Philippines. Based on the limited information collected during this short visit, these units or similar designs appear to have immediate, cost-effective applications in a number of rural areas within those two countries and in nearby Asian nations for domestic drinking water supply, livestock watering, and low-lift irrigation. Widespread dissemination appears to be hampered at the moment by the low efficiency of the units, the lack of readily available credit, and shortages of spare parts. A modest amount of technical assistance, coupled with one or more revolving credit programs such as those used in Nepal to finance biogas plans and micro-hydro mills, might be able to solve these problems in the near future.

2.4.4 Photovoltaic Systems in India

The government of India (GOI) has embarked on an ambitious program for the production, installation and field testing of photovoltaic (PV) cells for a variety of stand-alone applications. India currently has a local capacity for producing 250 to 300 kilowatts (or 10,000 modules at 30 watts each) of PV cells per year, and plans are for this production to reach one megawatt per year in the next 24 months. Applications that are being field tested include water pumping systems, lighting systems, community TV and radio sets, power supplies for micro-wave repeater stations, oil platforms, ship navigational aids, battery charging, and cathodic protection of oil pipelines. A number of these application areas are already commercial in India and elsewhere in Asia, particularly in the communications and telecommunications fields. It is expected that India's indigenous production will be insufficient to meet just these commercial demands (to include purchases by governmental and parastatal agencies) for the next several years.

For rural development purposes, AID and the Indian Department of Non-Conventional Energy Sources have jointly funded the installation of community radio and TV installations, street lighting, and micro-irrigation units at the Salojipally village energy center. These have proved to be very popular and completely trouble free. The village TV enables villagers to watch local language agricultural extension and health programs and have provided a focal point for other community activities. Partly as the result of three years of operating experience with the radio/TV installation and more than a year of operation of street lighting units at Salojipally, the GOI has installed lighting and TV systems in Andhra Pradesh, West Bengal, Rajasthan, Delhi, Kashmir and Tripura. Similarly, two small PV irrigation systems are operating satisfactorily at the Salojipally site, and a large system was soon to be installed. While the systems were not producing as much water as they might have because of the use of relatively inefficient (but locally produced) pumps, their operation has been continuous since the time of installation. Little or no maintenance is required, other than a periodic cleaning of the PV array surfaces to remove dust, and the output of the systems is greatest on those bright, sunny days when the crops require the most water due to increased transpiration.

2.5 Other Asian RET Developments Worth Noting

The national RET programs of several Asian countries have begun to test and market a number of units which appear to have widespread applicability. Although not funded by AID, these RET systems are worth noting as models for future AID programs in Asia and elsewhere. Briefly, these include:

- Low-cost mass-production metal cookstoves in India -- Costing from three to seven dollars (U.S.) depending on size, these standard design units have been licensed to more than 20 commercial metal fabricating firms throughout India. The production goal for 1984 through 1986 is 400,000 units.

- Photovoltaic cell production in India -- India has two commercial production lines, with an estimated capacity of single-cell crystalline PV cells of 300 kilowatts in 1984 and 1.5 MW(e) by the end of 1986. While the initial plan is for all of this output to be used within India, it appears likely that this large a productive capacity will lead to efforts to market PV arrays in other Asian countries within the next five years. The current cells being produced by the Central Electronics Laboratory have performance and durability characteristics similar to those of commercially produced first-generation PV cells.

- Rice husk-fired Sterling engines in Bangladesh and India -- Under funding from AID, a simple, low-cost Sterling engine was developed and successfully operated in

Bangladesh. Powered by the combustion of rice husks, it can be used to power various grinding, milling and dehulling machines in a rural rice mill. There is currently a joint venture by the U.S. developer and an Indian firm to build and market a larger version of this machine to rural rice mills and rural industry in India.

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PART II

Country Case Studies

3.0 PHILIPPINES

3.1 Host-Country Context

The development, testing and dissemination of renewable energy systems have a relatively long and complex historical context in the Philippines. Initially, small-scale experimentation was conducted at the University of the Philippines and other research facilities. In 1977, the Non-Conventional Energy Center (Non-Con Center) was created within the Bureau of Energy with a strong demonstration and promotional mandate from the highest levels of the government of the Philippines (GOP). The Non-Con Center undertook an ambitious program of testing and feasibility studies for a wide range of technologies, including solar water heaters, solar dryers, biomass gasifiers, wind water pumpers and photovoltaic (PV) water-pumping units, using financial support from the GOP, AID, and other major international donor agencies.

The technologies which proved promising in the laboratory or Non-Con Center were turned over to other government agencies or parastatal groups for field-testing and widespread dissemination. For example, the Farm Systems Development Corporation (FSDC), which was set up in 1975 to provide complete packages of agricultural services to newly formed rural farmer cooperatives, had a mandate to install and test water-lifting devices for rural villages. FSDC helps set up and organize the cooperatives, and then works with each group to introduce new high-yield plant species, irrigation schemes, fertilizers, cultivation and harvesting machines, and new farming practices. FSDC also serves as a credit source, lending the cooperatives money to buy equipment or make improvements, and then taking repayment over an extended period (six or more years) out of the increased farm income.

In 1979, FSDC installed five experimental biomass gasifiers on irrigation projects in Bulcan, using designs developed by Dr. Ibarra Cruz and his colleagues at the University of the Philippines. These units, ranging from 10 to 60 HP, proved satisfactory, so FSDC then set up 12 regional pilot projects. Twenty-five gasifiers were added to existing diesel engines that had been installed earlier by FSDC. In addition, FSDC began using funds from AID and technical expertise from the Non-Con Center to install simple wind water-lifting pumps at certain of the Baranguay Integrated Services Associations (village cooperatives of ISAs).

Satisfied with the results of the preliminary pilot field experiments, the GOP decided in March 1981 to set up a parastatal gasifier production firm called GEMCOR (the Gasifier Equipment Manufacturing Corporation). While six government agencies cooperated in GEMCOR's founding, it is seen primarily as the creation of FSDC and the Ministry of Human Settlements (headed by

Mrs. Marcos). Gasifier production began in November 1981. By mid-1982, it was estimated that GEMCOR would produce and install as many as 1,000 gasifiers per year for various applications--irrigation pumping, sationary power generation, and vehicular transport. Almost half of the initial output was to go to FSDC for ISA irrigation systems.

Since these ambitious projects were launched, a number of institutional changes have been made. Renewable energy activities, formerly under the Non-Con Center, have been split up among several government agencies. Dendrothermal (wood-fired) power plants and mini-hydro development have been taken over by the NEA. The Energy Research and Development Center (ERDC) was created, under the Philippine National Oil Company (PNOC), to undertake basic research and technology development for both renewable and fossil fuels, and now houses the Non-Con Center. The Bureau of Energy Development (BED), under the Ministry of Energy, funds energy technology development and testing at a number of institutions, including ERDC and the University of the Philippines.

While all this detail is not central to the understanding of the field performance of biomass gasifiers and wind water pumpers in the Philippines, it is important to note that internal incentives and imperatives of different institutions involved in the gasifier development process sometimes worked at cross purposes, to the detriment of the performance and durability of the technology. While this will be explained in detail in the sections on economic and technical performance, the example of biomass gasifier can be sketched out here. FSDC was under pressure to locate sites for gasifier units and to get them installed as rapidly as possible. With limited field expertise in the technology, FSDC developed a few standardized designs, even though there was a large variety of different diesel pump sets from a dozen or more manufacturers already installed in the various ISAs. GEMCOR was under pressure from FSDC and other implementing agencies to produce a low-cost unit and to build systems rapidly to meet production quotas. To keep costs low, GEMCOR tried to produce a few standardized designs and let FSDC and others undertake the system/load matching. Neither FSDC nor GEMCOR had an incentive to follow up on installed systems or to modify the designs to meet problems encountered in the field. The result was gasifiers that coupled well with certain diesels but not others and that were redesigned only after several years of production.

3.2 Site Selection Process

3.2.1 Gasifiers

In the case of the FSDC-funded gasifier installations, the initial set of sites considered included those local cooperatives that already had an existing ISA with a diesel irrigation pump set. In general, each ISA contained a group of small farms, located next to or near an all-season river with an overall pumping head requirement of not over five to six meters. There were several advantages to starting with existing ISAs: a pre-existing local organization with strong ties to FSDC; local experience with irrigation and water handling; and a local operator experienced in the operation and maintenance of a diesel engine and a suction pump. However, this approach neglected the search for locations where the replacement fuel (charcoal) was plentiful and cheap, and where diesel fuel was difficult to obtain. Also, not much attention was paid to local land availability for the planting of fast-growing trees for future charcoal production. FSDC had planned that five (later reduced to three) hectares of ipil-ipil would be planted for each gasifier installation, harvested on a four-year rotation, and converted to charcoal by the participating villagers. However, little or no planting took place, in part because villagers feel that land near irrigation schemes is too valuable for crops to be wasted on trees. In some cases, proximity to nearby industrial sites (particularly sugar cane processing) led to unexpected competition for charcoal as fuel prices rose between 1980 and 1984.

3.2.2 Windmills

The site selection process for the BED/FSDC windmill installation was dictated by wind availability and by local demand for water-lifting assistance. In most mountainous and seaside locations, the wind resource appears to be adequate for shallow, low-volume wind-pumping systems. In some cases, FSDC provided a water pumper unit to an existing ISA with another pumping system already in place. The diesel or gasifier was used for pumping of surface irrigation water, while the wind fanmill lifted drinking water from a dug well or borehole. In other cases, such as San Jose, the local political leaders actively sought out a windmill to power a new borehole to replace an older well that had become contaminated.

3.3 Technology and System Selection and Design Process

3.3.1 Gasifiers

The technology being used in the AID-sponsored irrigation programs was largely the result of indigenous Philippine research and development work. It was the success of the initial local, laboratory-scale units, combined with the national program to reduce use of diesel fuel in the wake of the 1979 oil price increases, that spurred the decision to field-test the units,

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run a national pilot-testing program, and move to full-scale production in the course of two years. While extensive basic technological development took place in the cooperating Philippine universities and research centers, these were still research prototypes. The technology modification and production engineering was done by GEMCOR staff in a very short period of time, while they were gearing up for commercial production. To simplify the task of developing production models, GEMCOR engineers settled on two standard designs, the IS-30 and IS-60 (roughly 30 and 60 HP respectively) for irrigation applications. There were also different models for Jeeps and trucks, small fishing boats, and stationary models for applications such as ice plants. With a guaranteed market for its initial production from the FSDC and other government agencies, there was no need to carefully survey the marketplace to see what size and models of diesel pumpsets were already in use. For provinces where the land area of the ISAs was small and the diesel pumpsets were modest in size, the two models available were unusually sufficient and provided good diesel displacement. For other provinces, the existing irrigation pumps were more normally 90-120 HP, so the gasifiers were undersized. This reduced their economic utility to these groups of farmers. More importantly, however, the standardized cleaning and cooling systems that were installed with the first generation of GEMCOR irrigation units were not sufficient for continuous operation such as is normal during the second rice planting and growing season. Diesel engines were damaged by the excess heat, tars, and particulates carried by the producer gas from the GEMCOR units. GEMCOR, faced with trying to meet unrealistic production schedules in its first two years of existence, was unable to devote scarce engineering manpower to designing new models or upgrading the existing cleaning systems.

It was only in 1984 that GEMCOR began installing improved "demister" cleaning systems on its irrigation models, more than two years after the initial "commercial" installations. These improved cleaning system (which use a fine mist of water diverted from irrigation water to both cool and clean the gas stream prior to its entry into the diesel engine) would have made the earlier models much more reliable and attractive, and would have spared many of the ISAs the damage that their expensive diesel pumpsets recieved from the GEMCOR units.

3.3.2 Wind Pumper's

The wind pumpers that were installed as part of the AID-supported Philippine Nonconventional Energy Development project are conventional, high-solidity, multi-blade fanmills. They were built in the Philippines, using designs borrowed with little modification from traditional U.S., Australian, and British farm

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wind pump designs. Each fanmill has six to 16 metal blades, with a rotor diameter of three to six meters, mounted on a conventional tower above an existing well or borehole. The rotary action of the spinning blades is translated into reciprocating vertical motion, which is transmitted to the pump by means of a sucker rod. The windmills are commercially produced and sold in the Philippines by at least three firms, using virtually all locally produced parts. In the case of the systems installed under AID sponsorship, the site selection, installation and trouble-shooting were done not by the manufacturers but by contractor crews operating under the supervision of FSDC staff. However, the FSDC staff appear to have had little or no role in the system design or adaptation, but simply to have installed off-the-shelf models, sized for local wind conditions and pumping heads.

3.4 Local and Private-Sector Involvement

3.4.1 Gasifiers

Gasifiers in the Philippines have been the exclusive reserve of the parastatal firm, GEMCOR. While GEMCOR operates as a private entity, it is believed to be losing money because of its low selling prices and the recurrent need to replace or modify installed units free of charge. There has been a consistent interest on the part of U.S.- and European-based gasifier firms to enter into the Philippine market, either with a wholly owned local subsidiary or on a joint venture with a Philippine firm, but none of these has yet come to fruition. Foreign firms have turned down requests by the Philippine government and Philippine firms to buy a single unit in the 150-300 HP range, since they rightfully fear that the unit will then be copied and sold locally, shutting out the market for future sales and perhaps even being exported to other Southeast Asian countries.

One interesting occurrence in late 1984 has been an increasing emphasis by GEMCOR management on commercial sales (i.e., sales to private firms rather than to sponsoring government agencies). There appears to be a strong demand for large direct-heat gasifier models, and GEMCOR is currently building several units. In these installations, the producer gas is fed directly into a boiler to produce processed heat or steam. Such installations are simple (since no cleaning system is required), efficient, and cost-effective (since they displace either imported bunker fuel oil or coal). In these markets, GEMCOR must compete against other well-known technologies: biomass direct-combustion boilers and fossil fuel boilers.

3.4.2 Wind Waterpumpers

As previously mentioned, windmills for various water-pumping applications are made and sold in the Philippines by several

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firms. It is not clear, from the limited documentation available, to what extent these systems were modified to meet local conditions, were wholesale adoptions of designs available from appropriate technology organizations (SWD in Holland, ITDG in England, VITA in the U.S.) or were borrowed from commercially available foreign models.

While windmills are locally produced, no figures are available on the magnitude of local sales or the percentage of total sales to government agencies (such as FSDC) rather than to private buyers.

3.5 Monitoring

In general, renewable energy systems in the Philippines have been well monitored in their initial laboratory tests and pilot field applications, but little or no data have been collected on the "commercial" installations. This is due in part to a lack of monitoring equipment as well as to the minimal training that local operators have received in the collection of operating data. Once systems are installed, the responsible government officials only come back to make major repairs, not to collect and analyze data.

However, the picture is better for systems funded by AID under the Non-Conventional Energy Development and the Rural Energy Development projects, in part because of the insistence of local AID officials that records of performance and problems be kept. Evidence of the data collection was found at most of the field sites visited, but there was not much analysis based on the historical information.

3.5.1 Gasifiers

There are three levels of monitoring that have taken place on the AID-sponsored GEMCOR gasifier installations. First, the AID Office of Capital Development (OCD) certifies that each FSDC system is installed and capable of being operated (not necessarily working) before FSDC is reimbursed for an installation. This means that an ODC field engineer visits the site and examines the system personally before the FSDC is repaid. Second, the local ISAs are required to keep daily records of simple operating information, such as number of hours of operation, consumption of charcoal and diesel, maintenance performed, etc. While the completeness of the data varies from ISA to ISA, there are considerable useful historical data, covering up to three years of operation, at a number of sites. Third, AID, together with the GOP Ministry of Human Settlements (MHS), began in early 1984 to systematically examine the FSDC gasifier installations. After receiving reports that many of the gasifiers were damaged or abandoned, teams of AID and GOP staff visited different regions to determine the actual status of the units and whether provision had been made for a sustainable local fuel supply. The results were very disappointing, as will be detailed in section 3.7.1 below, because very few of the installed units appeared to be working. One summary estimated that 169 of the 242 gasifiers installed by FSDC were not working as of May 1984. Equally important, only 95 woodlot sites had been established with fast-growing tree species, totalling only 148 hectares rather than the planned 750 (three hectares per gasifier). This monitoring (probably more accurately titled a performance audit) has led to a major debate within AID and within the GOP over the long-term viability and advisability of a major gasifier dissemination program.

3.5.2 Wind Waterpumpers

By December 1983, with technical assistance from the Bureau of Energy Development and financial assistance from AID, FSDC has installed 17 wind water pumpers throughout the Philippines. Many were located in mountainous or coastal regions of some of the smaller Philippine islands. As in the case of the gasifiers, the local operators were asked to keep daily logs of simple information, such as amount of water pumped (measured roughly as the level within the storage tank), windless days, and mechanical failures. These 108 were dutifully kept and were presented for inspection, although there was no sign that this valuable information had ever been collected or analyzed.

FSDC did not appear to have the mandate or institutional interest to do performance monitoring of these wind-pumper installations. This was a one-time nationwide experiment, which was then turned over to the local Baranguay governments for operation and maintenance. While BED was interested in the systems and has the in-house expertise to monitor field installations, it is not currently in its mandate to conduct historical data collection or analysis of systems previously installed.

