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TECHNICAL FINDINGS ON THE PERFORMANCE OF RENEWABLE ENERGY TECHNOLOGIES IN AFRICA: RESULTS FROM FIFTY-FIVE PROJECTS IN SEVEN SAMPLE COUNTRIES

April 1984

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PREFACE

The following report is a compilation of the findings of an intensive effort to gather information on field experiences with renewable energy technologies in Africa. The gathering of these data was truly a group effort, involving four different teams, with membership drawn from Associates in Rural Development, Inc. (ARD), the U.S. Agency for International Development (AID), and independent consultants. Seventeen individuals were involved in the data collection, analysis, and initial report preparation. The field research for this report took place during October and November 1982.

After collecting the data, ARD prepared an initial analysis, which resulted in a preliminary report submitted to AID in late January 1983. Preparation of the final report by AID staff, including integration of the findings into the larger AID policy formulation process, is still taking place and will result in the publication of a major AID evaluation report in the near future.

Because of the importance of these data--being based, as they are, on a large and geographically diverse field sample--ARD has decided to publish the technical findings portion of the preliminary report so that researchers and policymakers will have access to it while the comprehensive AID document is being prepared. ARD hopes that this information on field performance of systems will help decision-makers determine whether these systems have potential for meeting their site-specific needs for small energy systems, while simultaneously alerting energy researchers and system designers to prevalent field problems that require immediate attention.

The research contained in this report was sponsored by the AID Africa Bureau, under a contract with ARD. AID will be publishing, in the near future, a revised and edited version of the findings, including a number of recommendations for new policy directions, for revisions of AID energy policy, as well as for the integration of energy concerns into other AID areas of concentration. For this reason, only technical findings, based on the field research, have been included in the present document. It is hoped that these will provide useful grist for energy researchers and policymakers alike until the AID evaluation report is released.

The major author of the technical sections that follow is John Ashworth of ARD, with George Burrill, also of ARD, authoring the section on project monitoring, evaluation and management. The overall management of the project was provided by Mark Ward of AID's Africa Bureau. However, the data collection and revision of the first draft were the responsibility of a number of individuals.

The field teams were composed as follows:

- Botswana - Bernadette Bundy, Eric Petersen, Ron White
- Kenya - Bernadette Bundy, Eric Petersen, Ron White
- Lesotho - Shirley Burchfield, Clarence Kooi, Martin Wulfe
- Mali - George Burrill, Wallace Tyner
- Rwanda - Shirley Burchfield, Mark Ward, Martin Wulfe
- Senegal - George Burrill, Weston Fisher, Clarence Kooi, Wallace Tyner
- Upper Volta - John Ashworth, Mark Ward

In addition, Janine Finnell, Ted Jonas and Mike Zak of AID and Edwin Harvey of ARD played major roles in collecting data for national energy profiles for the seven sample countries.

The preliminary drafts were greatly improved by the comments and assistance of a number of individuals, in addition to the field staff listed above. These include Richard Donovan (ARD), Martin Wulfe (ARD), Shirley Burchfield (Argonne National Laboratory), Janine Finnell (AID/AFR/TR/SDP), Clarence Kooi (AID/AFR/REDSO/W), Wallace Tyner (Purdue University), Richard Cirillo (Argonne National Laboratory), and Edwin Harvey (ARD). Valuable suggestions on policy directions were provided by Molly Hageboeck (AID/PPC/E).

GLOSSARY

AID	U. S. Agency for International Development
ARD	Associates in Rural Development, Inc.
BTC	Botswana Technology Center
BTU	British thermal unit
CEAER	Centre d'Etudes et d'Application de l'Energie au Rwanda
CERER	Centre d'Etudes et de Recherches sur les Energies Renouvables
CES	Commissariat a l'Energie Solaire
CFA	Communaute Financiere Africaine
CIDA	Canadian International Development Agency
CIEH	Centre Interafricain d'Etudes Hydrauliques
CMDT	Compagnie Malienne de Textile
EDI	Energy Development International, Inc.
FAC	Fonds d'Aide et de Cooperation
FAO	Food and Agriculture Organization of the United Nations
FY	fiscal year
GDP	gross domestic product
GNP	gross national product
GJ	gigajoule
ISRA	Institut Senegalais de Recherche Agricole
ITA	Institut de Technologie Alimentaire
ITDG	Intermediate Technology Development Group
kcal	kilocalorie
kwe	kilowatt electric
kwh	kilowatt-hour

LVIA	Lay Volunteer International Association
MCRD	Ministry of Cooperatives and Rural Development
MHER	Ministere de l'Hydraulique et d'Equipement Rural
MMRWA	Ministry of Mineral Resources and Water Affairs
MTC	Ministry of Transport and Communications
NASA	National Aeronautics and Space Administration
ORTPN	Office Rwandais de Tourisme et Parcs Nationaux
PCV	Peace Corps volunteer
PPC/E	Office of Evaluation, Bureau for Program and Policy Coordination, Agency for International Development
PV	photovoltaic
PVO	private voluntary organization
REDSO/ESA	Regional Economic Development Services Office/East and South Africa
REDSO/WCA	REDSO/West and Central Africa
RET	renewable energy technology
RIIC	Rural Industries Innovation Center
RSA	Republic of South Africa
SIDA	Swedish International Development Agency
SINAES	Societe Industrielle pour l'Application de l'Energie Solaire
SOFRETES	Societe Francais d'Etudes Thermiques et d'Energie Solaire
toe	tons of oil equivalent
UNDP	United Nations Development Program
VITA	Volunteers in Technical Assistance