3.6 Economic Analysis vs. Diesel and Grid Extension

The different applications of the wind-powered and gasifier-powered water-pumping units make it difficult to compare them directly or to use the same analytic techniques. Also, the sample of information that was available was very limited, based as it is on a few site visits. The gasifiers were used to directly displace diesel fuel in existing diesel irrigation pump sets. Thus, the economic calculation is based on the diesel fuel saved versus the cost of the charcoal consumed, the capital cost of the gasifier, and any other additional operation and maintenance costs attributable to the installation of the gasifier (including premature wear on the diesel pumpset).

In the case of the wind pumpers, windmills are largely used to provide drinking water or water for other communal village needs such as washing, for example. As such, they either replace hand pumps or, in rare instances, water which is trucked in or commercially sold. The wind waterpumper's value is measured by the savings of time and effort, in the case of hand pumps, or of money, where water is purchased, versus the initial capital cost and subsequent maintenance costs.

3.6.1 Gasifiers

To analyze the profitability of the FSDC gasifiers installed under the AID-funded Rural Eenrgy Development Project, it is necessary to have good information about fuel prices (both for charcoal and diesel) at any given point in time, as well as the number of hours that the gasifier pumping sets have actually been operated. Relative fuel costs have fluctuated constantly in the Philippines, as can be seen in Table 3-1. To complicate things still further, the Philippine peso has continuously devalued against the U.S. dollar in the period 1981 to 1984, as can also be seen in Table 3-1. It is also crucial to note, before beginning the economic analysis, that the initial plans were for the gasifiers to be fueled by wood chips, produced locally by the farmer cooperatives, rather than by purchased charcoal. In the AID project paper, approved in August 1982, it was assumed that wood chips would be produced for a cost of $0.75 per million BTUs. Assuming that this is dry wood, which normally has a heating value of 16 to 17 MBTUs per ton, then AID was assuming that the cost of wood chip fuel would be $12.00 per ton. Charcoal was estimated by AID to cost almost twice that of wood, or $24.00 per ton (or 0.29 pesos/kg at the conversion rate of 8.083 pesos to the dollar). This was considerably below the actual market price of charcoal at the time, as gathered from the other sources, and these prices were soon to explode because of increasing demand and rapid fuel substitutions in the face of spiralling imported fuel costs.

In Table 3-2, the implications of rapidly changing fuel costs and the rate of diesel substitution for one particular irrigation project (the Lourdes ISA in Occidental Mindoro) are spelled out. The data are those gathered from the gasifier operator and from an examination of the daily records kept of fuel consumption. This ISA is operating a charcoal gasifier, retrofitted to a 36.9 HP diesel engine, operating 1,650 hours per year. Before it was installed, the diesel consumption was 40 liters every 12 hours, or 55 liters per year. After the gasifier was installed, fuel consumption dropped to 20 liters of diesel and two bags of charcoal per 12-hour period, or 2,750 liters of diesel and 175 bags or charcoal per year. This system operated best at a 50 percent diesel fuel substitution, as was true of other sites visited, but also calculated was the economic return if the 70 percent diesel substitution initially planned was achieved. Looking at the initial figures, it is easy to see why gasifiers seemed so attractive to those seeking to disseminate the technology. Assuming a 70 percent

Table 3-1

Relative Prices of Charcoal and Diesel Fuels

Date	Exchange Rate (peso-dollar)	Price of Charcoal Peso/kg	Price of Charcoal US$/ton	Price of Diesel Fuel Peso/liter	Price of Diesel Fuel US$/liter
Oct 81	8.083	0.42	51.96		
Oct 82	8.832	0.60	67.95	2.81	0.32
Oct 83	14.002	0.90	64.27	3.43	0.24
May 84	14.002	1.34	95.70	4.89	0.35
Oct 84	20.180	1.90	94.62	7.26	0.36
Jan 85	19.170	2.60	135.62	7.04	0.37

Sources: "An Assessment of the Firewood and Charcoal Markets in the Philippines," 1985, sections 4.1-4.3. While charcoal prices vary drastically from location to location and from season to season, data have been selected to represent prices to rural consumers who pick up their supplies in the market place. Diesel prices and currency exchange rates provided by AID/Manila.

Table 3-2

Economic Analysis of Lourdes ISA Gasifier
(Using 1982 and 1984 Prices and 50% or 70% Diesel Substitution)

	1981	1983	1984
Capital Cost			
Annual loan repayment:	3,500	3,500	3,500
Operating Cost			
(50% diesel substitution)			
Cost of charcoal per year:	1,650	3,300	4,950
Spare parts and maintenance:	350	350	350
Total Annual Costs:	5,500	7,150	8,800
Fuel Savings			
(50% diesel substitution)			
Diesel saved:	7,727	9,430	19,965
Operating Cost			
(70% diesel substitution)			
Cost of charcoal/year:	2,475	4,950	7,425
Spare parts and maintenance:	350	350	350
Total Annual Costs:	6,325	8,800	11,275
Fuel Savings			
(70% Diesel Substitution)			
Diesel saved:	10,920	13,325	27,950

substitution of charcoal for diesel, the 1981 column shows that even at 6 pesos per 17 kilogram bag, the gasifier would save the local cooperative over 4500 pesos per year, even including the annual loan repayment of 3500 pesos. After six years, the loan would be repaid and the cooperative would have an additional 8000 pesos per year to spend on other development activities. However, 50 percent substitution appeared to be more feasible in the field, and the price of charcoal began to spiral while that of diesel was kept under control until late 1983. (The results can be seen in the 1983 column.) The cost of purchased charcoal has doubled, raising the operating cost to nearly 3650 pesos. When this is added to the annual loan repayment, and when one factors in the greater amount of operator time that must be spent on the gasifier compared to the existing diesel, it is understandable why a large number of the systems were either not operated or operated only on 100% diesel. It should be noted that the economic balance has now shifted back in favor of the gasifiers, primarily because of the decontrol of diesel fuel prices after mid-1984 that led to diesel fuel selling for more than 7 pesos/liter. In the face of such uncertainity over relative prices, however, it is difficult to determine what the farm-scale demand for gasifier-powered irrigation systems will be in the future. The result of the calculations, such as was shown in Table 3-2, is unique for each ISA. Those located in areas with rapidly rising charcoal costs have often chosen to go back to full diesel operation, which locations where gasifiers were undersized but charcoal plentiful and cheap, such as Iloilo, have applied to GEMCOR for newer larger gasifiers to replace the IS 30 to IS 60 units that GEMCOR originally installed.

No economic analysis was available from the FSDC or GEMCOR staff on the relative economic performance of the gasifier installations versus the extension of the electric grid. In general, the gasifiers were installed at ISAs that were at least 10 kilometers from the electric grid, although some are scheduled to receive electricity in the next decade. If we assume that extending the electric grid costs at least 40,000 pesos/kilometer in 1985, then the gasifiers look to be cost-effective for most rural Philippine locations, because of the low initial investment of 16,000-30,000 pesos.

3.6.2 Wind Waterpumpers

Evaluating the value of drinking water has always been a major analytic problem. This is particularly true when a labor-saving device is introduced at a waterpoint where there is already an existing well that is discharged by a handpump or by an open bucket. Clearly, there are health advantages to having the area over the water source sealed and protected from surface contamination, but this can be done while installing a hand pump as well as a wind waterpumper or diesel pumpset. Secondly, a power system such as a wind pumper can deliver the water to an elevated tower, from which it can be delivered to distributed water taps by gravity. This can be a major time-saving and labor-saving device for the citizens of the village, since they no longer have to walk back and forth to the well several times a day with water for drinking and domestic purposes.

Two different approaches to the economic valuation of the Philippine waterpumpers can be seen in the cases of the village of Lourdes, on Iloilo, and that of San Jose in Occidental Mindoro. In Lourdes, the waterpumper was installed in 1980 to provide drinking water to an elevated tank. Due to mud that is drawn up with the water, the villagers continue to use water from hand pumps for drinking and use the water from the storage tank only for washing and other domestic chores. Each family can draw a 20-liter tin of water each day from the tank, and then carry it back to their home. The value of the water is strictly that of the labor avoided in hand pumping 20 liters of water from a drinking well. In San Jose, however, the local drinking water supply was contaminated by the installation of a nearby salt production facility. Villagers had to travel to the nearby town by jeepney, where they could purchase 20 liters of water for one peso. The round trip by jeepney probably cost an additional peso. If each of the 100 village families spent two pesos per day on water and water transportation, then the cost to the village would be over 70,000 pesos per year. While it is not likely that this full amount was actually spent, the magnitude of the expenditure is clear. Therefore, the villagers were happy to donate 200 person days of labor to hand-dig the required new well (plus food for the workers). They also paid for the transportation of the unit to Occidental Mindoro, with FSDC paying for the unit and its installation (a total delivered cost of 48,000 pesos without a storage tank).

In none of the locations visited was grid electric power readily available. In general, electric power on the islands other than Luzon is restricted to the major urban areas, and even there it is unreliable. Even hotels located next to the main road rely on their own diesel generator sets for night lighting. In locations such as Lourdes, the nearest electrical power is 10 to 15 kilometers away, over very rough terrain. There is no plan to extend the grid in the direction of most of the rural ISAs, partially because of the low population density in these islands. Even if we assume that the cost of extending a 22kVa line is only $2,500 per kilometer, the cost of providing electricity to small ISAs is far above the cost of small-scale stand-alone units such as a gasifier and/or windmill.

3.7 Economic, Technical and Social Performance

3.7.1 Gasifiers

The performance, durability, and economic visibility of the

GEMCOR gasifiers has been a matter of serious debate within and among the GOP and AID. Due to rising concern that a substantial percentage of the FSDC units installed since early 1982 were not optional, AID and the MHS sent joint teams out in March 1984 to examine gasifier sites in the Bicol (Region V). They found that only 24 of the planned 103 gasifier installations had taken place, partly due to resistance from the local villagers to the gasifier technology. Of the 24 units installed, only two were operational. The reasons given for the 22 non-functional gasifiers were various: 12 were shut down due to economic considerations, meaning either an unacceptably high cost of charcoal or diesel fuel or both; seven were undersized (IS60s) units which were scheduled for replacement with larger GEMCOR gasifiers, but that are also being included in the National Irrigation Authority's Bicol gravity-feed irrigation plan in 1985, eliminating the need for pumps; two had defective gas scrubbing units which FSDC was scheduled to replace; and one had its water delivery flume destroyed by a recent typhoon. Subsequent visits by AID/MHS staff to other regions found similar types of problems. In Mindanao, 16 of the 30 units installed by FSDC were in operating condition, and seven were in actual use. In area VI, 21 systems had been installed, eight were optional, and three were in active use.

In May 1984, based on information provided by both AID and MHS, the Development Projects Fund Secretariat of the MHS completed an evaluation and redirection of the gasifier for the irrigation subcomponent of the AID-supported Rural Energy Development Project. The MHS Secretariat staff found that approximately 70 percent (169 units) of the 242 GEMCOR gasifiers installed to date were not operating. The report echoed the earlier site visit analyses, finding the major technical problems to be: "(a) the mismatch in the power requirements between the gasifier and the diesel engine; (b) damaged diesel engine, pumps and other accessories; (c) silting of the pump systems; (d) inoperative gasifiers due to defective piston rings; (e) damaged canals and canal structures; and (f) lack of spare parts to operate the pump/gasifier system." In addition, the report pointed out two local institutional problems: "the unavailability and/or high cost of charcoal; and the absence or lack of experienced gasifier equipment operators." The MHS staff recommended a sweeping series of institutional changes to both rectify the problems in the current systems, and to assure that FSDC lays out a realistic plan for developing additional gasifiers and the woodlot resources required to support them before continuing with the remainder of the Rural Energy Development Project. These recommendations have been accepted by AID and FSDC and, if fully implemented, will go a long way toward solving the problems encountered with the first generation of GEMCOR gasifiers.

In view of these series of site investigations, it seems appropriate to try to separate the analysis of the technical and economic performance of the units if properly installed and maintained and the poor overall field performance of the total set of FSDC-installed gasifiers. The GEMCOR units with the updated demister cleaning system work quite well, providing that they are coupled to a low-speed stationary diesel of approximately the same power rating as the gasifier. As an example, the 30-HP gasifiers installed at the Damires ISA and the Lourdes ISA were coupled to existing 23- and 37-HP diesels respectively. The diesels were installed in 1977 and 1980, and both had been meticulously maintained by the local operator/mechanic. Unlike a diesel, however, the gasifier needs a trained, dedicated operator to be present during the hours of operation. Not only must the charcoal be loaded every one to four hours, but the operator must be alert to bridging problems in the vessel (which prevents the gravity feed of the fuel into the reduction zone), and must occasionally alter the gas/diesel fuel mix to keep the engine operating properly. Operators must be diligent in following the schedule for emptying out the various filters, changing the oil used for cleaning as well as the diesel lubrication systems, etc.

It is highly recommended that the gasifier and the diesel pumpset (or gasoline engine pump set for smaller applications) be designed as a package, rather than the gasifier being retrofitted to whatever diesel that happens to be available. Not only was there often a mismatch betweeen the size of the gasifier and the existing diesel, the diesels themselves (often used automotive diesels) were ill-suited for a stationary application, much less coupling to a gasifier. They require more frequent maintenance, have undersized cooling systems and small capacity lubrication channels.

One important field observation is that gasifier operators use a much lower producer gas-to-diesel ratio than that originally envisioned by the designers of the Philippine systems. Instead of reducing diesel consumption 70 percent or more, the standard diesel reduction is 50 percent. Operators find that the engines work better on this richer mixture (ignition starts earlier in the compression cycle so there is more complete combustion). Also, the operator is minimizing the use of the fuel which is most difficult to procure and handle, namely charcoal. It is interesting to compare the charcoal consumption from the Damires and Lourdes ISAs with that predicted by the GEMCOR and GOP staff. The planning figure used by the ERDC is that the gasifier will consume one kilogram per horsepower hour for 70 percent diesel displacement. Thus, for Damires, the predicted charcoal consumption would be 23 kgs per hour or 184 kgs/eight-hour day. The actual charcoal consumption was 15-17 kilos. At Lourdes, with its 37-HP engine, the predicted charcoal usage would be 296 kilograms each eight hours, while the actual was approximately 25 kilograms.

The economic viability of a gasifier, assuming that it is well maintained and mated with a correctly sized diesel or gasoline engine of the proper design, depends largely on the relative local price and availability of diesel and charcoal. Operating costs quickly overwhelm the initial capital cost of either the diesel pumpset or the gasifier and pumpset combination. If we assume that a small unit such as the Lourdes ISA unit consumes 4,950 kgs of charcoal at one peso per kg, 2,750 liters of diesel fuel at seven pesos per liter, and pays the operator a price equivalent of about 6,000 pesos per season or 12,000 pesos per year, then the annual operating cost of 36,200 pesos is approximately equal to the cost of the gasifier (16,000 pesos) and that of the diesel pumpset (20,000-25,000 pesos).

Early 1983 GOP estimates that the gasifier would pay for itself in less than two years if the price of charcoal is less than 0.75 pesos/kg or 14 pesos per sack seem overly pessimistic, partly because they were calculated on the basis of diesel fuel at only 4.47 pesos per liter. In late 1984, a skillful operator appears to be able to save enough on operating expenses to more than repay the gasifier expense even if the charcoal costs one peso per kilogram. Above that, the savings begin to diminsh quickly and the local ISA is likely to either abandon the unit altogether or revert to 100 percent diesel operation.

The key to economical operation of any gasifier is the ready availability of low-cost or no-cost fuel. It was planned that each gasifier purchaser would plant and maintain a six-hectare (later converted to three) plantation of fast-growing tree species. This plantation was supposed to provide all of the wood chips required for the gasifier by cutting the trees on a three-year rotation. Charcoal was to be used only until the fuelwood plantations could be established. Unfortunately, in their haste to find locations for gasifiers and get them installed, the FSDC staff never considered whether this goal was either technically feasible or socially acceptable to the members of the irrigation cooperative. Only 148 hectares of ipil-ipil were planted in 95 sites, instead of the more than 700 hectares that had been projected. Farmers' initial reluctance to divert productive land near irrigation water from crops to trees was compounded by a lack in the promised financing for the plantations by FSDC. While ipil-ipil is frequently planted along roadways as a shelter belt and as a source of cooking fuel, these small quantities cannot make a contribution to the feeding of a 30-HP or 60-HP gasifier. Only a major planting program, with major built-in financial incentives and forestry management training, will enable any of the existing gasifier owners to lessen their independence on purchasing charcoal.

In closing, gasifiers are less convenient than diesel units, and so are less acceptable to the average farmer;however, they seem to have a great attraction to many mechanically inclined operators, in part because they require frequent adjustment and tinkering. The operators interviewed, and the ISA farmers in general, were pleased that they were using a local technology that was both saving the use of diesel fuel and reducing their collective expenses. Philippine farmers, however, may be atypical of Filipinos in particular and of other Asian farmers in general. They are quite accustomed to working with machinery, be it walking tractors or small-scale threshers, and maintain a number of mechanized agricultural implements. There are also skilled mechanics in most small and medium-sized farm communities, which is not a situation found in less developed Asian or African communities.

3.7.2. Wind Waterpumpers

In the short time spent in the Philippines, it was difficult to get good in-depth information on the economic, technical, and social viability of the wind waterpumpers installed with AID financing under the terms of the Nonconventional Energy Development Project. Of the 17 units installed, the majority are reported to be operating (despite a general lack of follow-up maintenance and spare parts from FSDC). BED is also monitoring more than 20 additional locally manufactured wind waterpumpers located throughout Luzon Island, many of which appear to be commercial sales.

The FSDC waterpumpers, without tanks, cost 30,000 to 48,000 pesos. Depending on the wind regime and the pumping head, they are capable of lifting up to 10 cubic meters a day up to an elevated storage tank. At this low capital cost, they appear to be quite attractive for remote sites where the daily demand is relatively modest (e.g., village drinking water systems) and the wind reliable. The one concern is that the country lies directly in the typhoon belt. It is buffeted by at least two major tropical storms each year, and as many as six in a particularly bad season. There was little information available in Manila, or at the two sites visited, on the ability of these high-solidity machines to endure winds in excess of 150 kms/hour that are found in major typhoons.

Wind waterpumpers have no major social or technical acceptability problems. They do require periodic lubrication of the rotating parts and maintenance of the seals, but this is well within the skills of most local Filipino farmers. However, the problems encountered by the Lourdes ISA with its FSDC-installed windmill show that skilled and careful installation is a prerequisite. After one week of start-up operation, the pump leather failed, as did the sucker rod seal. It appeared as if they are improperly installed, not lubricated, or both. After a month of similar problems, the local operator fabricated his own substitute leathers and seals, which are working today. No spare parts had been provided to him, nor had the windmill gone through a proper checkout to insure that it was operating. Once again, as in the case of the gasifier, the problem was not so much that the technology was defective or inappropriate but that insufficient planning had gone into the installation and follow-up process (including training and spare parts).

3.8 Potential for Replication

3.8.1 Gasifiers

The Philippine gasifier development and dissemination program has been one of the most closely followed energy projects in all of Asia. This is in part because of the high visibility that it was given by the GOP at international meetings, and in part because the technology attacks several common problems simultaneously.

First, it reduces diesel fuel consumption directly without requiring replacement of the original diesel engine. Second, the units are easily manufactured in existing machine shops, and relatively low in cost on a mass-production basis (less than $1500 for 60-HP units). Third, it substitutes a renewable and readily available fuel, wood chips and/or charcoal, for imported fossil fuels. Lastly, it contains a locally managed program for a sustainable harvest of the wood fuel using marginal lands and unskilled labor. Nearby countries, such as Thailand, Malaysia, and Indonesia, have launched their own gasifier research and development programs, although much more research and development oriented thus far.

The gasifier technology cum local woodlot could be easily replicated in other countries with ample available land and a heavy reliance on stand-alone diesel engines for power generation or irrigation pumping. The technology is simple, and can be built in distributed locations (as proved by models developed by machine shop operators in Chiangmai, Thailand, based only on photographs). However, to be more successful than the Philippine experience, the process must be different. First, field-test sites should be identified. These should not only have a need for an engine (and preferably none yet in place), but also land which can be bought and then turned over to local foresters or farmers for immediate planting of high-yield species. Alternatively, a long-term contract can be entered into with a local landowner for the planting of the trees and the delivery of the required wood at an agreed-upon price. The engine and pumpset should be bought and tested together, and then delivered to the site as a unit. Three or more operators should be trained, with the training taking place on-site for at least two weeks. During technology development, primary emphasis should be placed on the cleaning system and on a unit optimized for the anticipated end-use. One early application that should be explored is the coupling of the gasifiers to existing or new boiler installations. This would avoid all of the problems of the cleaning system, enabling the system to operate from the start on woodchips rather than charcoal.

Before a wide-spread dissemination program is attempted, a study of the economic feasibility of initial pilot installations should be done. Assured fuel supplies should be required of all sites prior to the installation of the gasifier unit, to include the handling of the material and the training of the operators.

4.0 THAILAND

4.1 Host-Country Context

Thailand has been designing and installing hydroelectric power systems for the past 20 years. Over this period, experience in system design and operation has been acquired by NEA, the Electrical Generation Authority of Thailand (EGAT), and the Provincial Electricity Authority (PEA). Until the early 1970s, much of Thailand's main grid power generation came from several large hydroelectric dams. To meet the rapidly rising electrical demand in Bangkok and the surrounding areas, EGAT began a major construction program for oil-fired thermal plants in the late 1960s, with much of the capacity coming on line just as international oil prices began to spiral upward.

In 1978, the overnment of Thailand (GOT) reorganized its energy activities. In the course of this reorganization, NEA was given responsibility for the development and commercialization of small-scale energy systems, including hydroelectric units under six MW(e) installed capacity. EGAT and PEA were charged with the design, installation, and operation of larger units.

By the beginning of 1979, NEA had already set up a small hydroelectric equipment laboratory and was working with several small, local manufacturers to build small hydroelectric units to NEA specifications. It had institutional capability and experience, but lacked investment capital, particularly for very small-scale units. AID, as part of its Renewable Nonconventional Energy Project (493-0304), agreed in 1979 to provide funding for several of the NEA planned installations that were either under planning or actually under construction.

4.2 Site Selection Process

For the past 20 years, Thailand has had a major program of collection and monitoring surface water flows. The GOT has also done preliminary site surveys of thousands of potential hydroelectric sites. NEA was able to draw on this inventory of sites for some of the initial AID and GOT-funded installations.

However, favorable physical characteristics (potential head, flow rates access roads for materials, etc.) are only a portion of the site selection process. The location of the electricity users must also be analyzed, since the costs of transmission and distribution can quickly overshadow the cost of site development and power generation.

In addition, NEA was looking for relatively remote sites, which would not be reached in the foreseeable future by PEA's aggressive program of rural electrification. In practice, it meant that NEA looked for small, isolated communities at least 15 kilometers from the existing grid.

Lastly, NEA decided to locate systems only in communities where the population was willing to agree to provide, free of charge, all the required construction materials and labor. This has not turned out to be a major constraint, since electrification is highly valued, and the villages usually agree.

Once the micro-hydro installation program began, the site selection process took on a life of its own. Inhabitants of unelectrified villages visited micro-hydro projects under construction and learned that local organization and participation was a prerequisite. They then returned home, gathered petitions promising the required labor and materials, and petitioned NEA or local political figures for inclusion in the program. There is now a backlog of such requests from villages with good hydroelectric potential.

4.3 The Process of Technology and System Selection and Design

NEA has a considerable design capability in-house for cross-flow, Pelton, and Francis turbines. It has a design staff in Bangkok, but also allows its field officers in Chiang Mai and Songkla to do the site and system design work.

Until recently, NEA designed and developed the complete micro hydroelectric installation, but used imported controllers. However, in the past three years NEA staff have taken a design initially provided by Intermediate Technology Development Group (ITDG) in London, modified and improved it, and now fabricate their own governors and load controllers. With 15 micro-hydro installations completed since 1979 and eight more under construction, NEA has ample experience to undertake the complete site assessment, design and installation process.

4.4 Local and Private-Sector Involvement

As already mentioned, NEA is striving to develop a completely local micro hydroelectric capability. Since 1978, it has worked with a local machine shop in Chiang Mai to build cross-flow turbines up to 50 kW(e) capacity. The same shop now has the capability to site-fabricate headrace and penstock steel pipe up to 1.5 meters in diameter.

NEA also has worked with a major pump manufacturer in Bangkok to cast Pelton turbines up to 100 kW(e) in size. Plans are underway for increasing this capacity to 500 kW(e). Generators are also made locally, and NEA itself produces the electronic governors and load controllers.

Even on relatively large mini-hydro installations, such as the 1.2 MW(e) unit nearing completion at Mae Sarieng, all of the installation is locally designed, produced and installed, except for the turbines, electronic control system, and generator.

While the GOT has not yet licensed any systems for export, it appears to be only a matter of time before this will be done. NEA senior engineers are still working to simplify the design of the electronic governor, but a complete package costing only 10,000 Baht ($430) per kilowatt of generating capacity should be commercially available shortly.

4.5 Monitoring

All the NEA micro-hydro units have only simple instrumentation, used mainly by the operator for starting up and balancing the generation. It reads out voltage, current, generator RPM, and system readiness. The operator also records when he turns the system on and off and the maintenance activities undertaken. In addition, each household has an energy use meter, which is read monthly and used by the local village committee for billing purposes.

4.6 Economic Analysis vs. Diesel and Grid Extension

For each of its micro and mini hydroelectric installations NEA conducts what it calls a "least-cost analysis." The cost of providing the same amount of power by extending the grid, by installing a diesel generator set, or by installing the micro-hydro unit are compared. The micro-hydro system is selected only if it has the lowest total present cost, discounted at 12 percent per annum, of the three options.

It is striking how much less expensive it is to install a micro-hydro unit than to extend the grid to these small remote villages. NEA uses a planning figure of 255,000 Baht ($11,000) per kilometer for extending a 22 kVa line, although NEA engineers said that the real costs were closer to 350,000 Baht per kilometer, with annual maintenance costs of over 12,000 Baht per kilometer.

The NEA analysis for each site shows that the stand-alone micro-hydro unit is also less expensive to install and operate than a diesel generator set, although the difference is less striking than with the grid extension. While the initial capital cost for the diesel is only about 300,000 Baht($13,100) or 20 to 25 percent of the civil works and generating equipment for a system such as those installed at Kham Pong or Mae Thon Luang, the operating costs are quite high (and diesel fuel is often not available in the rainy season). In addition, the diesel power plant has to be replaced every seven to 10 years, while the micro-hydro unit has an expected (although not yet proven) life span of 30 years.

4.7 Economic, Technical and Social Performance

It is too early to tell what the long-term economic and social impact of the NEA/AID micro-hydro program will be. Currently, the electricity is being used mostly for social functions--lighting, small appliances such as radios and TVs, etc. There is little or no demand during the day, when most of the villagers are out working in the fields. In fact, a number of the micro-hydro units are shut off during the daytime hours.

NEA is trying to encourage the local village associations to invest some of their income from energy sales in productive equipment, which will operate during the day and increase village earnings. Examples are devices to steam chewing tea, demold coffee, and sprinkle shitake mushrooms. It is hoped that the electricity will be used more and more for income generation as time goes on and villagers become more aware of the services that electricity can provide.

The technical performance of the AID-funded micro-hydro units appears to be fine, although there is no accumulated knowledge on long-term durability. Village operators, once trained by NEA on-site and at annual two-week training sessions, have no difficulty operating the units without NEA intervention. As long as the routine lubrication schedule is strictly followed, the systems continue to function.

Many of the NEA micro and mini hydroelectric units are run-of-the-river systems with very modest amounts of storage. It is expected that prolonged dry spells may substantially reduce water flows and therefore lower the electricity available. This may have an impact on industrial users in the future if they come to rely on the local grid for applications such as food processing.

It is the social performance of the NEA/AID micro-hydro systems that is most arresting and that may have the longest term impact. NEA staff work extensively with the villagers prior to the start of construction, making certain that the organizational infrastructure is in place to construct the civil works, string the distribution and transmission lines, determine electricity tariffs, collect the payments from each household each month, set aside funds for operation and maintenance, and invest any excess funds in local, productive activity.

The in-kind contribution of the villagers in terms of labor and material is converted by NEA to shares of the monthly income of the sale of electricity. For example, if the NEA cost is 800,000 Baht and the villagers' time and materials are valued at 200,000 Baht, then the village committee gets to keep 20 percent of all the income it collects. This money is spent on local upkeep and village improvement projects. Using the committee structure developed by NEA, and using the new skills developed during the construction phase of the micro-hydro installation (building of concrete forms, concrete mixing and pouring, etc.), the villagers can undertake new development programs.

4.8 Potential for Replication

In examining the AID-sponsored NEA micro-hydro program, the applicability of the villager involvement process as well as the micro-hydro technology itself must be looked at. The utility of the technology will vary from site to site and from country to country, depending on the quality of the water resource (head, flow rate, seasonal fluctuations), distance to electricity users, and distance from existing electricity grids. Thailand is blessed with thousands of potential hydroelectric generation sites. It also has an existing in-country fabrication capability for virtually all parts of a small hydro plant, which greatly reduces the overall system cost. NEA's in-house design capability is a major factor in the low cost per installed kilowatt (about 50,000 Baht or $2,200 per kilowatt). While other Asian countries share Thailand's interest in micro-hydro development, perhaps only in Nepal is the coincidence of local experience and natural resources as strong as in Thailand. However, micro-hydro is a proven technology, unlike some other renewable energy systems. Complete packaged systems are available in a dozen countries, often in conjunction with attractive, low-cost financing. For much of Asia, the manufacturing capability required to produce micro-hydro units--precision welding or casting, production of generator sets and electronic or electro-mechanical governors--already exists.

What will be difficult to reproduce is Thailand's hydro design capability and cadre of engineers with both field construction and design experience.

5.0 NEPAL

5.1 Host-Country Context

Nepal has had nearly a decade of experience with the testing, modification, production and operation of small-scale energy systems. The lack of indigenous fossil fuels, combined with alarming deforestation and burgeoning population, was apparent to development planners even in the early 1970s. Luckily, there were several strong governmental and private foreign assistance groups that took the lead in setting up indigenous testing and production facilities for RETs. Chief among these were Swiss foreign assistance (SATA or Swiss Association for Technical Assistance) and the consortium of church groups known as the United Mission to Nepal.

Early on, the RET development work became focused on two overriding objectives: 1) to develop and widely disseminate technologies that would displace dung and firewood as cooking fuels; and 2) to provide RETs that would provide cash income and employment to the rural 90 percent of the country's population.

A whole array of RET prototypes have been manufactured and tested in Nepal, ranging from Savonius and fanmill wind pumpers to solar water heating systems, but three have reached commercial status: solar water heaters, small micro-hydro units, and biogas plants (also known locally as gobar gas plants, after the Hindi word for manure - gobar). The analysis that follows will focus primarily on biogas plants and micro-hydro-powered mills.

While the institutional context for each of the technologies varies considerably and will be explained separately, there are three overriding aspects of RET development and dissemination in Nepal that set it apart from efforts in other countries. First, the initial impetus was to teach technical skills and to create employment as much as it was to produce energy technologies. Therefore, from the very beginning the emphasis was to concentrate on modifying existing foreign designs to promote virtually 100 percent Nepali fabrication using labor-intensive production techniques and low-cost materials. Second, the marketing, production, installation and maintenance of the biogas plants and micro-hydro units (as well as the solar water heating system) is done by private or semi-private firms, not government agencies. Sales are largely unsubsidized, except in the case of some small-scale biogas plants.

Third, credit is readily available to prospective purchasers on quasi-commercial, but still affordable terms. The ADBN has 120 branches throughout the country, and has taken the lead in extending financing for all types of RETs. The interest rates and collateral requirements are modest by rural Nepalese standards, and the processing of loan requests is quick. The repayment periods (five to seven years) are long enough that the purchasers can generate sufficient savings and earnings to meet the installment payments.

These three factors, along with extensive provisions for maintenance, are central to the success of Nepali RET installations and their remarkably low percentage of abandoned or non-functional systems. Within this broad country development context, the various technologies have very different institutional settings. All will be dealt with separately below, both generically and then in the specific case of the Rapti Zone project.

There are eight integrated rural development projects in Nepal, which seek to provide a whole range of services, ranging from roads to improved agricultural imports, to a particular area of the country. Each is financed by a different foreign assistance donor. The AID-funded Rapti Zone Integrated Rural Development Project began in mid-1981. It was a large (US $26 million) effort, with five components ranging from rural works to skills development. One small component was to set up an ATU in Tulsipur in the Dang District. The ATU was to serve as a catalyst for a variety of low-cost technologies for the five districts that made up the Rapti-Zone--Dang, Salyan, Piuthan, Rolpa and Rukum. The ATU began operation in November 1981, reaching a size of eight technical and seven support staff by mid-1984.

5.1.1 Biogas Plants

Biogas plants were set up in Nepal in the early 1970s by a variety of scientific and development groups, including Swiss foreign assistance, Development and Consulting Services (a part of the United Mission to Nepal effort based in Butwal), the Soil Sciences Research Centre of the Ministry of Agriculture, the Research Center for Applied Science and Technology of Tribhuvan University in Kathmandu (RECAST), and the Gobar Gas and Agricultural Equipment Company. Initially, the systems were all based on the Indian floating-metal-drum designs, but the Chinese drumless dome digesters were introduced in the late 1970s and are now the predominant model, except for very large units.

The Gobar Gas Company is the major producer and installer of biogas plants in Nepal. Set up in 1977 as a joint venture of the United Mission to Nepal, the ADBN, and the Nepal Fuel Corporation, it had installed more than 1200 units by July of 1984. Although headquartered in Kathmandu, it has a total of

11 offices, including its main workshop in Butwal, and a staff of 136. During the 12 months ending in July 1984, the Gobar Gas Company installed 177 units and has a target of over 300 for 1984-85.

Because of the remoteness of the Rapti Zone, only 25 biogas plants had been built prior to the establishment of the ATU. The ATU staff worked closely with the ADBN and the Gobar Gas Company to promote the technology, through visits to farmers, exhibitions, etc. ATU staff also developed and tested a low-cost, unlined trench or tunnel digester. By mid-1984, an additional 89 commercial units and 13 experimental units had been constructed, virtually all in the Dang District.

5.1.2 Micro-Hydro Mills

Nepal has had a long tradition of micro-hydro mills for grinding grain. Estimates vary widely on how many exist and are operational. Andreas Bachman, who has been involved in appropriate technology development work in Nepal for more than a decade, estimates that there are 25,000 to 50,000 of the traditional horizontal or undershot wooden water wheels, turning stone-grinding wheels (Bachmann and Shakya, 1982, p. 12). The very remoteness of the thousands of Nepali villages, combined with the abundance of swift-flowing streams and the traditional Nepali expertise at water management and canal construction for irrigation of terraces, made small-scale water power a natural development.