I. EXECUTIVE SUMMARY

In response to the multi-faceted energy problem which emerged in the mid-1970s, AID's Bureau for Africa initiated in 1977 an effort to test new, sustainable energy sources and technologies as part of an agency-wide program. This initiative was based on the unique situation in Africa with its especially heavy reliance on traditional energy sources, such as fuelwood, dung and agricultural residues. The testing and adoption of renewable energy technologies (RETs) and strategies was linked to AID's focus on the poorest of the poor, primarily in rural areas. It stressed ways of meeting energy needs in the areas of:

- cooking and heating by the rural and urban poor; and
- water supply, grain grinding, irrigation, handicrafts, other basic life functions.

In early 1982, the Bureau for Africa began an effort to determine what the projects undertaken by AID's African missions had learned about the prospects for extensive use of particular RETs in Africa. While many AID-financed projects are still in the research and development stage, with significant dissemination and consequent impact well in the future, it was felt that certain lessons could be learned that would improve the design and implementation of energy activities elsewhere.

This study's methodology was not a typical project evaluation effort--rather, it was designed to answer five basic questions:

- What has been the observed technical performance of renewable energy systems currently installed in selected AID African countries?
- What problems have been observed with renewable energy systems installed in the field in Africa, in terms of social acceptance, institutional compatibility and required technology delivery systems?
- What has been the comparative performance of alternative renewable energy systems in the provision of usable, cost-effective energy for specific African end-use applications in the areas of agricultural production, domestic consumption, agricultural processing and food preservation, and small-scale commercial and industrial operations?
- What mechanisms currently exist within ongoing AID and non-AID African development projects that allow for "real-time" monitoring of installed renewable energy systems and modification of technologies or project

elements to take advantage of lessons learned from technology monitoring?

- What is the potential of renewable energy systems presently installed in Africa to provide significant portions of the energy consumption projected for the countries examined and the whole sub-Saharan region by the years 1990 and 1995?

In October and November, 1982, the AID Bureau for Africa sent four teams of AID and contractor staff to Kenya, Botswana, Rwanda, Lesotho, Upper Volta, Senegal and Mali, spending about two weeks in each country and visiting more than 75 projects in all. Teams examined AID-sponsored projects as well as other multilateral, bilateral and private voluntary organization (PVO) development projects, and private-sector firms employing renewable energy systems.

As with most assessments of such a broad nature, certain factors--for example, the lack of good field data on some technologies--limit the extent to which generalizations can be drawn from the observations made. Despite these limitations, patterns emerged in the findings which can be most instructive for AID's Africa Bureau, and the donor community in general, in orienting future energy activities. The major findings are outlined here according to the five questions which guided the assessment. These are followed by a brief summary of the assessment teams' key conclusions and recommendations.

Question One--Observed Technical Performance: The main general finding concerning observed technical performance was that most of the renewable energy systems being adapted and field-tested in the seven countries visited have reliability, durability and physical output levels considered desirable by African researchers and, in the case of field-tests, local users. Although solar thermal pumps and anaerobic digesters are notable exceptions, other technologies, such as low-cost efficient stoves, factory-produced windmills and PV arrays, have higher levels of consumer preference and acceptance than technologies or practices currently in use. Certain systems, such as low-cost wind water pumps and efficient charcoal stoves, are currently undergoing country-specific adaptation that promises increased reliability and durability in the near future in these nations. It was also found that sufficient data exist to narrow the broad range of RET options being considered for widespread application in Africa. Several appear to have very limited applicability in most African settings, including family-scale bio-gas digesters and solar dryers, solar cookers and hydraulic rams for potable water pumping.

Question Two--Social Acceptance and Dissemination: Since many RETs are just emerging from (or are still in) the laboratory prototype and field-testing stages, field data from dissemination

efforts are severely limited, except for a few technologies, such as stoves. One key finding, however, is that the widespread application of many RETs in Africa is hampered by the lack of local repair facilities, supplies of spare parts, and trained operation and maintenance personnel.

Question Three--Economic Viability: Although good technical data sometimes exist on RETs' field performance, accurate assessment of their cost-effectiveness and affordability is severely restricted. Little usable information is being collected on current economic costs or long-term economic viability for most of the renewable energy systems examined. Where information is available and RETs appear cost-effective, two different sets of findings emerged. First, significant commercial sales and distribution networks are currently operating for several manufactured RETs, while some low-cost systems are being built or sold at the village level. Second, little attention has been paid thus far to the question of making the more capital-intensive RETs accessible to potential African end-users as investments. The result is that the first to adopt many technologies will probably not be the rural and urban poor, but rather relatively well-off urban dwellers, medium- to large-scale entrepreneurs and organizations providing social services in remote locations.