In the early 1970s, Swiss technical advisers began to work together with a quasi-private firm, Belaju Yantra Shala (BYS), on the testing of modern turbine designs. Gross-flow and later Segner turbines, as well as metal versions of the traditional wooden "ghatta" or water wheel, were developed and field-tested. There are now four indigenous commercial water mill manufacturers active in Nepal: National Structure and Equipment Engineering Co.; Nepal Yantra Shala, Ltd.; Belaju Yantra Shala, Ltd.; and Butwal Works, Ltd. Together they have installed several hundred micro-hydro units, each providing shaft power to a number of agricultural processing units. Typically, the hydro unit will be coupled to a rice dehuller, a grinding unit, and an oil seed expeller. Less commonly, a small electric generator will be coupled for the lighting of nearby houses.

5.2 Site Selection Process

In the case of both biogas plants and micro-hydro installations; site selection and promotional activities are intertwined. Representatives of the ADB, the ATU (in the case of the Rapti Zone), and the various manufacturers visit prospective purchasers and farmer groups. In some cases, this is in response to a request for more information by the prospective customer, and in other cases it is to drum up business. There appears to be a strong "demonstration effect," with interest being stimulated in nearby communities by the installation of one or more units in a village.

5.2.1 Biogas Plants

Because of the small size of most of the installations--10 to 15 cubic meters of gas per day--sites with sufficient manure are not difficult to find. A 10 cubic-meter installation requires 60 kgs of dung and 60 liters of water per day, which can be provided by five to seven water buffalo or cattle. Even with small landholdings in Nepal, many rural families have enough dung or have access to it. However, ambient temperatures can drastically affect the operation of the biogas units. Cold night temperatures can inhibit the microbial activity that produces the biogas, even for the Chinese-type "drumless" plants that are burned in the ground.

In many upland locations, the biogas plants virtually cease gas production in the winter months as the temperature drops to 0°C or below in the thin air. In addition, upland sites are much more difficult to reach both for promotional purposes and for installation and maintenance. Installation and maintenance costs are therefore higher, while per capita income tends to be lower. For all of these reasons, the installations tend to be located in the tropical lowlands (the terrai), near major roads, or in small commercial centers in the hill areas below 2000 meters in elevation.

In the AID-sponsored Rapti Zone Project, 96 of the 102 installations put in with ATU's assistance or promotion were built in the Dang District. These sites are both warmer and more readily accessible than those in the other four highland districts. For example, Rukum and Salyan districts are accessible only by foot or pony trails from the lowlands, and the trip usually takes three to 10 days, even under the best of conditions.

5.2.2 Micro-Hydro Units

Small-scale hydro installations require more extensive site analysis than biogas plants. The amount of water available, the estimated head, the seasonality of the water flow, and the existing water rights must be examined and analyzed. The results of this analysis must be translated into terms that the prospective purchaser will understand: the estimated cost of the system, monthly payments, the expected volume of rice, corn, grains, or oil seeds that can be processed per hour, etc.

All of the turbine manufacturers provide for site assessment services. In the case of Butwal Engineering Works, Ltd., the site work and installation are done by its sister organization, Development and Consulting Services. In the Rapti Zone, however, the staff of the AID-funded ATU has taken a lead role in responding to requests for site assessments. In the 32 months ending July 31, 1984, ATU staff had performed 71 feasibility studies, and then prepared basic designs, cost quotations, and bank loan documents on 51 of the original sites visited. The ATU is acting as intermediary between the farmer and the two actors required for any installation the manufacturer and the ADBN.

It is interesting to note that the close relationship between the ATU and ADBN staff leads to a very quick loan approval process. For example, of the 31 micro-hydro mill feasibility assessments completed in the period July 1982 to June 1983, the time that elapsed between a favorable site assessment and the completion of the loan formalities was normally five to 30 days, and only once exceeded 90 days.

5.3 Technology and System Selection/Design Process

In the cases of both anaerobic digesters and micro-hydro mills, the technology used is a local modification of a system developed elsewhere. The modifications are extensive, designed to minimize the use of imported materials, use labor-intensive assembly and fabrication techniques, and minimize the transportation problems in a country where virtually all sites are accessible only by pony or by foot paths.

5.3.1 Biogas Plants

The Gobar Gas Company started with the India-type units, utilizing a floating steel gasholder. However, in 1978 or 1979, they began experimenting with the Chinese-type fixed concrete dome units, and now these account for 90 percent of the installations.

However, the dome is not built up from bricks, as in the Chinese designs, but poured in a site-built earthen mold, which is then excavated after the dome is dry to form the digester vessel. The Butwal shops of the Gobar Gas Company have designed a number of useful componenets and now build them for sale, including a hand-driven dung/water mixer and a diesel engine biogas conversion kit.

The low-cost ATU biogas plants are uniquely Nepali, taking advantage of the very heavy, non-porous clay soils of the Tulsipur area. By substituting low-cost labor for imported concrete or steel, they greatly reduce the overall economic viability.

5.3.2 Micro-Hydro Plants

The small-scale hydro mills are an amalgam of traditional Nepali water-powered grinding mills and modern metal fabricating. The advantage is that the unit is seen as an upgrade of an age-old practice, and so encounters little initial resistance. The horizontal turbine even resembles the traditional "ghatta," using a direct drive through the mill floor to the milling area. It also uses a belt drive from the power take-off rather than a gear system, since this allows the owner to use a number of different machines from a single-power sources, according to seasonal demand. Belts are also easily fabricated on site, while it may take months to get gears replaced or re-machined.

The complete "multi-purpose processing unit" or MPPU, which consists of the water turbine plus the belt driven machines, is a collection of both Nepali and imported components. Each of the four turbine manufacturers produces its own turbines, but the choice and country of origin of the other components--grinders, dehullers, oil expellers and electrical generators--is largely a question of price and the sizes required. Virtually all of the oil expellers and electrical generators are made in India, while organizations such as Butwal Engineering design and produce grinders and other agricultural processing machines in Nepal.

The technology design process has been dictated by three considerations: use of locally available fabrication techniques (basically welding but with casting as well); maintenance of low costs; and construction of units that are easily maintained at remote sites. Since all of the systems are sold commercially and carry a limited (usually one-year) warranty, these priorities make sense. Instead of striving for the highest feasible efficiency, the micro-hydro mills are designed to be moderately efficient, durable and easy to repair.

5.4 Local and Private-Sector Involvement

As already mentioned in section 1.0, local design and fabrication have been a goal of most small-scale energy development in Nepal for the past decade. This is most prominent in the case of small-scale hydro and solar water heaters, but is also ture for low-cost and modified Chinese dome digesters. Each technology will be discussed briefly in the subsections that follow.

5.4.1 Biogas Plants

Biogas plants in Nepal are built and maintained by a parastatal firm, the Bio-Gas and Agricultural Equipment Development Company (referred to by its original name, the Gobar Gas Company). It has a de facto monopoly on biogas plant installation and sells its units to customers using financing provided by the ADBN. While the units are commercial successes (over 1200 have been sold by the Gobar Gas Company at prices ranging from 10,000 to 25,000 rupees, the company runs at a loss because of its high overhead, large staff, and unprecedented warranty (seven years), which requires a continuous process of call-backs and maintenance checks. The Nepali biogas program could move to complete commercialization (i.e., break-even or profit generation) through a number of small changes, including: reducing the warranty from seven to one or two years; selling service contracts two (or three) to seven; reducing costs by moving its low-cost designs; and providing profit incentives to local Gobar Gas Company managers for the number of systems installed.

The local Tulsipur ATU manager, Mr. Shreshtha, has been trying to persuade the ATU biogas technician to start up a small business building and selling low-cost tunnel digesters. He estimates that the units could be built for 4000-5000 rupees total, broken out as follows: 3000 rupees for materials, labor, stoves and lamps; 500 rupees for profit; 500-1500 rupees for the warranty. The technician is not yet willing to give up his secure job and salary unless he sees more of a profit. The ADBN would have to be persuaded that it should issue a loan for more than 4000-5000 rupees or accept a warranty shorter than the life of the loan (now seven years) before the technician would strike out on his own.

5.4.2 Micro-Hydro Units

Nepalese small-scale hydro power units are produced and sold by several small private firms, plus one NGO-supported workshop (Butwal Engineering Works, Ltd.). The firms (and Butwal) operate at a profit, partly due to the promotional assistance of the ADBN and various foreign assistance organizations, and partly because they have few call-backs and maintenance problems. The mills do not need to be subsidized since they generate a healthy profit for their owners. There is competition among the different producers, and it is common for a prospective purchaser to ask for quotes from two or more firms.

Local fabrication firms are also involved in designing and building agricultural processing machines that can be powered by the micro-hydro units. Prototypes that have been tested include a new flour mill, turbine-driven water heaters, carpentry tools, electrical generators, etc. While these are being tested, most of the units being commercially installed are Indian in origin.

5.5 Monitoring and Data Collection

There is no organized data collection process for either biogas plants or micro-hydro units. The Gobar Gas Company does have a good sense of the operational status of its units because of the visits that its technicians make to each site during the rainy season, but this information is not processed. There are a number of biogas units that are being monitored for gas production, but these are laboratory units located at sites such as the Soil Sciences Research Centre and the RECAST facility.

5.6 Economic Analysis vs. Diesel and Grid Extension

5.6.1 Biogas Plants

Biogas plants in Nepal are alternatives to diesel systems or to the extension of the grid only in the small number of shaft power applications, such as the grinding mills in the Pokhara area. In these installations, the biogas plant is coupled to a diesel, displacing a portion of the diesel fuel (generally 50%) for 3-8 hours per day. When the biogas is exhausted, or during seasonal periods of high demand, the diesel can be run on 100 percent diesel fuel.

The economic viability of the biogas mills can be determined by weighing the additional capital cost of the installation versus the savings in diesel fuel displaced (while there is a slight increase in the fertilizer value of the dung as the result of having been processed by the digester, this is not a factor to the system purchasers and so will not be considered here). The systems are installed by the Gobar Gas company under a seven to 10 year loan, with 12 percent interest, and one or two repayments per year. The annual repayment is 17% of the initial cost for the longer term loans or 22 percent for the seven-year loan. We have conservatively assumed a 7-year repayment or 2688 rupees per year. For purposes of analysis, we will examine a fixed dome or Chinese-type digester system, 15 cubic meter capacity, which is the normal size for operating a 7 HP Kirloshker diesel engine. The Gobar Gas Company charges 12,270 rupees for this system, including installation and a seven-year guarantee. The retrofit package for adapting the diesel engine to use biogas (the mixing box, fuel intake modification, etc) have been rolled into the seven-year loan that the farmer must pay for the installation, and are given as an engine modification annual payment cost below. The farmer is required to provide sand, bricks, and concrete valued at 1,760 rupees, plus labor valued at 960 rupees for site preparation and construction. This is a one-time payment and is not included in the system loan. Therefore, we have assumed that the mill owner has a 20 percent opportunity cost for his investment, and that this initial investment will be amortized over the seven-year life of the loan (although the biogas plant is expected to last longer than this period).

Table 5-1 below provides an analysis of the cash flow generated by the system, as well as the annual payments and expenditures that the mill operator must cover. Based on the data provided by two mills in the Pokhara region, we are assuming that the mill will operate for six days of the week, ten months out of the year. It will operate for 4 hours per day on a biogas/diesel mix during the cold months, but will operate on the biogas/diesel mix for 7 hours per day during the hot months of March to June. Conservatively, this would provide 1350 hours of biogas-assisted operation for the diesel mill per year. We are assuming that diesel costs 7.6 rupees per liter, the Kirloshker engine consumes 1.5 liters per hour when run on diesel alone, and the operation and maintenance costs for the diesel mill will be the same whether it is operating on 100% diesel or a diesel/biogas mixture.

The biogas-powered grinding mill is a sound investment for entrepreneurs in remote locations, just as is the micro-hydro mill discussed elsewhere in this section. Because of the limited reach of the main electrical grid, it is cost-competitive everywhere in Nepal, except in the Kathmandu valley. It is easily competitive with diesel units, except in locations where they could only be operated for 630 hours or less per year with 50 percent diesel displacement. This is true in many of the higher elevations in Nepal, where the unheated digesters do not produce enough usable gas to drive an engine because of the reduced microbial activity during much of the year. For the warmer lowland or terrai locations, however, the mills can operate year around. It should also be noted that the two systems examined in the Pokhara area were routinely achieving 60 to 75 percent diesel substitution, so that the returns are even greater than the 50 percent diesel savings used for our calculations.

Table 5-1

Economic Analysis of the Costs and Income of a 10-Cubic Meter Biogas Plant Operating a Grinding Mill in Nepal

Capital Cost	
Annual loan repayment	2,688
Engine modification payment	153
Farmer's initial investment	755
Operating Cost	
Cost of dung and water	0
Additional spare parts/maintenance	0
Total Annual Costs:	3,596
Fuel Savings (50% diesel substitution)	
Diesel saved:	7,695
Fuel Savings (70% diesel substitution)	
Diesel saved:	10,773

5.6.2 Micro-Hydro Mills

The analysis for Nepalese micro-hydro mills follows much the same analysis as that for the biogas-powered mill in section 5.6.1, except that the capital cost is greater, displacement of the diesel fuel is 100 percent, there is no need to purchase a diesel as backup, and the hours of operation are limited only by local demand. The capital cost is about 50,000 to 75,000 rupees, and the loan is repaid with 12 percent interest over five to seven years. The mills operate for long periods of time each day, generally 18 hours or more, and 24 hour a day in the periods preceding major festivals and during harvest. Assume 7000 hours of operation per year, with the 10 HP diesel requiring two liters of fuel per hour. Therefore, to compare the hydro mills to a diesel plant, we have set forth examples of two identical, multipurpose mills, one powered by a 10-HP diesel and one by a micro-hydro installation. The income stream from each is considered identical (even though the diesel will, in fact, have more downtime due to maintenance and repair), so we will only compare capital and operating costs. Each has three identical machines--an oil expeller, a rice dehuller, and a grain grinder, which are powered from a power takeoff by belts. Each has two or three full-time mill operators, depending on the season of the year. The hydro mill requires similar labor and greasing, but none of the maintenance and overhauls that the diesel requires every 1000 to 15000 hours.

It costs nearly four times as much to operate a diesel mill at a remote location as a micro-hydro unit. Since consumers are extremely sensitive to the cost of basic services, such as milling and grinding, the owner of a micro-hydro unit can lower his charges slightly below those of nearby diesel mills and gain a significant market share. The local consumers benefit from lower costs, and the amount of diesel fuel that Nepal has to import is also reduced proportionately.

Table 5-2

Comparison of Costs of Diesel and Micro-Hydro Grinding Mills

	Microhydro mill	Diesel mill
Capital Cost		
Annual Loan Repayment	13,600	4,970
Operating Cost		
Wages for 3 operators	16,450	16,450
Maintenance costs	800	4,000
Fuel costs	0	106,400
Total Annual Costs	30,850	131,820

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5.7 Economic, Technical and Social Performance

It is apparent from Table 5-3 that biogas plants are more clearly economical in fuelwood-scarce areas. It is also important to note that most of the biogas plant owners interviewed stressed that the fertilizer value of the slurry was as important to them as any savings from reduced use of kerosene and fuelwood. The anaerobic digestion process produces more readily available nitrates than the original cow or buffalo manure. The difference is more striking when the slurry produced each day is immediately applied to crops rather than being dried. The loss of nitrogen is reduced from 18 percent to one percent, and carbon losses are reduced from 35 percent to seven percent. The nitrogen content of a ton of digester effluent is approximately five kilograms (0.5 percent), while that of manure composted for 30 days is only 2.5 kilograms per ton (0.25 percent). For a digester operated continuously throughout the year, this is a difference of 32.8 kilograms of nitrogen fertilizer. This is the equivalent of 70 kilograms of urea fertilizer, which sells for 3500 rupees per ton in the Pokhara area. While we have only assigned the fertilizer a value of 250 rupees in the above analysis, based on the nitrogen value, the farmers interviewed gave the effluent a much higher value. The technical and social performance of the biogas plants appears to be specific to the individual operator.

Table 5-3

Annual Costs and Benefits of a Family-Sized Biogas Plant Used Solely for Domestic Application

	Tulsipur	Pokhara
Capital Cost		
Annual loan repayment	1,808	1,808
Farmer investment	552	552
Operating Cost		
Maintenance and spare parts	0	0
Total Annual Costs:	2,360	2,360
Fuel Savings		
Kerosene for lighting	880	880
Fuelwood for cooking	627	3,135
Fertilizer value	250	250
Total Annual Savings:	1,757	4,265

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5.7.1. Biogas Plants

In the previous section, we have discussed the comparative economic value of the biogas-driven vs. diesel grinding mills, so that analysis will not be repeated here. Rather, we will focus on the use of biogas plants for domestic applications, which is the predominant use for the more than 1200 systems installed in Nepal to date. Domestic biogas plants are used primarily for lighting and cooking. In the case of lighting, biogas replaces kerosene, which sells at 6.0-7.0 rupees (US$.34-.40) per liter, depending on transportation costs. To provide four hours of lighting per night for two to three lamps, as the biogas plant does, would require a great deal of kerosene--at least 20 liters per month. In fact, most households have a single kerosene pressure lamp. We will follow the assumptions of the government of Nepal, which is that a family installing a biogas plant saves 137 liters of kerosene per year, or 822-950 rupees per year.