Question Four--Monitoring and Evaluation: A clear positive correlation was found between projects and technologies that were making progress and developing sound technologies, and the use of a monitoring and evaluation scheme or system. Also, formally gathering and incorporating user/client opinions was found to be a key element in modifying technology designs to produce better, more socially acceptable renewable energy systems. Again, a clear lack in collecting and analyzing financial/market information was evident. Of equal interest is the finding that there is often little sharing of lessons learned from field-testing between projects, even in the same country. Thus, information being collected in technology monitoring is not available to practitioners addressing similar problems.

Question Five--RETs' Applicability to Africa's National Energy Needs: The role that renewable energy systems can be expected to play in Africa's future varies widely depending on the end-use application. RETs have a particularly strong potential role in domestic and small-scale applications, such as cooking and energy-intensive cottage industries--restaurants, breweries and potteries. In laboratory and field trials, efficient fuelwood and charcoal stoves have demonstrated the technical capacity to reduce cooking fuel use by 20 percent or more--an end-use that accounts for more than 90 percent of total energy consumption in many African countries. However, many stove projects are just now beginning dissemination in the field, so the actual long-term impact on fuelwood and charcoal consumption is unclear, though it looks promising.

AID in general, and the Bureau for Africa in particular, have as a central principle the promotion of increased agricultural productivity through the introduction of modern farming practices and the provision of secondary inputs required to support modern agricultural methods. The Africa Bureau's draft strategy statement reiterates this emphasis--the need to raise each country's gross domestic product (GDP) by increasing production in the agricultural sector. To date, renewable energy systems have been experimentally applied to a wide variety of agricultural production and processings steps--irrigation, watering livestock, drying grains and fruits, processing organic fertilizer, and grinding grain and other foodstuffs.

In agricultural production, water pumping is the only major near-term application of RETs. In areas with a sufficient wind regime, wind energy systems have considerable potential to provide water for irrigation, livestock and human consumption. PV-powered water pumps have proved reliable, but too costly, except for small potable water applications. The renewable energy systems examined in this assessment do not have major application to other agricultural tasks, such as plowing, cultivation and crop transportation, and only limited applicability to grain grinding and milling.

In urban and institutional settings, RETs may have major impacts on several small, but important, end-uses--water heating, and remote-site lighting and refrigeration. Here, RETs will displace fossil fuels directly or lower consumption of fossil fuel-generated electricity. Major U. S. and French PV manufacturers have set up commercial distribution networks in virtually all the countries visited for this assessment. These local distributors are aggressively marketing PV systems for a variety of small-scale applications besides lighting--for example, telecommunications, clinic refrigeration and potable water pumping.

Small-scale RETs have little potential to reduce the amount of fossil fuel consumed for transporation and electricity generation. However, energy conservation measures directed at electric utilities and truck operators could significantly reduce the fossil fuel consumed per unit of delivered electricity or mile driven. Such measures could also greatly reduce certain substantial electrical loads, such as air conditioning in hotels and commercial office buildings.

II. INTRODUCTION

A decade ago, neither AID as a whole nor its Bureau for Africa had an energy program. Fossil fuels were readily available and had been growing progressively cheaper in real terms since the early 1960s. Energy was seen as a relatively inexpensive factor input that, coupled with rapidly evolving agricultural research and advances in rural health practices, would transform the developing world. Ten years later, the lack of reliable, affordable energy is considered one of the primary constraints on sustained economic and social development in the third world. In Africa, the provision of energy has contributed to deforestation, increased domestic loads on rural women and children, balance of payments problems for many national governments and arrested development in energy-intensive sectors. The energy program of AID's Bureau for Africa was formulated in this decade of energy-induced dislocation. As a result, it is a reflection of the search for both immediate solutions to pressing human needs as well as technical options that will produce a long-term transformation in the energy sector in Africa.

The Africa Bureau's energy program was initiated between 1977 and 1980 as part of an agency-wide program to test new, sustainable energy sources and also as a response to the especially heavy reliance on traditional energy sources--primarily fuelwood, dung and agricultural residues--among Africa's rural poor. It should be remembered that sub-Saharan Africa was wracked by unrelenting drought beginning at about the same time as the first rise in crude oil prices (1973 to 1974). As months without rain became years, the development community mounted a massive relief program for millions of hungry, sick, malnourished people, displaced by drought and the encroaching desert. This situation further reinforced the realization that a major portion of the desertification problem was due to over-cutting of forest reserves and a loss of soil conditioners--dung and agricultural residues--which were being consumed to meet daily household energy needs, mainly for cooking.

Out of the unique situation in Africa, as well as the agency-wide initiatives on new energy sources, a program for testing and adapting renewable energy sources was formed. It had a relatively narrow aim, linked to AID's focus on the poorest of the poor and primarily rural areas. Its principles were succinctly explained in the following policy guidance cable sent to AID's African missions and subsequently refined in the Africa Bureau's programmatic energy planning documents:

> "This message suggests an approach to the Africa Bureau's energy program. The information provided here supplements materials circulated earlier on AID's energy policy and on programs of the DSB energy office...

In general, the Bureau's program will stress ways of meeting energy needs in the areas of:

-- cooking and heating by the rural and urban poor;

-- water supply, grain grinding, irrigation, handicrafts, other basic life functions.

At present, the activities mentioned above account for roughly 80 percent of all energy consumed in Africa for all purposes, and 90 to 100 percent of all energy used by the poor. By concentrating our resources in these areas, we are therefore addressing virtually the entire range of energy issues now relevant to the people whom it is AID's mandate to serve. At the same time, we are beginning a planning process which should allow us at the appropriate time to deal with the next generation of African energy problems."*

AID's energy-related programs in Africa have expanded during the past four years. Funding for energy activities, including fuelwood, rose from six million dollars in fiscal year (FY) 1978 to $13 million in FY 1980 and $30 million in FY 1982 (of which $20 million was earmarked for the Sudan Blue Nile grid). AID is financing 24 renewable energy projects in 15 countries, and 15 fuelwood and forestry projects in 12 countries. Unlike most AID projects, these were not aimed at delivering services so much as learning about the <u>future</u> potential of a number of technologies (many still in the prototype or development stages) to provide services in Africa. Their economic viability was usually unknown, and questions concerning reliability, durability and local acceptability were only little better understood. Thus, the purpose of many projects was of a pilot or experimental nature--to test and adapt RETs; set up local institutions that would participate in the design, development, adaptation and testing of a variety of small energy systems; and collect baseline data on local energy consumption patterns and resource availability. In keeping with the bureau's overall energy policy, noted above, most of the systems examined were designed for small-scale domestic and village applications, such as cooking, crop and fish drying, potable water pumping, irrigation and livestock water pumping, water heating, vaccine refrigeration, and lighting for schools and clinics.

In December, 1981, at a major AID-sponsored workshop in Nairobi, Kenya, AID's Assistant Adminsitrator for Africa raised a number of major policy-level questions about the content and direction of the African energy program:

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*AIDTO CIRCA-204, "Energy in Africa--AFR's Program Emphasis," August 30, 1979.

- was the ongoing program, with its emphasis on renewable energy systems, producing usable, workable answers for Africa;

- what had been learned that could focus future efforts, given Africa's resources and needs;

- had technologies lived up to their promise, and were they capable of directly addressing the most pressing energy problems, in terms of both current consumption and future development strategies; and

- had some technologies already proved more useful than others in AID's highest priority areas for Africa, such as agricultural production and processing?

Shortly after the conference, the Bureau for Africa set out to answer these questions--to determine what the projects undertaken by AID's African missions had learned about the prospects for the extensive use of particular RETs in AFrica, and the degree to which various technologies tested by experimental projects held significant promise for becoming major energy sources, in either specific countries or for particular end-use applications. While many AID-financed projects are still in the research and development stage, with significant dissemination and consequent impact well in the future, it was felt that certain lessons could be learned that would improve the design and implementation of energy activities elsewhere.

This study's methodology was designed to answer five basic questions, which are presented in the Executive Summary. In October and November, 1982, AID's Bureau for Africa sent four teams of AID and contractor staff to seven countries to examine AID-sponsored projects as well as other multilateral, bilateral and PVO development projects, and private firms employing renewable energy systems. Local representatives of host and donor governments and organizations were most cooperative and helpful in sharing information and their views.

Advice on project selection was sought from a number of sources--AID missions, representatives of other donors, host governments and private organizations. An effort was made to choose projects according to their physical accessibility, goals and objectives, types of institutional mechanisms used in implementation, degree of success in technology demonstration and dissemination, and technologies employed. The project selection process was intended to provide a good mix within and across these factors.

Teams went to Botswana, Kenya, Lesotho, Mali, Rwanda, Senegal and Upper Volta, spending about two weeks in each country and visiting more than 75 projects in all. While data were being collected in the field, AID/Washington staff assembled energy

consumption and resource availability profiles for each of the countries visisted from secondary sources. After the field research, a team of AID and contractor personnel analyzed the information collected.

Besides gathering valuable information about RETs and the relationship between projects and technology success, this assessment proved to be a learning experience in collecting field data on new technologies to inform senior decision-makers about technologies' effectiveness and impact, as well as their appropriateness in a larger development context. Based on experience gained in the field using the methodology and workbook developed for this assessment, the AID Office for Energy asked ARD to develop a simplified data guide to assist AID field missions. The resulting publication, A Data Collection Handbook for Energy Systems Installed in Developing Countries by McGowan, Ashworth, Burrill and Donovan (Burlington, Vermont: ARD, February 1984), is available from ARD or the AID Office of Energy.