In the case of cooking, the fuel displaced by biogas is normally wood. In rural areas, wood is often gathered, but increasingly wood is purchased (or bartered for) even in smaller market towns. The government of Nepal estimates that the average family in the Terai consumes 2280 kilograms of firewood per year. The price of wood varies greatly in the districts visited. In Tulsipur, wood was quite inexpensive. One very large bundle of wood (all that a man can comfortably carry--40 kilos) retails for 10-12 rupees. Local estimates are that such a bundle will last a large family for one to two weeks, which correlates well with the estimate of a little over 2 tons consumption per family per year.

The other extreme is Pokhara, where a combination of a large tourist population, a growing local service industry, and expanding agriculture makes wood relatively scarce. The same 40 kilogram bundles of wood would cost 50-60 rupees each.

In the following Table 5-3, we have estimated the economic return from a small, 10 cubic meter biogas plant, installed by the Gobar Gas Company. The initial charge is 8,256 rupees, which includes not only installation but also free operation, maintenance, and spare parts for seven years. We also assume the standard farmer contribution of 1,990 rupees in materials and labor, a 7 year loan period, and 12% annual interest rate. As in section 5.6 above, we assume that the farmer will expect a minimum of 20% return on his initial cost for the seven year life of the system repayment. We assume that the plant is able to meet the complete lighting and cooking needs for a family of six, so there will be no need for purchased fuels.

Those who enjoy loading the digester daily (or who have children or hired help to do it), who have ready access to dung and water, and who stir the digester periodically appear to have little problem obtaining sufficient gas for cooking and lighting. It is common wisdom among users that the stirring is not really necessary for gas production, but that it may help prevent long-term buildup of solids. The light produced by the biogas mantle lamps is highly valued by most rural users because of its brillance. We were able to get little information from the women in the homes visited about their preference of biogas vs. wood as a cooking fuel, although most said that they had plenty of biogas for cooking except in the coldest months of the year.

5.7.2 Micro-Hydro Mills

Micro-hydro mills have encountered little resistance in the past five years that the technologies have been introduced. This is due, in part, to the existence of 40,000 or more traditional Nepalese water-powered mills throughout the country. The new manufactured systems are seen as a modernization of a proven design, which also provide the mill operator with the option to run other machines (the oil expeller and rice dehuller) in conjunction with the grinding mill. This makes the machine much more valuable as a revenue source, and allows for better utilization of both the hired labor and of the power source. As has been shown in section 5.6 above, the micro-hydro mills are able to underprice diesel mills for the same services, because of the absence of fuel costs and the reasonable credit terms offered by the Agricultural Development Bank.

The technical performance of the systems also appears to be quite good. They come with a warranty from the manufacturer, as required by the ADB, so there is free service for the first year or more of operation. They provide enough power to run two or more machines simultaneously, which allows the miller to engage in more than one profitable activity at a time in peak seasons. The machines that are operated from the power take-off are commercial units, either made in Nepal or India, and the parts are readily available in major market towns.

The social performance of the micro-hydro mills is also worth noting. It allows local villagers to receive their agricultural processing servies without having to walk to nearby town mills. It also may provide these services at a slightly lower price, although this is not true in all locations. It provides employment for 3 or more local laborers, as well as a significant income for the local entrepreneur who has undertaken the task of opening and operating the mill.

5.8 Potential for Replication

In examining Nepal's experience with micro-hydro mills, we should keep in mind that markets in Nepal are very fragmented, partly due to the lack of good roads and other modes of surface transportation. Many locations are a 3-7 day walk from the nearest road, with the only connection being a foot or pony track. This has encouraged the development of small-scale agricultural processing units, to service one or two remote villages. In part, it is these isolated villages that are the natural purchasers for micro-hydro units. Because of its mountains, Nepal has tens or perhaps hundreds of thousands of all-year streams which can be tapped as power sources. However, all these caveats aside, the Nepali experience with small-scale hydro mills may be an excellent example for other countries in Asia because of its harnessing of small-scale entrepreneurs, combined with readily available credit, to promote the introduction of a new technology. The mills in Nepal are built by local fabricators, and they compete actively with one another for sales. They are constantly canvassing the countryside for new customers and adapting their systems to meet perceived demand. The government, through the Agricultural Development Bank, makes credit available to interested purchasers and provides payment directly to the manufacturers. Also, it is the income stream that the hydro-mills provides to the local mill operators that is the force that is driving the continued success of the systems. These are renewable energy technologies that help a local farmer or businessman increase his income. They pay back the initial investment rapidly (it is common for micro-hydro mill operators to repay their 7 year ADB loans in 3 years or less), and then have little or no operating costs for the rest of their lifetimes. Because they are vital to an entrepreneur's income, they are well maintained and cared for. These are important lessons that can be applied in many other locations in Asia, regardless of the availability of isolated communities with year-round streams. However, in countries such as Thailand and the Philippines that have a large number of small mountain streams, microhydro units for shaft-power applications, such as grinding, would seem to be immediately useful. This is particularly for those areas that will not be reached by the national electrification programs in the next decade.

6.0 INDIA

6.1 Host-Country Context

India is engaged in a massive renewable energy development and commercialization program, scheduled in the next five years to surpass the U.S. program in both size and breadth. In recognition of the importance placed by the current government on renewable energy systems, the Committee on Alternative Sources of Energy has been upgraded to a full-fledged governmental agency, the Department of Non-Conventional Energy Sources (DNES). In 1984, DNES funded 136 research programs, in every field from low-cost cooking stoves to magneto-hydrodynamics. This research program is coupled with a national program of direct subsidies to encourage both widespread demonstration of systems and the development of a network of commercial fabricators. Unlike the tax-based subsidy programs in the United States and other countries such as West Germany, the Indian government directly subsidizes the sale price by paying the manufacturer a certain percentage over the government-approved sale price.

In developing its research and development program, DNES has relied heavily on the traditional centers of technology development in India: the academic institutions (particularly the various Indian Institutes of Technology) and the large public-sector research and hardware production groups. Unlike in the United States, little of the cutting-edge research in RETs is conducted by private, for-profit corporations. This leads to a problem that will be pointed out again in the sections that follow, namely an overemphasis on technical performance and a minimum of attention to cost-effectiveness and to tailoring systems to meet the needs of potential users.

In the area of PV, India is funding both basic research and large-scale commercialization in single-crystal and amorphous-crystal solar cells. In 1983-1984, DNES funded 33 research projects for various facets of PV cell development and is underwriting the creation of large-scale PV module fabricating facilities at Central Electronics Limited (CEL) and Bharat Heavy Electricals Limited (BHEL), with the ultimate objective being to create more than one megawatt of in-country production capacity within the next 24 months. This indigenous capacity is largely protected from external competition by large (80 percent) import duties, but there are signs that the government of India (GOI) is now considering opening the market somewhat in order to force cost reductions by the major parastatal PV producer, CEL.

In solar thermal energy systems, India is actively encouraging research in every available area. Of the systems being explored, only solar water heating can be considered as commercial or even adequately field-tested. <u>It should be noted</u>

that the solar thermal concentrator and solar rice drying units discussed in the sections that follow are experimental units still in the developmental stages. They are not fully field-tested, as the India PV cells are, nor are they commercial products, in the sense that the Nepalese micro-hydro units discussed in section 5 are. Given the development approach taken to date, which emphasizes technical performance over cost-effective delivery of services, it is doubtful if some of the Indian solar thermal units will ever reach commercial status, but this will not be known until much more field-testing and technology adaptation is conducted.

Solar water heating systems, for every application from single-family residences to very large hotel complexes, are being built by a variety of Indian firms. These units are being subsidized directly by the GOI, partly as a way to stimulate the growth on an indigenous flat-plate solar collector industry. While it was not part of the scope of work for this field assessment, the systems observed appeared to be reasonably well designed and constructed and should be a commercial commodity providing that the value of the fuel displaced is high enough to offset the capital investment cost within a reasonable payback period.

With the technical assistance of several U.S. collaborators and funding provided by AID through the Technologies for the Rural Poor (TRP) project, Indian research institutions have designed and are now testing a variety of medium- and high-temperature solar thermal concentrating systems, as well as low-temperature solar air heating units. As previously mentioned, these are all prototype units and, therefore, should be considered to still be in the research and development stages. In ascending order of complexity, they are: forced and natural convection solar hot air systems for rice drying (Annamalai University and Colorado State University); line-focus parabolic trough collectors producing medium-temperature steam for industrial applications (India Institute of Science (IIS), Bangalore, with the University of Houston); and two-axis, point-focusing, parabolic solar concentrators producing high-pressure steam for power generation (BHEL, with Jet Propulsion Laboratory of the U.S. National Aeronautics and Space Administration, or JPL).

The institutional context, developmental approach, and the problems encountered by the IIS and BHEL are fundamentally different from those of the Annamalai researchers, so these two systems will be treated together under the overall label "tracking concentrating collectors" in the sections that follow.

6.2 Site-Selection Process

For each of the PV or solar thermal technologies examined in India, one major site was selected by the India researchers to field-test the units. In the PV case, commercially available U.S. and Indian systems were installed at the Salojipally Energy Center. In the case of the solar thermal heat production systems, prototype units were developed through the U.S.-Indian scientific collaboration and then put out in the field for additional data gathering. In general, the locations were primarily selected for their accessibility to the research institution, followed by other considerations, such as the cooperation provided by state-operated (rather than private) facilities. Each PV or solar thermal technology or end-use application also had specific requirements which, narrowed the range of sites considered.

6.2.1 PV Pumping Systems

The three PV systems examined were all located at the Salojipally Energy Center, as part of the TRP project. This site was selected to meet a number of criteria, which included remoteness, availability of government-owned land near a village, size of the village population, distance from the BHEL research and development center, etc. In many ways, the site is representative of many villages in central and eastern India, with great seasonal fluctuations in surface water availability, good solar insolation, and little local availability of electrical or shaft power except through diesel generator sets. The applications selected (providing educational radio and television, street lighting, and small- scale irrigation pumping) are also representative of the priorities of the GOI for the near-term use of PV power.

6.2.2 Solar Rice Dryers

The Annamalai University staff had developed a variety of different-sized rice dryers, ranging from very low-cost black polyethylene drying platforms for small farmers to industrial-scale dryers for the medium-sized commercial rice mills that dot the South Indian countryside. The Annamalai staff provided one-day training programs, with the collaboration of various nearby farming groups and institutions, to groups of farmers in the Tamil Nadu state.

To test the industrial-scale units, the Annamalai/Colorado State University (CSU) team looked for a nearby rice mill that was of average size (e.g., 10 tons per day of throughput), operated year-round, produced parboiled rice (which requires two drying cycles) and that was interested in reducing its costs of operation by use of the solar dryer. Because the project was funded in part by the GOI, and because the DNES programs are implemented by the state governments, the search was directed toward Tamil Nadu state-owned rice mills. Finally, of course, the site selection process focused on funding a rice mill whose management was vitally interested in the drying services that the prototype unit could offer and would consider buying one or more units if the initial units proved satisfactory. This they found in the Tamil Nadu Civil Supplies Corporation Limited rice mill located in Chidambaram, only a few kilometers from the Annamalai University campus. This mill had the additional advantage, for demonstration purposes, of being located within 200 meters of three other similar-sized mills.

6.2.3 Solar Concentrators

The researchers at IIS/Bangalore considered a number of potential applications for their parabolic trough collectors, ranging from village-level electricity production to industrial process heat generation. Like the Annamalai test installation, the selection of the field-test site was a complex process that weighed budget availability, the desire to have a site relatively close to the IIS staff and easily accessible by truck transportation, and the political ease of working with a state-owned rather than private energy-using client. After discussions with three or four potential cooperative parastatal factories, the IIS team selected the Karnataka Silk Industries Corporation (KSIC) factory in Mysore, 100 kms from Bangalore via a good road.

The choice of a site for the integrated village energy system planned by BHEL and its PV collaborator, CEL, was even more complex and time-consuming than either the Annamalai or IIS subcomponents. The system was to be installed at a small, relatively impoverished village not yet connected to the electric grid. Because of the large size and weight of the solar dishes (nearly nine meters in diameter) and their support structure, and the need to bring in materials ranging from steam engines to large quantities of concrete, access to an excellent all-weather road capable of carrying heavy trucks was required. Because of the permanent nature of the installation (poured concrete foundations and several large buildings housing instruments, batteries and supplies) and the problems of negotiating for the purchase of private land, the search focused on available public land that adjoined an unelectrified village. Because of the complexity of the overall system and the need to do such activities as alignment of concentrator mirrors on-site, the BHEL staff wanted the site to be near their research and development center in Hyderabad. Lastly, for such a highly visible project, there are complex political considerations within the Indian national and state political systems. After considering a number of locations, BHEL selected Salojipally, a small village in Indira Gandhi's constituency and 110 kilometers west of the BHEL research center.

6.3 Technology and System Selection and Design Process

The selection of the technology for the PV system must be considered to be quite different from that of the solar thermal units, because the modules installed are commercially available, mass-produced units, while the solar thermal units are fundamentally lab prototypes. The PV cells have already been packaged into a system which is essentially a mature, if first-generation product, that has already gone through the production engineering process and several generations of field testing. The solar thermal units are being built in part to test the limits of the technology, rather than to market-test a commercial unit.

6.3.1 PV Systems

The Indian-made CEL and U.S.-Photowatt PV modules installed at the Salojipally Energy Center are composed of standard single-crystal silicon solar cells. The cells are protected from moisture, impact and surface damage by glass covers and silicon seals, as is now standard throughout the PV industry. The U.S.-made units were selected by the JPL staff through a competitive procurement process from the various major U.S. PV manufacturers. Each Photowatt module was then individually tested for its performance characteristics at the JPL PV test bed, which is an unusual and expensive process for commercial installations. It would have been far cheaper to simply purchase 5-10 percent extra modules and replace any defective or sub-optimal modules at the Salojipally site, but this advance testing did insure that the system would perform as well or better than the manufacturers performance specifications.

The Indian PV arrays were designed, fabricated and installed by the CEL staff. These are high-quality, single-crystal cells, cut from ingots at the CEL factory. All the steps of the fabrication process were done by those produced by U.S., German and French firms. The systems appear to be standing up well to field operation, although there may be some problems with premature degradation with a few of the modules.

The PV arrays have been installed in two different systems. The first is a small, stand-alone system which is mounted in the middle of the village to power the community television and radio. It was designed by the CEL staff, using the same basic model as has been used at other village test sites, using a small battery bank to store the power for nighttime community use. The second system is much larger and more complex and was designed jointly by the CEL and JPL staffs. It uses a large battery bank and electronically controlled timer to power a series of street lights for the village. It will also power irrigation pumps for fields near the village, once all the pumps are installed. It should be noted that the electricity provided by the PV systems is not being provided to the individual village homes for lighting and domestic applications, but rather to community lights and community entertainment. This decision was made mostly to insure that the load was constant, predictable and within the design parameters of the system, rather than to provide the services that the local villagers most value--household lighting.

6.3.2 Solar Rice Dryers

The design of the Annamalai University drying system was based on its extensive in-house experience in dryer testing, combined with assistance provided by CSU for optimization of several parameters (such as the best thickness for the contents of the drying bed for different air-flow rates and varying moisture counts). The design process seems to have been a highly iterative one, with suggestions by faculty researchers and mill operators being incorporated in successive models until the final design evolved.

Several original design concepts were tried and rejected, based on field tests. Several dryers, which used only natural convection, were tried, but these failed to either process enough rice per day to satisfy the millers or move enough air through the beds to ensure uniform drying (necessary to prevent the grains of rice from cracking which would reduce their market value). Therefore, several different configurations and sizes of blower were tested. Likewise, a whole variety of different low-cost solar absorbers were tested, both for absorptivity and durability. Successive versions of the industrial dryer were each larger and more automated, in response to comments provided by local millers, and the current 1.75-ton-per-day system is now going to be upgraded to two- and three-ton-per-day versions for commercial production.

6.3.3 Concentrating Collectors

The IIS/Bangalore linear parabolic trough collectors were designed and developed by the Indian scientists, after an examination of a number of existing U.S. systems and a thorough literature review. The design was optimized for thermal performance, but a number of different fabrication techniques were considered to find one that would be amenable to Indian assembly but still sturdy enough to maintain normal tracking accuracy at wind speeds up to 25 miles (40 kilometers) per hour and survivability at wind speeds up to 80 miles (128 kilometers) per hour. The Indian scientists then developed and tested three different methods of construction that seemed appropriate for Indian fabrication (semimonocoque, sandwich and stiffened rib structures). Prototype-design, miniature models were tested in wind tunnels for their durability and stability.

The major design problem was the high reflectivity and precise alignment of the collector surface that was required to

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focus the incoming sunlight on the absorber tube to achieve the design parameters of 60 percent efficient solar energy collection at 250°C. Also, an absorber tube of very high absorptivity and low emissivity is required to convert most of the concentrated solar insolation into usable heat. Using information provided by the Accurex Company, a commercial manufacturer of solar concentrators, the IIS staff finally settled upon a stiffened rib design, using high-reflectivity West German flexible mirrors. These could be easily attached to a metal backing, which in turn is clamped to locally designed and milled support ribs. In order to concentrate all of the solar radiation on the small (33.5mm outside diameter) receiver tube, the ribs had to be milled to very fine tolerances. This was done in India, using numerically controlled drilling or nibbling machines normally employed in aircraft manufacture.

One of the most notable accomplishments of the IIS staff was to develop a batch process for depositing an inexpensive but highly effective black chrome selective surface on the absorber tube. The high absorptivity (α = 94 percent) and low emissivity (ε = 0.15) of the absorber tubes rivals those produced commercially in the United States, and contributes materially to the excellent performance of the first prototype collectors.

The BHEL point-focus dish solar collector was designed in close collaboration with JPL specialists. It reflects the latest (1978) U.S. design attempts to build a high-concentration (15,000:1) dish concentrator using elements that could be mass-produced. While the designs were optimized from the start for Indian fabricating and operating conditions, the primary emphasis was on very high efficiencies and concentration ratios. This called for the use of many precision components which had to be custom-fabricated in the United States. It should be emphasized that the design was pushing the borders of existing technology not just in India but anywhere in the world. The constant need to alter the system when one component, which had been designed but never before built, proved unavailable was one of the constant problems confronting the BHEL and JPL staffs.

It should be noted that the solar dish technology was selected as an appropriate area for concentration by both senior GOI and JPL officials <u>before</u> any application was settled upon. There seemed a genuine desire to prove that India could build and operate this very complex technology, and that applications would then be found as a matter of course. There appeared to have been no consideration of alternative technologies that could have done the same work for less money or with less-sophisticated control systems.

One of the most interesting technical choices made early on in the joint design process was the selection of a prime mover. The problem was how to convert the concentrated sunshine into electrical or mechanical power efficiently. A number of thermodynamic system options were considered--Brayton cycle, Stirling cycle, and Rankine cycle--but only the Rankine cycle system was available, even in experimental configuration, in the size and weight required for the planned Salojipally village installation. As a prime mover, BHEL opted for a screw expander, but neither that system or a steam turbine is available in the small size needed for the project. Therefore, since JPL was able to procure prototype steam Rankine engines, it was decided to use one central steam engine, using steam provided by six tracking collectors. Given the inherent low conversion efficiency of the steam engines (13 percent is the rated steam to electricity efficiency) and the need to pipe the high-temperature steam over considerable distances (from the six dishes to the engine, with a resulting loss of 100°C during the transmission), a cost-effective system was simply not possible. Given the overall total solar energy-to-electricity design efficiency of only 8.1 percent, a set of six dishes (each with a diameter of eight meters and a surface area of 48.67 m^2) is required to produce 19.5 kW(e) at 800 watts/m^2/insolation of 12.4 kW(e) during the average rainy season minimum insolation of 550 watts/m^2. If a highly complex tracking collector, with multiple motors and parasitic drives, is unable to have even a design efficiency higher than a non-tracking PV system, which has no moving parts, then one has to wonder about the utility of the technology design for the rural poor.

6.4 Local and Private-Sector Involvement

Before discussing private-sector involvement in AID-sponsored energy components co-funded by DNES, it is important to note that the local state governments play an active role in selecting recipients of demonstration RETs and dispersing funds for RET subsidies. Because of this fact, state government-run enterprises often are asked to play the role of demonstration site for a new system that in the United States would be given to a private firm. Likewise, quasi-governmental production firms are often asked to act as prime contractors or subcontractors on the development and refinement of a technology. This has a pronounced impact on the resulting technologies, but it is difficult to measure in any systematic way. In general, state-run enterprises seem less efficient than their private counterparts, since until recently they did not have to compete for certain markets with either imported or locally produced goods. The same appears to be true for academic research institutions, such as were involved in the solar thermal development work. In addition, both the Indian parastatals and research institutions seem to be more interested in technical performance than in the delivery of low-cost energy services. At a number of critical junctures in the design process for several of the solar thermal systems, the decision was made to opt for high performance but expensive components, rather than for a unit with lower initial investment costs, less maintenance, and lower efficiency, but still enough performance for the needs of the potential users.

The price being charged to purchasers of CEL's PV output is really a transfer price, since DNES subsidizes CEL to cover portions of its capital investment and production costs. Moreover, many of the purchasers are other government agencies or parastatals, who prefer to deal with government-owned industries. The CEL PV systems are protected by large tariff barriers from competition by U.S., Japanese, French or German systems, which means that CEL management has little incentive in the short run to lower the costs charged to their customers (or the subsidies provided by DNES). One other important effect is that more emphasis is put on technical performance and less on cost per delivered unit of energy than there would be if Indian private-sector firms were involved. At a number of critical junctures in the design process for several of the solar thermal systems, a choice was made in favor of higher performance even though a less efficient system would meet the needs of potential consumers, require less maintenance and have lower initial investment costs.

6.4.1 PV Systems

Until recently, CEL (a GOI parastatal company) has had a virtual monopoly on PV sales in India. CEL PV systems have been protected by large tariff barriers from competition with U.S. Japanese, French or German systems. The GOI is now fostering internal competition by allowing BHEL (another parastatal company) to produce PV modules and has been discussing gradually reducing the amount of protection from external competition.

To date, the price being charged to purchasers of CEL's PV output is really an arbitrary transfer price, since DNES provides direct subsidies to CEL to cover large portions of its capital investment and production costs. CEL's sale price of $8 to $10 per peak watt is quite attractive for both public and private consumers in India, particularly for remote applications, such as telecommunications, pipeline cathodic protection and microwave repeater stations. Many of the purchasers at present are other GOI agencies or parastatals, who prefer to deal with other government-owned industries.

While CEL has been quite successful in producing a high-quality PV system, it seems clear that the lack of competition in the marketplace and its parastatal status has meant more emphasis on technical performance and less of the unsubsidized cost per delivered unit of energy than there would be if Indian private-sector firms were involved. With a backlog of customers at the subsidized price, there is also little incentive to aggressively sell the product or look for new applications.

6.4.2 Solar Rice Dryers

The Annamalai/CSU rice dryers were developed with an eye toward the needs and interests of three sets of users: small individual farmers, groups of farmers within a village, and commercial rice mills. The constant involvement of these sets of interested private rice producers and processors was crucial to the incremental development of the final successful designs. As soon as the Annamalai University developed one or more working prototypes, they tested them with one or more of the user groups and asked for their suggestions. As is true with good agricultural extension groups throughout the world, the Annamalai University staff seems to have a longstanding relationship with progressive farmers and processors in their area. Having introduced useful innovations in the past, they are listened to with respect and interest by the local farmers. Having showed in the past that they incorporate suggestions given them to produce still more useful technologies, the staff receive attention and cooperation when they bring new, unproven concepts to busy farmers and businesspeople.

The major design criterion for much of the solar dryer work was whether private individuals and/or firms would find a proposed system useful enough to purchase it. This was most crucial in the case of simple drying systems for small individual farmers, since the traditional, open-air drying method used by these farmers requires no capital investment. In order to win approval for even small investments, such as black plastic sheeting to spread over the ground, researchers had to demonstrate to groups of farmers that this would shorten drying time and increase rice quality and yields by lessening contact with the wet ground and crawling insects. With each modification that required additional investment or labor (addition of an insulating layer, the leap to a batch dryer with a forced air blower for groups of farmers, etc.), private users were consulted to see if they felt the change was significant enough to warrant the added investment or inconvenience. Several changes or prototypes were discarded because they failed this crucial test.

There was close collaboration between the solar drying research team and commercial rice mill operators during the development of the large, fan-assisted vertical dryers. Operators would examine and critique each successive model, asking for such changes as larger capacity, more automated feeding, shorter drying periods for each batch, and other commercial considerations. Private operators provided suggestions on equipment use, the amount of space the collector should cover before interfering with normal operations, and the research staff then tried to incorporate these into the next sets of prototypes.

6.4.3 Solar Concentrating Collectors

The development of both the trough and dish concentrating systems were primarily applied research efforts done within the research community, based on external patterns rather than on discussions with potential users. After the initial technical designs were completed, the demonstration site was then selected and the final system design tailored to the needs of the local user. IIS, in particular, designed its system to dovetail with the existing steam lines and production schedules of the KSIC in Mysore--an older facility that is currently undergoing a major renovation and expansion program, funded in major part by the World Bank.

Both of the concentrating collector projects were noteworthy because of the size of the talent pool that they employed for design and fabrication work. For example, the IIS team sought assistance from the Hindustan Aeronautics Ltd. for fabrication of the stiffened ribs, one of the BHEL facilities for the design and fabrication of a steam flash boiler, another group for the construction of the end flanges, etc. Because of the interest of the other quasi-governmental institutions and because of interpersonal ties among them, this work was often done at noncommercial rates. BHEL and CEL had an even more formidable task in building and assembling the Solajipally project, and so had to rely on a mixture of private Indian contractors, internal resources within their companies, JPL, U.S. firms hired by JPL, and U.S. firms hired directly by the Indian project managers. However, most of these public and private firms were simply making one or more custom pieces, built to BHEL, CEL or JPL specifications. They were not involved in the design process, nor were they interested as end-users in the final product.

6.5 Monitoring

A great deal of instrumentation and data acquisition equipment has been installed in conjunction with the Indian PV and solar thermal systems, but thus far it has produced few data that are useful for decision-makers. Part of the problem has been that certain types of information on items, such as user acceptance, maintenance problems, ease of operation, etc., are not yet the focus of attention for the technical staff. To date, the participating scientists have been interested only in system technical performance. Secondly, most of the systems have been field-operated for very short periods of time. While the PV systems have now been in place at Salojipally for more than a year, virtually all of the solar thermal units are still awaiting the start of their formal field monitoring. Another year or two of data collection will be required at a minimum before technical performance can be assessed for different loads, for all of the seasons of the year, and for the normal fluctuations of the resource base.

6.5.1 PV Systems

The initial plan was to collect comparative performance information on the Indian and U.S. PV systems, which were installed side-by-side at the Salojipally village energy site. This would be extremely valuable information, both for potential purchasers of the Indian systems and for the U.S. manufacturers. This was to include information such as energy output, fluctuation of power production versus levels of solar insolation, power production over time (which would help measure any cell degradation due to ultraviolet damage, heat stress, etc.), and a variety of other factors. Unfortunately, CEL staff had not installed the nece sary monitoring equipment as of December, 1984. It is planned that more extensive monitoring equipment will be installed in the near future, which will allow comparative data collection on two banks of PV modules, providing that funding can be found for the purchase of the data acquisition systems. Data are being collected on the overall electrical production from the PV array, the daily electrical demand and key parameters, such as the water pumped per day by irrigation system.

6.5.2 Solar Thermal Systems

Of all the solar thermal systems, only the solar rice dryer has actually undergone field trials. Data of interest to both the research community (half-hour readings of inlet and outlet temperatures, instantaneous solar insolation, moisture content of the rice batch being dried) are being measured and recorded, as well as the data being requested by the mill operators (time per batch to reach the required moisture content, consumption of electrical energy, and percentage of broken grains by weight in each batch). Very simple measurements of moisture content versus time were also logged for each field trial of the low-cost drying methods and the fan-assisted batch dryers.

Although not yet operational, both the BHEL/CEL and IIS projects have plans to install extensive monitoring and data acquisition systems that continually measure a host of performance characteristics of the solar collector and all the auxiliary systems versus the solar insolation, the demand, and any important environmental characteristics. In particular, the BHEL team will have no difficulties acquiring and analyzing enormous quantities of data, since there will be four computers used for data collection and interpretation in the daily operation of the six point-focusing collectors. However, some of the information that might be most useful to other countries from the Solajipally project, such as load put on the system by the collective use of the villagers for lighting and household appliances, cannot be measured because only street lighting is being provided by a timer switch.

IIS staff are planning to gather and collect system performance information on the 30 trough collector fields to be installed in Mysore by May 1985. It will include basic information on the solar insolation, the duration of the period of steam generation per day, the quantity and temperature of steam produced, the amount of fuel displaced (coal for the steam line's dedicated boiler), and the auxiliary power consumed for the various drives, motors and pumps.

6.6 Economic Analysis versus Diesel and Grid Extension

Because of their different applications, it will be necessary to analyze PV systems, solar rice dryers, and solar thermal concentrators separately for their economic feasibility. PV systems will be largely installed in India as alternative power sources to storage batteries for applications such as microwave repeaters, cathodic protection, navigational buoys, remote radio and television, and remote telecommunications. In virtually all such cases, as long as the installation is more than three to five kilometers from the electrical power, PV systems are normally a cost-effective alternative to batteries, with the initial investment bing paid back in three to 18 months from the savings in time for the system operators, reduced transportation costs, battery charging fees, and the frequent replacement costs of the batteries. For applications requiring 1.0 kW(e) or more in installed capacity, such as village lighting systems or pumping units at Salojipally, the logical alternative is a small diesel engine generator set or pumpset. In contrast, the low-temperature solar thermal rice drying unit is largely a space- and labor-saving device, as little electrical energy or fossil fuel is currently used in rice drying. Lastly, the solar thermal concentrator systems are either used to displace coal as a boiler fuel or as an electric-power generation unit, displacing diesel fuel directly.

6.6.1 PV Systems

For this analysis, we will examine the 7.5 kW(e) PV installation at Salojipally village and look at its costs and benefits vis-a-vis a small diesel installation. To avoid biasing the results, we will assume that all of the PV modules were produced in India at a cost of $10/peak watt. This eliminates the high cost of testing and shipping the U.S. arrays, although the India price underestimates the actual cost of system design and fabrication due to concealed subsidies to CEL. The PV system has 55 battery cells of two volts each, as in the Salojipally system, with the batteries requiring replacement every three years. Batteries are assumed to lower system efficiency by 20 percent. The total system costs will be 995,000 rupees for the PV unit (including 55,000 rupees for the batteries) and 8,215 rupees for diesel unit. In order to make the diesel and PV systems comparable, assume that each is bought with a seven-year, 12 percent loan in annual installments. The diesel selected will be a popularly available 7 HP Indian-made diesel, which produces about 5 kW(e) and is, therefore, slightly oversized for the application, but still the system of choice in most rural villages. The diesel unit will require routine maintenance every 400 hours and a major overhaul every 1500 hours of operation. The diesel engine will consume 1.5 liters of fuel per hour at a cost of 5.5 rupees per liter. Further assume that the same diesel generator set is used for both village lighting and water pumping. The costs for the lighting units, water pumps, transmission lines, and electronic controls are taken to be the same in both cases and so can be ignored. The results are given in Table 6-1.

In Table 6-2, we have recalculated the same installation, using a smaller PV system (5 kW(e)), a 20-year loan repayment, six percent interest, and the replacement of the diesel every five years, which is accounted for in the annual equipment sinking fund. While this analysis still favors the diesel system on a cash flow basis, the disparity between the systems is much smaller, reflecting the importance of both the length of the loan and the interest rate on the annual repayment schedules for system purchasers.

However, recent studies of PV systems that have been carefully sized and installed just for water pumping, without battery storage and many of the losses that multipurpose sytems require, can be cost competitive with both diesel and wind waterpumpers. In Table 6-3A (produced by Richard McGowan of ARD) appear the results of a detailed analysis for rural Yemen, based on 1985 price data. It shows that under conditions of high solar insolation, moderate wind regimes, and moderate diesel fuel costs, 2 to 3 kW(e) pumping systems can be price competitive based on a 20-year life cycle cost. (Table 6-3B is a graphic presentation of the same data.)

6.6.2 Solar Rice Dryers

Small farmers do not use either electricity or fossil fuels for drying their own rice crops. Rather, they dry the rice that they intend to keep for their own consumption and for future seed to 12-13 percent by spreading it on the ground, on mats, or on the roadway in the sunshine. Rice that is to be sold to rice mills is only dried to 18 percent, since the mills visited in southern India pay no more for rice dried below that point, but they offer lower prices for rice between 18 and 20 percent and refuse rice over 21 percent moisture. Open air drying for a single day will normally produce the required 18 percent level. Therefore, the economic analysis of the small-scale dryers must focus on the yield per hectare in terms of usable rice retained for the farmer's personal use and rice sold to the rice mills, with and without the drying sheets. The three-sheet system--in

Table 6-1

Comparison of the Annual Cash Flow Requirements in Indian Rupees of PV and Diesel Units for Village Lighting and Irrigation Pumping Purchased with a 12%, 7 Year Loan

	PV System	Diesel Genset
Capital Cost		
Annual Loan Repayment	209,250	1,800
Operating Cost		
Wages for operator	1,000	3,650
Maintenance Costs	0	3,300
Fuel Costs	0	11,660
Equipment Sinking Fund	0	1,680
Lubricants/Spare Parts	0	2,000
Total Annual Costs:	210,250	24,090

Table 6-2

Comparison of Annual Cash Flow Requirements in Indian Rupees for PV and Diesel Systems for Village Lighting and Irrigation Pumping Purchased with a 6%, 20 Year Loan

	PV System	Diesel Genset
Capital Cost		
	56,669	735
Operating Costs		
Wages for Operator	1,000	3,650
Maintenance Costs	0	3,300
Equipment Sinking Fund	0	1,680
Fuel Costs	0	11,660
Lubricants/Spare Parts	0	2,000
Total Annual Costs:	57,669	23,025

Table 6-3A

Financial Comparison of Various Irrigation Pumps

Assumptions:
Equipment costs inflate at 5%/year. No storage costs are included
Diesel fuel cost inflation is zero. All initial capital costs are current.
Diesel shipping included in capital cost.