This assessment's design and methodology was comparative in nature. As such, it went beyond the scope of evaluations that AID usually undertakes and represents a ground-breaking effort. Several comparative aspects of this assessment which influenced its design, and the specific data collection and analysis techniques employed, include:

- examining the effectiveness of specific energy systems for particular end-uses under differing conditions (i.e., in different countries, institutional and economic contexts);

- evaluating the relative merit of different energy systems for a given end-use, both within a specific country and across countries; and

- comparing the utility of particular energy systems applied to various end-uses, both within and across countries.

Incorporating these types of comparisons into the assessment design constitutes an innovation in AID evaluation pracice, in contrast to efforts where a number of individual project evaluations, performed using different methodologies, are reviewed in an attempt to extract comparable information. (It should be noted that AID has been developing the basis for comparative evaluations in some other programmatic areas, e.g., the draft guidance on evaluating cooperatives and in several other topical fields.)

The results of this study are not definitive. Certain factors limit the extent to which generalizations can be drawn from the observations made:

- projects visited were limited to those concerned RETs;
- a number of RETs that warrant evaluation were not observed at all or were found only in scattered locations;
- the shortness of field teams' visists limited their ability to carry out thorough, systematic searches for all relevant project information; and
- the great variety of resources and circumstances in individual African nations resulted in exceptions to and local variations in broad generalizations.

Despite these limitations, patterns emerged in the findings which can be most instructive in orienting future energy activities. In some cases, they simply confirm what has already been suspected from previous examinations of projects--in others, they suggest paths to follow or shifts of emphasis in energy projects and programs, and the manner in which they should be evaluated.

III. BACKGROUND ON ASSESSMENT VISITS

Central to the development of this assessment's findings were the visits of teams of AID/Washington, AID/REDSO and contractor staff to the seven countries sampled--Kenya, Botswana, Rwanda, Lesotho, Upper Volta, Senegal and Mali. To ensure that teams asked the same questions of individuals contacted at different projects in different countries, a comprehensive data workbook and field inquiry methodology were developed by the contractor, Associates in Rural Development, Inc. (ARD). An abbreviated version of the field data collection and analysis methodology is presented in Appendix C and the field data collection data guide in Appendix D. A training session on the assessment methodology and use of the data collection workbook was held in Abidjan, Ivory Coast from October 25 to 26, 1982, prior to the first field visits.

During the two-week visit to each country, two- to three-person teams examined a wide range of installed renewable energy systems, as well as energy technology development laboratories. The number and types of systems seen in each country are presented in Figure 1. At all times, an effort was made to focus on the performance, durability, reliability and economic viability of systems installed in the field, as well as social, cultural and institutional factors affecting their use and acceptability. As Figure 1 shows, the number of systems visited varied widely from country to country. Senegal and Mali account for over 70 percent of all observations, primarily because of their large wood stove dissemination program. Unforeseen circumstances, such as a coup d'etat in Upper Volta, and amount of travel required accounted for the smaller number of observations for some of the other countries. In one or two cases, such as Lesotho, the use and testing of most RETs is just beginning, so there were few systems, or even prototypes, to examine.

In all cases, teams focused first on AID-funded installations and then examined projects that complemented AID-financed renewable energy systems. Using the project selection process outlined in Appendix C, each team sought to ensure a distribution of technologies weighted first toward agricultural applications and then non-agricultural (mainly domestic) uses of renewable energy systems. A complete listing of the projects visited, along with the distribution of end-use applications and technologies seen at each is provided in Appendix A.

As emphasized by the senior management of the Bureau for Africa from the initiation of this assessment, <u>field visits were not designed to serve as either formal or informal project evaluations.</u> Teams were instructed to focus on renewable energy systems--their performance, problems and potential contribution to the energy needs of each of the seven countries visited. Projects themselves were examined primarily to establish their

Figure 1. Summary of the Number of Renewable Energy Systems Observed by Field Team in Each Country

COUNTRY	ENERGY SYSTEMS															
	Earthen stove	Metal stove	Charcoal kiln	Wind - fanmill	Wind - electric	Mini-hydro	Hydraulic ram	PV	Biogas	Gasifier	Animal power	Active solar-low temp.	Passive solar	Solar cooker	Solar dryer	TOTALS
Botswana				1				2	2		1	1	1			8
Kenya	1	1	1	1		1	1	1	1	1						9
Lesotho	12					1	1	3	4			10	1	3	1	36
Mali	44			6				16	10			3				79
Rwanda	4					2		1	4			1			1	13
Senegal	57			3	2			6	5			7			6	86
Upper Volta	8							2	1							11
TOTALS	126	1	1	11	2	4	2	31	27	1	1	22	2	3	8	242

relationship to the technologies, technology performance and evolution of technologies to better serve local energy requirements. Field teams also considered projects' capacity to learn from their experience, and the results on project monitoring, evaluation and management are presented in Appendix B.

IV. FINDINGS

NOTE: THOSE INTERESTED ONLY IN PARTICULAR END-USE APPLICATIONS SHOULD TURN TO APPENDIX B, PAGES B-1 THROUGH B-32, WHILE THOSE INTERESTED ONLY IN PARTICULAR TECHNOLOGIES SHOULD TURN TO APPENDIX B, PAGES B-33 THROUGH B-44.