	PHOTOVOLTAIC PUMPS				WINDMILLS				DIESELS			
Total Pumping Head (meters):	5	10	15	20	5	10	15	20	5	10	15	20
Amortization Period (years):	20	20	20	20	20	20	20	20	20	20	20	20
Pump/Motor Lifetime (years):	7	7	7	7	2	2	2	2	4	4	4	4
Discount Rate:	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
COSTS												
Initial Capital Cost	$24,200	$24,200	$24,200	$24,200	$12,500	$12,500	$12,500	$12,500	$4,349	$4,349	$4,349	$4,349
Shipping	$1,200	$1,200	$1,200	$1,200	$2,500	$2,500	$2,500	$2,500	$0	$0	$0	$0
Installation	$700	$700	$700	$700	$1,000	$1,000	$1,000	$1,000	$500	$500	$500	$500
Total Init.Cost	$26,100	$26,100	$26,100	$26,100	$16,000	$16,000	$16,000	$16,000	$4,849	$4,849	$4,849	$4,849
Annual O+M Costs	$100	$100	$100	$100	$400	$400	$400	$400	$2,365	$2,365	$2,365	$2,365
NPV of Replacement Parts Costs	$2,368	$2,368	$2,368	$2,368	$2,216	$2,216	$2,216	$2,216	$10,631	$10,631	$10,631	$10,631
Life Cycle Cost	$29,320	$29,320	$29,320	$29,320	$21,621	$21,621	$21,621	$21,621	$35,615	$35,615	$35,615	$35,615
BENEFITS												
Water Pumped per Year (m3)	179,945	89,790	59,860	44,895	108,004	53,984	35,989	27,010	161,220	80,592	53,728	40,304
Value of Output @$.05/m3	$8,997	$4,490	$2,993	$2,245	$5,400	$2,699	$1,799	$1,351	$8,061	$4,030	$2,686	$2,015
NPV of Benefit Stream	$76,599	$38,222	$25,481	$19,111	$45,975	$22,980	$15,320	$11,498	$68,628	$34,306	$22,871	$17,157
Effective Water Cost ($/m3)	0.02	0.04	0.06	0.08	0.02	0.05	0.07	0.09	0.03	0.05	0.08	0.10
Benefit/Cost Ratio	2.61	1.30	0.87	0.65	2.13	1.06	0.71	0.53	1.93	0.96	0.64	0.48

Financial Comparison of Water Pumps

PHOTOVOLTAICS, WINDMILLS AND DIESELS

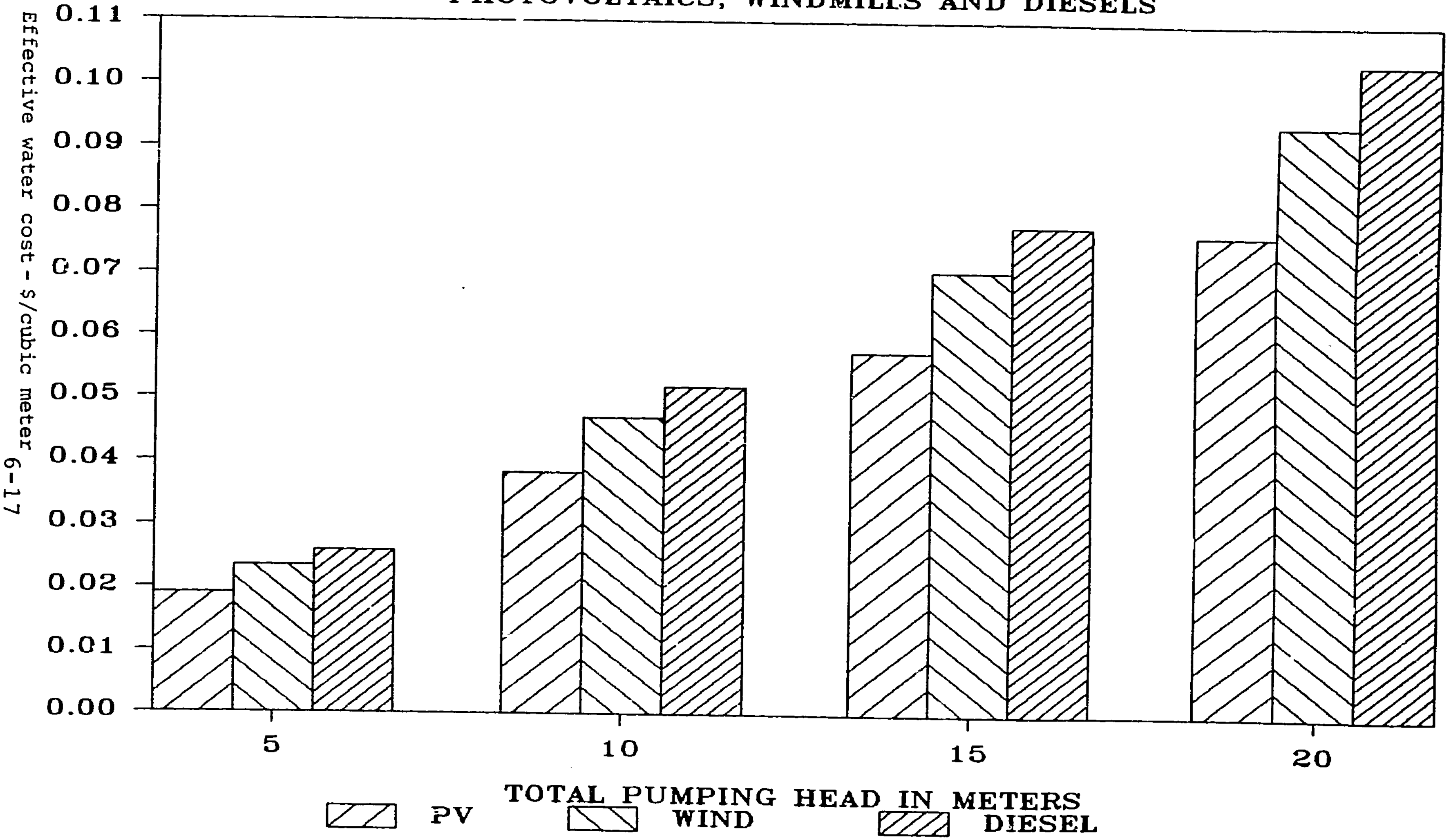


Table 6-3B.

which one black plastic sheet, used as a ground cloth, is covered with rice husk as an insulating layer, and a second black ground cloth, plus the rice to be dried and a translucent cover are supported over the rice--seems to offer the greatest advantage to small farmers. This system dries the rice more quickly, protects it from sudden rain squalls, blowing dust and marauding birds, and breaks fewer grains per unit volume. Because of the accelerated drying, the small farmer can get most or all of his personal drying done in a single day.

The medium-scale batch dryers developed by the Annamalai University staff do not appear to be economically viable. They require a small diesel or gasoline engine to power the blower--a capital and operating expenditure which the time saved in the drying process does not warrant. The large (1.75 ton/day) vertical dryer designed for commercial operations, however, has three advantages for mill operators. First, it produces a more uniformly dried product, which means fewer broken grains and a higher selling price per ton. (Annamalai University staff estimate that this will yield 10 rupees per ton or 17.5 rupees per day.) Second, it reduces the need to have large land areas for drying (a ton of rice requires 1,000 square feet of specially prepared surface) within or next to the mill. Third, it eliminates the need for a number of unskilled workers to be constantly turning the rice that is drying in the sun.

Annamalai staff estimate that the 1.75 ton/day dryer would save 35 rupees per day in wages, for a total savings (excluding the land not purchased) of slightly over 50 rupees per day. Most of the southern rice mills operate for 250 days per year, which means a total savings of 12,500 rupees per year. The dryer costs slightly over 32,000 rupees and requires slightly over 2,000 rupees per year in electricity for the 1 HP electric blower and the 1 HP elevator motor. While various replacement parts are required each year, the system seems to repay the initial capital investment plus interest in 3.5 to five years, without taking into account the large subsidies provided by the GOI.

6.6.3 Solar Concentrator Systems

Since there is already a coal-fired boiler installed at the KSIC factory in Mysore, the operation of the IIS-designed solar concentrator field will displace fossil fuels directly. Based on information provided by the KSIC engineering staff and IIS documents, it is estimated that the collector field will produce 80 kilograms of steam per hour for six hours per day, 300 days of the year. This 144,000 kilograms of steam is equivalent to 53.31 tons of coal. At the subsidized price provided to government factories in Mysore of 650 rupees per ton, the solar collector field displaces 34,651 rupees worth of fossil fuel per year. At the free market price (for private firms) of 1,250 rupees per ton of coal delivered to Mysore, the solar concentrator field saves

66,375 rupees in fuel costs per year. Given the initial capital investment for the solar concentrator system of 1,238,000 rupees, as well as labor and operating costs for the electrical drives and motors, the system does not yet seem appropriate as a private investment. However, the system can be upgraded to its full planned capacity of 80 collectors with an additional investment of approximately 1,000,000 rupees, since the boiler, steam line, and auxiliary systems have all been sized to accept the output (250 kilograms of steam/hour) of the larger collector field. The out-of-pocket fuel savings for the KSIC factory would then rise to 103,950 rupees per year, while the savings to a firm paying the real market price for coal would rise to 199,125 rupees. Even with these additional savings, the solar concentrator systems do not compete with coal if any market rate of interest on the initial investment or discount rate on fuel savings is applied.

The recent evaluation of the TRP project (Technologies for the Rural Poort Project: Findings and Recommendations of AID/DNES Evalution Team, by Ashworth, McGowan and Sootha, ARD, January 31, 1985) presented a detailed evaluation of comparative cost of the solar trough concentrator system versus coal and diesel under a number of different scenarios. Table 6-4 shows the detailed calculations for seven different solar concentrator costs alternatives, five coal alternatives, and four diesel fuel pricing structures. The results are more easily seen in a simplified graphic version of the data, which appears as Table 6-5. In this graph,

- column A is the current cost of the concentrator system,
- column C is the cost if the capital cost of the concentrator were to fall 50 percent,
- column H is the current subsidized price of coal,
- column I is using the free-market price of coal in India, and
- column M is using diesel oil instead of coal for the boiler fuel.

The BHEL/CEL Salojipally village energy system does not compete with either local diesel generated or grid extension costs. Looking at the point focusing dish collector field, the cost per installed kilowatt of capacity is $13,500 at 22 kW(e) output, or $24,800 for the less optimistic 12 kW(e) output figure. This is considerably more expensive than the installed cost of the 7.3 kW(e) of PV cells installed at the same site, which have no moving parts and require no attention except for occasional checks on the battery cells. Ironically, the solar thermal system requires a large substantial back-up unit to start

Table 6-4 Comparative Economics for Steam Generation

LINE-FOCUSING SOLAR CONCENTRATORS

SYSTEM:	A	B	C	D	E	F	G
Amortization Period (years):	20	20	20	20	15	20	20
Hardware Lifetime(years):	10	10	10	10	10	10	10
Discount Rate:	12%	12%	12%	12%	12%	16%	8%
Fuel Inflation Rate:	0%	0%	0%	0%	0%	0%	0%
COSTS							
Initial Capital Cost	$103,167	$77,375	$51,834	$25,792	$77,375	$77,375	$77,375
Shipping	$0	$0	$0	$0	$0	$0	$0
Installation	$0	$0	$0	$0	$0	$0	$0
Total Init.Cost	$103,167	$77,375	$51,834	$25,792	$77,375	$77,375	$77,375
Annual O+M Costs	-$2,063	$1,548	$1,037	$516	$1,548	$1,548	$1,548
NPV of Annual O+M Costs	$15,412	$11,559	$7,743	$3,853	$10,540	$9,173	$15,194
NPV of Replacement Parts Costs	$3,322	$2,491	$1,669	$830	$2,491	$1,754	$3,584
Life Cycle Cost	$121,901	$91,425	$61,246	$30,475	$90,406	$88,304	$96,153
BENEFITS							
Steam Generated (kg/year)	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
NPV of Benefit Stream	$74,575	$74,575	$74,575	$74,575	$68,000	$59,194	$98,024
Effective Cost of Steam ($/kg)	0.06	0.06	0.04	0.02	0.07	0.07	0.05
Benefit/Cost Ratio	0.61	0.82	1.22	2.45	0.75	0.67	1.02

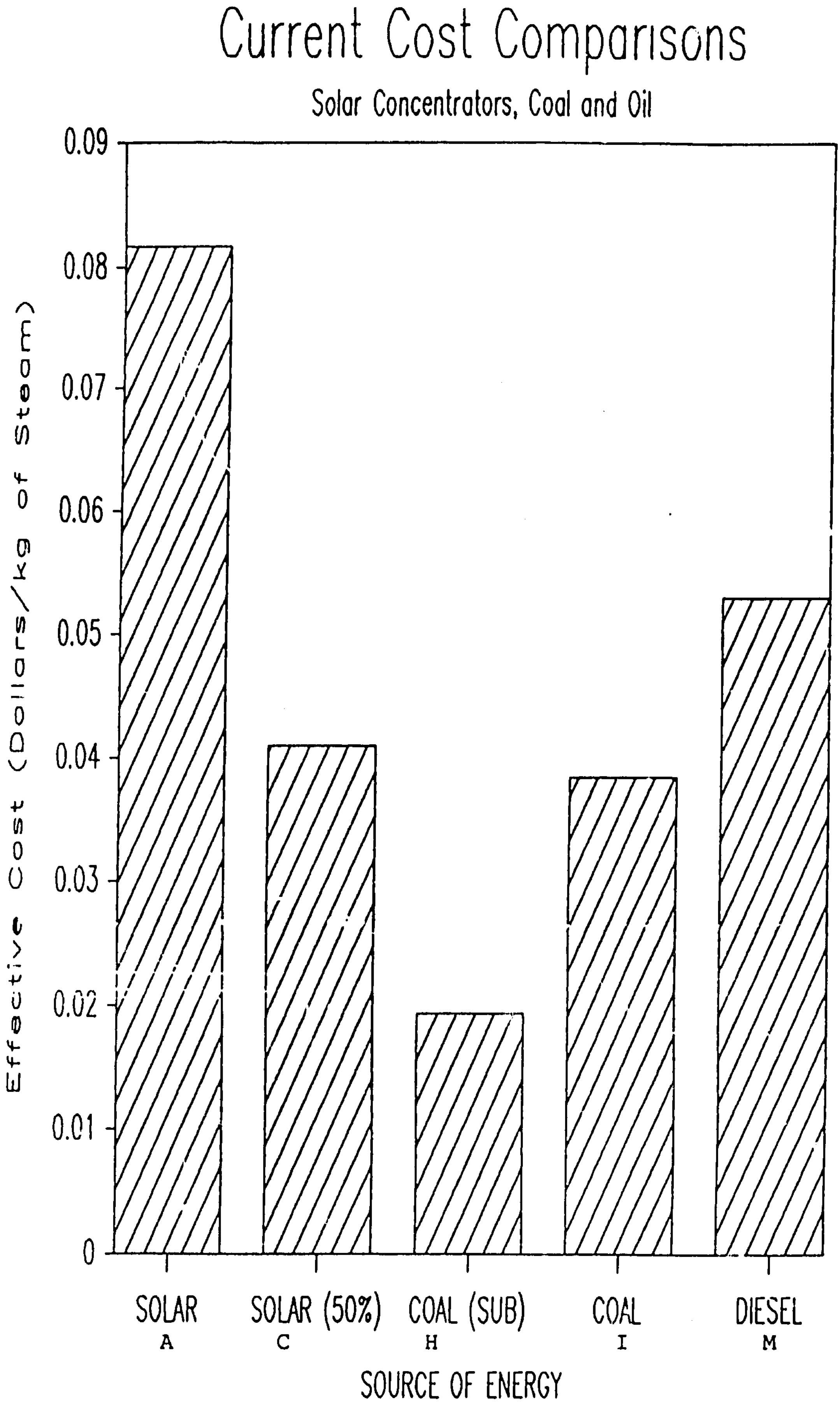
COAL-FIRED BOILERS

SYSTEM:	H	I	J	K	L
Amortization Period (years):	20	20	20	20	20
Hardware Lifetime(years):	20	20	20	20	20
Discount Rate:	12%	12%	12%	12%	12%
Fuel Inflation Rate:	0%	0%	2%	4%	6%
COSTS					
Initial Capital Cost	$0	$0	$0	$0	$0
Shipping	$0	$0	$0	$0	$0
Installation	$0	$0	$0	$0	$0
Total Init.Cost	$0	$0	$0	$0	$0
Annual O+M Costs	$3,883	$7,704	$7,704	$7,704	$7,704
NPV of Annual O+M Costs	$29,004	$57,545	$65,172	$74,426	$85,710
NPV of Replacement Parts Costs	$0	$0	$0	$0	$0
Life Cycle Cost	$29,004	$57,545	$65,172	$74,426	$85,710
BENEFITS					
Steam Generated (kg/year)	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
NPV of Benefit Stream	$74,575	$74,575	$74,575	$74,575	$74,575
Effective Cost of Steam ($/kg)	0.02	0.04	0.04	0.05	0.06
Benefit/Cost Ratio	2.57	1.30	1.14	1.00	0.87

Diesel-Fired Boilers

SYSTEM:	M	N	O	P
Amortization Period (years):	20	20	20	20
Hardware Lifetime(years):	20	20	20	20
Discount Rate:	12%	12%	12%	12%
Fuel Inflation Rate:	0%	2%	4%	6%
COSTS				
Initial Capital Cost	$0	$0	$0	$0
Shipping	$0	$0	$0	$0
Installation	$0	$0	$0	$0
Total Init.Cost	$0	$0	$0	$0
Annual O+M Costs	$10,594	$10,594	$10,594	$10,594
NPV of Annual O+M Costs	$79,131	$89,621	$102,345	$117,863
NPV of Replacement Parts Costs	$0	$0	$0	$0
Life Cycle Cost	$79,131	$89,621	$102,345	$117,863
BENEFITS				
Steam Generated (kg/year)	199,680	199,680	199,680	199,680
Value of Output @ $0.05/kg	$9,984	$9,984	$9,984	$9,984
NPV of Benefit Stream	$74,575	$74,575	$74,575	$74,575
Effective Cost of Steam ($/kg)	0.05	0.06	0.07	0.08
Benefit/Cost Ratio	0.94	0.83	0.73	0.63

Table 6-5.