There is a danger of being overwhelmed with detail in an assessment that examined as many different technologies in as many different settings as this--over 240 units at nearly 80 sites in seven countries. Because no large-scale comparison of renewable energy systems has every been attempted by U. S. foreign assistance organizations, the temptation is to focus on systematic analysis of the mountain of technical data collected, particularly since project and technology designers, both within and outside AID, are eager for technical information on technology performance, reliability and durability. Adding to the temptation is the fact that little raw data have come back to the United States despite the large number of laboratory tests and field installations in Africa and elsewhere, and what has been collected has not been analyzed and disseminated to interested parties.

Regardless of the paucity of such information, a narrow focus on technologies and their performance obscures two key questions:

- what has this assessment learned; and
- where should AID go from here?

Thus, it was decided that this report would be more useful to senior decision-makers at AID and African planning ministries if detailed findings on RETs' applicability to specific sets of crucial end-uses were covered in a separate section, along with information on the reliability, economic viability and local acceptability of the most important technologies. Those interested in particular end-use applications (pumping, food preservation, cooking, etc.) or specific technologies (PV, wind turbines, etc.) will find detailed data in Appendix B, as well as specific findings on the role of monitoring and evaluation in African projects using renewable energy systems.

This section presents general findings that correspond to the five questions used to guide the assessment, thus providing a policy-level distillation of application- and technology-specific data. Then, short summaries of broad findings concerning agricultural and non-agricultural applications are given, including rough estimates of the future potential of renewable energy systems in Africa. Throughout, the emphasis is on new information the assessment developed and what actions should be taken to follow up on the lessons learned.

A. General Findings

QUESTION 1: WHAT HAS BEEN THE OBSERVED TECHNICAL PERFORMANCE OF RENEWABLE ENERGY SYSTEMS CURRENTLY INSTALLED IN SELECTED AID AFRICAN COUNTRIES?

- RETs work in the African context.

Most of the renewable energy systems being adapted and field-tested in the seven countries visited have reliability, durability and physical output levels considered desirable by African researchers and, in the case of field-tests, local users. Solar thermal pumps and anaerobic digesters are notable exceptions--both have serious and continual operation and maintenance problems. Certain technologies, such as low-cost, efficient stoves without chimneys, factory-produced windmills and PV arrays, have higher levels of consumer preference and acceptance than technologies or practices currently in use, primarily because of their ease of operation and reliability. Other systems, such as low-cost, wind water pumps and efficient charcoal stoves, are currently undergoing rapid adaptation that promises to increase reliability and durability in the near future.

- There is now sufficient data to narrow the broad range of RET options being considered for widespread application in Africa.

In an effort to attack Africa's two-part energy problem--firewood depletion and lack of low-cost energy for basic, productive household and village activities--in a broad way, a large number of technological alternatives have been tested over the past five years. For different reasons, several appear to have very limited applicability in most African settings, despite significant investments of time and effort by a number of research and development organizations. These include family-scale bio-gas digesters and solar dryers, solar cookers and hydraulic rams for potable water pumping. Despite the technical fascination of some of these technologies for local scientists, it seems appropriate for AID and other donors to restrict future support of these systems until they can demonstrate unsubsidized acceptance and reliable delivery of valued services outside the laboratory. This winnowing of technological options will permit concentration on technologies that have the capability to provide cost-effective, useful energy for high-priority applications, such as agricultural production, health and community services, and basic human needs at the household level.

QUESTION 2: WHAT PROBLEMS HAVE BEEN OBSERVED FOR RENEWABLE ENERGY SYSTEMS INSTALLED IN THE FIELD IN AFRICA, IN TERMS OF SOCIAL ACCEPTANCE, INSTITUTIONAL COMPATIBILITY, AND REQUIRED TECHNOLOGY DELIVERY SYSTEMS?

- Many RETs thought to have large potential impacts for Africa are still in the laboratory prototype or field-testing stages.

Widespread dissemination, as well as the concomitant issues of social acceptability and support infrastructure, are still mainly in the future.

- The widespread application of many RETs in Africa is hampered by the lack of local repair facilities, supplies of spare parts, and trained operation and maintenance personnel.

Inadequate maintenance and incorrect operation were two major causes of system failure for a number of technologies examined in this assessment. As technology adaptation and field-testing have progressed, the lack of local technical skills and support infrastructure to operate, maintain and repair installed systems has become a more pressing problem at most of the sites visited. In some cases, trained manpower was simply unavailable in the area and adequate provisions for in-depth training of local personnel had not been made. In others, adequate funds for follow-up inspection, maintenance and parts replacement had not been budgeted. This is a particular problem when a local government extension organization or line agency is given responsibility for equipment installed in the field without supplemental operation and maintenance funding. Many line organizations have virtually no operating funds and cannot even afford the fuel required to visit remote sites periodically, much less purchase or fabricate replacement parts. While AID has paid more attention to operation and maintenace than some foreign donor agencies, its projects do not focus sufficiently on the creation of repair and maintenance facilities, as well as training specialized individuals to service installed systems.

QUESTION 3: WHAT HAS BEEN THE COMPARATIVE PERFORMANCE OF ALTERNATIVE RENEWABLE ENERGY SYSTEMS IN PROVIDING USABLE COST-EFFECTIVE ENERGY FOR SPECIFIC AFRICAN END-USE APPLICATIONS IN THE AREAS OF AGRICULTURAL PRODUCTION, DOMESTIC CONSUMPTION, AGRICULTURAL PROCESSING AND FOOD PRESERVATION, AND SMALL-SCALE COMMERCIAL AND INDUSTRIAL OPERATIONS?

- Little usable information is being collected on current economic costs or long-term economic viability for most of the renewable energy systems examined.

The first generation of renewable energy systems installed in Africa were viewed mainly as experiments. The emphasis was on technical performance monitoring, technology adaptation and creating institutions to conduct RET research and development. Capital costs were expected to change drastically as technologies matured and/or local fabricating facilities were created. One-time extraordinary costs were not kept analytically separate from expenses that would be required for subsequent installations. The problem increased when assessment teams attempted to gather economic data on systems installed by private volunteer groups, relief organizations and some government agencies. Often, these institutions did not keep track of recurrent costs, operation and maintenance expenditures or system output so that benefits and costs could be calculated and the cost-effectiveness of installed systems compared with commercially viable alternatives.

- Thus far, not enough attention has been paid to the question of making renewable energy systems accessible to potential African end-users as investments.

Technologies that appear to have a number of potential applications are often thwarted mainly by users' lack of access to capital. Africa's rural and urban poor, in particular, as well as small-scale entrepreneurs, do not have the savings or access to reasonably priced credit to invest in capital-intensive, but fossil fuel- or firewood-conserving, technologies. As the foreign assistance community moves from technology testing and adaptation to serious promotion of energy-conserving systems, more consideration must be given to credit and cost-effectiveness.

- The first to adopt renewable energy systems will probably not be the rural and urban poor, but rather relatively affluent rural and urban dwellers, medium- to large-scale entrepreneurs and organizations providing social services at remote sites.

Renewable energy systems are usually capital-intensive, compared to the technologies or techniques they displace, even

though life-cycle costing may be extremely favorable. The poorest of the poor, particularly those living outside a monetary economy and practicing subsistence agriculture, have virtually no access to capital, even for basic necessities, such as seeds and tools. For example, in some countries, people find it difficult to purchase low-cost earthen stoves priced under under $4.00 (U. S.). In contrast, urban dwellers and medium- to large-scale energy-intensive industries devote substantial portions of their monthly incomes to purchasing fuelwood, charcoal, fossil fuel products and/or electricity. At a number of sites visited by assessment teams, these individuals and businesses demonstrated a willingnesss to invest in renewable energy systems to reduce or eliminate ongoing fuel expenses. Thus, if the donor community in general, and AID in particular, want to focus on displacing fuel and introducing renewable energy systems, they may have to target initial project and program activities on higher income groups.

Another group which is already using RETs includes government and private agencies that provide public services in remote areas (e.g., clinics, hospitals, schools, community centers, forest ranger posts). All require energy to provide their services to the general populace. Since they often purchase significant amounts of fuel for their daily operations, and interruptions caused by fuel shortages and mechanical failures often have serious consequences for their clients, they are willing and sometimes financially able to invest in renewable energy systems. By working with them to design and procure appropriate units, AID could not only lower levels of fossil fuel consumption, but also improve the quality of services that such organizations deliver.

QUESTION 4: WHAT MECHANISMS CURRENTLY EXIST WITHIN ONGOING AID AND NON-AID AFRICAN DEVELOPMENT PROJECTS THAT ALLOW FOR "REAL-TIME" MONITORING OF INSTALLED RENEWABLE ENERGY SYSTEMS AND MODIFICATIONS OF TECHNOLOGIES OR PROJECT ELEMENTS TO TAKE ADVANTAGE OF LESSONS LEARNED FROM TECHNOLOGY MONITORING?

- Of the projects demonstrating progress, evidenced by positve changes in technology design or dissemination strategies, 99 percent had formal or informal monitoring and evaluation systems.

Assessment teams found that a monitoring and evaluation system was an essential component of projects developing successful technology designs and strategies. Laboratories that placed the greatest emphasis on the experimental method and nature of their work also carried out the most extensive, thorough analysis. However, almost all projects were missing some major aspect of data gathering and/or analysis of a technical, econoimc or social nature.

- Formally gathering and incorporating user/client opinions was a key element in modifying technology designs to produce better, more socially acceptable renewable energy systems.

- There was little formal financial/market information collected in "real-time" monitoring of renewable energy field demonstrations at the projects visited, which seriously detracts from the utility of monitoring for selecting technologies for future dissemination.

While a few AID projects visited were striving to base technology selection on rigorous economic analysis, this is an area that needs immediate attention, if the field-testing/ technology-selection process is to yield commercially viable systems.