Current Cost Comparisons
Solar Concentrators, Coal and Oil
Effective Cost (Dollars/kg of Steam)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
SOLAR A
SOLAR (50%) C
COAL (SUB) H
COAL I
DIESEL M
SOURCE OF ENERGY

the tracking system and auxiliary systems in the morning until the steam engine is generating at least 3 kW(e) of output. The unit being used, a Kirloshker 25 kW(e) diesel generator set, is capable of supplying the needs of the village without the use of the solar dish array.

BHEL researchers maintain that the current configuration of six solar dishes and one steam engine should be replaced by six Sterling engines, since this could increase the system electrical output by 200 to 240 percent. Unfortunately, these Sterling units are not commercially available, so we have no cost figures. We assume that they would cost a minimum of 1,000,000 rupees, but would eliminate the need for the steam engine, steam storage, condenser, tank, control valves, etc. If the net price rise was just 500,000 rupees, then the cost would rise to a total of $335,000, but the cost per installed kilowatt of capacity would drop from $12,400 to $6,750, due to the 200 percent increase in power. Even with this reduction, the solar thermal system is marginally competitive with PV units (because of the parasitic losses and skilled labor requirements), and not competitive with diesel or grid extension for virtually any village-scale site.

6.7 Economic, Technical and Social Performance

Of the technologies examined in India, only PV arrays can be said to have had enough field testing to assess economic, technical, and social performance. Therefore, the bulk of this section will be devoted to PV arrays and their future in Indian rural applications. The solar thermal concentrator units, as has been stressed throughout this section, are still in the prototype development and modification stages, and it would be inappropriate to talk about them other than in broad generalities. The solar rice drier has been briefly field-tested in one rice factory, so that experience will be recounted.

6.7.1 PV Systems

As was shown in Table 6-3, PV systems can be the least-cost solution for certain rural applications, even for countries with subsidized diesel prices, providing the system is carefully matched to the end-use In India, this had led to the installation of hundreds of locally made PV systems for applications such as microwave repeaters, battery chargers, navigational buoys, remote radio-telephone transmitters, and remote educational television. For example, CEL staff are expecting to manufacture and install this year 170 low-power TV transmitter and retransmit packages for remote locations, which will be powered by PV arrays. They are also planning to supply 100 small PV-powered pumping systems, each 300 watts, to DNES for irrigating two-hectare plots. These are each expected to provide 40 cubic meters per day at a head of five to six meters at a subsidized price of 25,000 rupees.

Thus far, there appear to be few technical problems with the PV systems installed in India, other than the normal difficulties with systems that use batteries in remote sites and require frequent battery maintenance or replacement. PV arrays normally are the easiest of power supplies to maintain, since they have no moving parts and little degradation over time. The only design question is whether there is a need to fence off the PV arrays to protect them from vandalism, animals, wind or hail damage, and other natural environmental problems. There did not appear to be any major problems with the systems observed at Salojipally, other than some discoloration and possible degradation of several of the CEL PV modules.

PV systems do not have any apparent obstacles to social acceptance in rural India. They are noiseless, produce no smoke or pollution, and provide a highly valued service--electricity. They require very little expenditure of local time and energy, other than attention to any batteries and electrically driven equipment. The one unanswered question, of course, is whether these advantages outweigh the high initial capital cost of PV systems in the eyes of rural consumers. Thus far, virtually all purchases have been made by government agencies, parastatal firms, or foreign assistance projects supported by international donors.

6.7.2 Solar Rice Dryers

Of the solar technologies under develoment in India, only the rice dryers have been successfully tested under operating conditions. They seem to meet both technical and economic performance criteria of end-users and have a wide-scale applicability throughout the rice belts of India and Southeast Asia. The technical performance is quite acceptable for small rice mills (10 tons per day of throughput), but might not be sufficient for those Indian regions and for those other Asian countries where rice milling is more centralized. Given the fact that India has more than 300,000 rice mills and countries such as Thailand have more than 40,000 commercial mills, this technology seems to be widely applicable. The GOI and Annamalai University are discussing the construction of a number of demonstration units, probably two to three tons per day in capacity, to be distributed at rice mills in the major rice-producing regions.

The major question remaining is what is the trade-off between solar rice dryers and drying units that are fired with the direct combustion of rice husks. While larger, more complex and more expensive than solar units, boilers fired with rice husks can produce process heat for drying and electricity. Such units are commercially available and are widely used in the larger, more modern mills in India, Thailand and the Philippines.

It is too early to comment on the performance of either the IIS linear solar concentrators or the BHEL point-focus concentrators. Given the outstanding technical capabilities of the research staffs working on both of these projects, the still-unresolved technical problems can probably be overcome. The IIS concentrators, for example, have yet to go through systems integration testing, and the long-term durability of the flexible mirrors in field conditions has yet to be determined. The BHEL system has so many complex components that it is difficult to do more than list the technical components that need to be field-proven: the receiver coils, custom-fabricated in the U.S.; the Carter prototype steam engine; the computer-based "memory" tracking system, which allows the six dishes to continue to track when the clouds obscure the sun; the flexible joints that allow the pressurized steam lines to connect six moving collectors to a fixed steam engine, etc. In both cases, there is no information yet available on the vital question of whether the units can be routinely operated by technicians with modest solar thermal training, or whether research engineers will have to service the units continually to keep them running.

As noted in section 6.6, neither of the solar thermal concentrator systems has yet demonstrated its economic viability for current Indian applications. The IIS trough concentrators appear to have promise for a variety of middle temperature industrial process heat applications (125-200°C steam). Widespread commercial applications will require either a price reduction of 30-50 percent kilogram of steam delivered or continuing GOI subsidies. If the technology proves to be simple to operate and durable, mass-production of batches of 200 could probably achieve these price levels without major modifications in the system design, providing that the expensive imported components (the flexible glass and the collector array drives) can be fabricated inexpensively in India. The BHEL system will have a great deal of difficulty becoming commercially viable, because of its complexity and fine tolerances. It has little applicability in any locations where there is not a set of highly trained engineers in residence. Because of the high temperatures and precise tracking required, the system is not very "forgiving" of human errors or mistakes in fabrication or operation. The analogy used by several Indians of the Salojipally project development effort as a "moonshot" is extremely fitting. While scientifically exciting and stimulating, operating a missile launching is not an activity that one would expect to turn over to a technician for routine, unassisted execution. There is too much that can go wrong, and someone who is intimately familiar with the operation of the system must be present to pinpoint the malfunction.

Social performance and acceptability cannot be inferred from laboratory testing. Within their given skill ranges and experience, people throughout Asia have shown a willingness to operate and maintain renewable energy systems that provide a valuable service, particularly if it helps to boost their income. The IIS concentrator may well be able to meet these criteria for industrial users of low- to medium-temperature process heat, especially if they are dependent on expensive imported fuel.

It is planned that the existing engineering staff of the KSIC factory will take care of the operation and maintenance of the solar concentrator system, so this will be a vital test of its suitability for future industrial applications. The BHEL system does produce an end product--electricity, which is highly valued by both rural and industrial users. The BHEL staff is planning to use it principally for irrigation pumping, an application that is among the highest priorities of rural farmers. But it is difficult to assess how the concentrating dish technology will be "accepted" by the villagers, since they will have no part in building, operating, or financing the unit. It will be "acceptable" in the same way as a very small nuclear power station is, only without the concern about radiation or radioactive contamination. The BHEL system will never be a part of a village and could, in fact, be located at a distance with the power transmitted to local users. BHEL has already suggested that the solar dishes be located in clusters of 30 to 35 dishes, each dish with its own Sterling engine, which would then serve as a 120-200 kW(e) mini-power station for five to 10 surrounding villages. It is doubtful that this approach will be less expensive, even using life-cycle costing, than extending the existing electrical grid.

6.8 Potential for Replication

When discussing replication of a technology, it is useful to differentiate between the adoption of the technology, which means that users find it useful and cost-effective relative to other ways of doing the same work, and production of the technology, which may imply the creation of a technically sophisticated and cost-competitive industrial infrastructure. For example, the video cassette recorder (VCR) technology has been adopted with a vengeance by consumers in virtually all of South and Southeast Asia, but production of VCRs has been restricted until recently to Japan, Korea, Singapore, and now Malaysia. As we have seen in case studies in sections 3.1 to 6.7, these two characteristics may be independent of one another, but they do tend to be self-reinforcing if they both exist simultaneously in the same country. Users in countries that do not produce diesel generator sets do purchase and use them, but those living in countries that have in-country diesel production and or maintenance facilties tend to adopt them more readily. We have found that local participation in system adaptation or construction is often very important to widespread adoption of the technology. In the two sections that follow, we will apply these lessons to the cases of PV and solar rice dryers in India, in order to attempt to gauge the windspread applicability of these technologies in that country and in other Asian nations. It is an interesting comparison because of the question of suitability for local production of the two technologies. Concentrating solar thermal technologies will not be analyzed here, since the systems are still prototypes that have not been fully field-tested, making it difficult to judge their replication potential.

6.8.1 PV Systems

PV systems have a potential for very widespread application, in India as well as the rest of South and Southeast Asia. For small-scale, remote applications, the technology is already commercial and the system of choice for specific sets of clients. If the price of PV per kilowatt of peak power drops, as it is expected to do gradually over the course of the next five years (as amorphous and thin-film PV cells are mass-produced in commercial quantities), it will find a broader and broader range of applications. Of the PV systems examined in India, those powering radio, TV and community lighting are quite cost-competitive with other technologies now and will be widely replicated in the next five years. The PV irrigation systems are still too capital-intensive for private investments at present, partly because of the low-cost of small-scale diesels throughout India and the rest of Asia, due to high volume, local production. These pumping systems will be built, on a limited basis, as part of the long-term GOI plan to build a local production capacity for PV-powered remote systems.

The most interesting question that is yet unanswered is whether the Indian decision to create a large, indigenous PV production capacity, largely with its own resources and research, should or will be replicated in other developing countries in the Asian region. Indian officials are discussing the creation of an in-country production capacity of seven megawatts of PV cells per year by 1987, which would make India one of the leading producing countries in the world. India has an extremely large scientific infrastructure, which has enabled it to catch up quickly with the U.S., French, German, and Japanese firms in the quality of its product. It also has an enormous internal market for small remote-power system, which guarantees a ready audience for CEL and BHEL PV arrays so long as foreign modules are excluded. It is difficult for the outside observer to estimate what is the implicit subsidy for each CEL module, but it appears to be quite substantial--perhaps 50 percent of more of the sales price.

By subsidizing the price, the GOI is trying to create a demand-pull situation, where rapidly rising demand will provide the investment funds necessary to create a world-caliber PV industry. However, other countries in Asia maintain that this approach has two basic problems: it requires protection from developed-country suppliers, so that the PV cells are more expensive to the society than they would be otherwise; and it locks the country into a first-generation technology that will require increasingly greater protection as newer, less expensive PV technologies are created in foreign private firms (with large quantities of research and development assistance from their governments). For these reasons, it is expected that other Asian countries will move to the assembly and wiring of PV modules or will form joint ventures with foreign PV firms for in-country production in order to gain direct access to ongoing research and development work. Most will not chose to follow the Indian example of indigenous research and development, at least for the next five years, until one or more of the second-generation PV systems is established as being superior to the other candidates.

6.8.2 Solar Rice Dryers

Of the solar thermal technologies examined in India, the Annamalai CSU rice dryers seem prime candidates for replication there and possibly in other major rice-producing countries as well. The largest initial Indian market will be in the southern states because of the tradition of parboiling the rice (and then drying it a second time) at the local mill. The GOI is actively considering building 10 to 20 more demonstration solar rice drying units, each slightly larger than the existing 1.75 ton day model. The hope is to get firms that are currently in the business of supplying equipment to rice mills or individuals involved in building or selling other renewable energy technologies interested in building these demonstration models under contract to the GOI. If they prove durable and economically feasible, the hope is that the firms will then add these solar dryer models to their existing lines of equipment and actively market them to rice mills, cooperatives, and other potential users.

There are over 300,000 rice mills in India, most of them relatively small. The vast majority use open air drying, which requires a great deal of labor to constantly stir and rake the rice to prevent sun damage to wet rice kernels. The Annamalai University solar rice dryer offers an attractive capital investment. Because the solar dryer requires a substantial amount of space (although only half that of open air drying), it might be suitable only to smaller rice mills in countries such as the Philippines, Thailand and Bangladesh. However, since Thailand has over 40,000 rice mills, many of them small and located in rural areas, the design may well be readily transferred with appropriate design modifications for the specific needs of the Thai miller.

7.0 LESSONS FROM THE FIELD

During the field visits in Nepal, Thailand, the Philippines, and India on which this report is based, a large number of installed renewable energy systems were examined. Operators, owners, and system designers were interviewed and their opinions solicited on how the design might be altered to make the technology more useful, durable, reliable, and competitive with other available energy systems. While many of the answers gathered are technology and site specific, there are a number of general observations that apply to many or all of the systems and that appear to be applicable throughout the Asian region. Five of the most important injunctions are briefly explained below, as guides to project managers who are seeking to promote the use of renewable energy technologies or who are trying to understand the roles that such systems will be able to play in the future, or who are simply trying to better understand the process of technology development and adoption.

7.1 Provide a High Value Service

Asian rural families and entrepreneurs have rapidly adopted renewable energy technologies (RETs) that provide them with a service that they value at a cost competitive with or slightly lower than that provided by traditional technologies. While this seems simplistic, it is the key to the rapid success of systems such as the Nepalese microhydro mills and the commercial PV installations in India. It also explains the willingness of Northern Thai villagers to provide 20-30% of the cost of a microhydroelectric installation, in the form of labor and materials: they feel that the coming of electricity will dramatically improve the quality of their lives.

7.2 Provide Additional Income for Owners or Operators

This is really a corollary to the first admonition above. Renewable energy systems that help generate an income stream for the owners and operators are both more highly valued and better maintained than those that provide a social service. Biogas plants in Nepal that are used for operating mills appear to have received better maintenance attention than those which provide their owners only with lighting or lighting and cooking fuel. The Thai microhydroelectric systems seem to be troublefree in part because the systems generate enough income, through user charges, to provide the operator with a monthly salary. That salary is dependent on system performance, so he insures that all maintenance schedules are met. Philippine gasifiers were more successful in locations where the savings from the substitution of charcoal for diesel fuel was great enough that the cooperative could avoid costs and still pay the operator a good salary.

7.3 Promote Technologies with a High-Quality, Well-Distributed Local Resource Base

The output of renewable energy technologies are directly dependent on the strength of the resource base, whether it is solar insolation, moving water, wood, wind energy, or animal manure. The performance of any given RET design, and therefore its economic viability, will be at least partially dependent on the resource base locally available to power it. Solar systems work best in areas with intense sunshine and little cloudiness, while microhydro mills are normally installed on streams with year-round flows. While this point seems to be self-evident, there have been many efforts to promote RETs in developing countries that have failed because the resource base was only barely adequate, or badly matched to the pattern of demand. Wind energy conversion systems for electrical power generation have been tested in many countries in Asia, but few locations have the constant high wind velocities that make such systems economical.

In order to have a technology be useful for national development, its resource base should be available at a large number of sites. This is one reason why microhydro mills have been so popular in Nepal, since there are thousands of potential sites scattered throughout the foothills of the Himalayas and a corresponding number of small villages that highly value the services the mills provide. It is the widespread dispersion of the resource base and its current lack of utilization that makes any biomass technology that uses rice husks as a fuel so appealing to researchers and entrepreneurs alike in India, the Philippines, and Thailand.

7.4 Promote Technologies that Can Be Locally Repaired and Fabricated

Most countries in Asia actively promote the replacement of imported goods with locally produced products. This extends from textiles to microprocessors, although the emphasis varies drastically from country to country. Given the sophistication of many of the industrial sectors in South and Southeast Asia today, there are few RETs, including PV arrays and large solar thermal dishes, that cannot be fabricated on a pilot basis. However, to become commercially viable, such technologies have to be serviceable by local maintenance facilties. If a system is to function well for an extended period of time in a rural Philippine village, it has to share the same repair and maintenance facilities that currently service small walking tractors, threshers, motorcycles, and other small engines. Belts for the Nepalese microhydro mills can be site-repaired or new ones fabricated without going back to the factory. All the parts for the collector of the solar rice dryers are readily available in most Indian small agricultural market towns, as are the spare parts of the blower and bucket loader. If the parts have to be sent back to the capital city or to an overseas supplier for repair or replacement, the system will likely be unused for much of the year.

7.5 Have Potential Users Participate in the System Design, Adaptation or Construction

Systems that have been modified to meet local operating procedures, preferences, feedstocks, and environmental conditions generally are rewarded with more rapid local adoption. Some communities, for example, are comfortable with cooking gas produced by the anaerobic digestion of both human and animal manures, while others are not and will not use the gas. Some want electrical power to be provided to community facilities, while others are only interested in receiving power at their individual households. All of these factors, along with the nature of the resource base, the value of the service to be provided, and possibility of local repair, must all be considered. This type of information is best obtained from potential system users or purchasers, and then should be incorporated into subsequent system revisions prior to widespread promotion or dissemination.