- There is little sharing of lessons learned from field-testing between projects, even in the same country, and thus, information being collected in technology monitoring is not available to practitioners addressing similar problems.

QUESTION 5: WHAT IS THE POTENTIAL OF RENEWABLE ENERGY SYSTEMS NOW INSTALLED IN AFRICA TO PROVIDE SIGNIFICANT PORTIONS OF THE ENERGY CONSUMPTION PROJECTED FOR THE COUNTRIES EXAMINED AND THE WHOLE SUB-SAHARAN REGION BY THE YEARS 1990 AND 1995?

- Findings on the relative potential of RETs to provide useful energy in Africa must be presented on an end-use basis. (See the following two sections.) Even so, the findings vary dramatically across countries.

B. Findings on Agricultural Applications

AID, in general, and the Bureau for Africa, in particular, have as a central principle the promotion of increased agricultural productivity through the introduction of modern farming practices and provision of secondary inputs required to support modern agricultural methods--the need to raise each country's gross domestic product (GDP) by increasing production in the agricultural sector. Thus, assessment teams focused on the current and potential role of renewable energy systems in both agricultural production and the subsequent processing and preservation of produce. Major findings are outlined below, organized by end-use applciation, and detailed findings for several key agricultural end-uses of energy are presented in Appendix B.

- Renewable energy systems have been experimentally applied to a wide variety of agricultural production and processing steps--irrigation, watering livestock, drying grains and fruits, processing organic fertilizer, and grinding grain and other foodstuffs.

Field experience has been mixed. The potential of various energy systems to address specific end-uses is summarized in Table 1. Some of the more important applications are discussed below.

- Other renewable energy systems and/or traditional power sources may have substantial potential to meet these end-uses, but were not examined in this assessment.

For example, animal traction is being used for plowing, cultivating and transportation, and wind and micro hydro installations employing an electric arc process may have the potential for fertilizer production. However, such alternatives are not listed in Table 1 because they were not studied as part of this assessment. Several applications are technically feasible (grinding, drying and fertilizer production, in particular), but do not appear to afford the farmer or market-town entrepreneur enough value to warrant the required capital investment, except at especially favorable sites. For Table 1, RET potential was analyzed relative to all the African countries and regions visited, on a general level. Country- or site-specific exceptions were not taken into account in formulating these generalizations.

Table 1. Potential of Renewable Energy Systems Examined to Address Particular African Agricultural End-Use Applications

END USE: Current Energy Sources	Observed Renewable Energy Alternatives	RET Potential To 1987	Long-term
WATER PUMPING:			
human/animal power	wind fan-mill	high	high
small-scale diesel	PV	medium	high
grid electricity	bio-gas digester	low	low
	solar thermal	low	low
	hydraulic ram	low	low
PLOWING/CULTIVATING:			
small-scale diesel gasoline engine	none	--	--
FARM/MARKET TRANSPORT:			
diesel/gasoline vehicle	none	--	--
FERTILIZER PRODUCTION:			
factory production/import	none	--	--
application of dung/ agricultural residues			
GRINDING/MILLING:			
small-scale diesel	micro hydro	high	high
human/animal power	PV	low	medium
grid electricity	bio-gas digester	low	low
DRYING/PRESERVING:			
open-air, sun drying	solar dryer	low	medium
firewood for smoking	biomass smoker	medium	medium
salting			
COOLING/FREEZING:			
small-scale diesel electricity	PV	low	low

- Wind and PV systems have good performance records in pumping water for human and livestock consumption, as well as small-scale irrigation of high-value plants (vegetables and cash crops).

Wind regimes are normally quite low in equatorial Africa. However, where an adequate regime prevails, fan-mills are the technology of choice to substitute directly for diesel pump sets. Evidence of this includes the commercial sale and maintenance of fan-mill systems, as well as numerous, low-cost, site-built units fabricated by local craftspeople. PV systems, with their large initial capital cost but high reliability, are being used mainly to provide water for human consumption rather than irrigation, except in locations with water tables close to the surface and established markets for vegetables and other high-value crops. Donor agencies and PVOs have shown interest in expanding PV use for remote potable water systems, despite the capital investment required, because of system reliability compared to small diesel generators.

- The renewable energy systems tested thus far in Africa have little near-term application for several of agriculture's major energy-consuming sectors--farm-to-market transportation, plowing and cultivation.

In most cases, these tasks are now performed using human and/or animal power. Although not studied in this assessment, the possibilitiy of increasing available energy through improved, widespread use of animal traction probably exists in number of African countries. Where mechanized, motive-power applications are driven by diesel or gasoline engines, but because of the continent-wide shortage of grain protein, there seems to be little potential for the creation of biomass-based liquid fuels to substitute directly for diesel fuel or gasoline. There may, however, be localized opportunities for liquid fuel substitution that could have a significant impact in a particular locale. Similarly, firewood shortages make it unlikely that wood- or charcoal-powered biomass gasifiers will have an important role in powering tractors, trucks and cultivators. Although not directly examined, it appears that an intensive program of engine inspection and maintenance could have a significant effect on the consumption of fossil fuel in agricultural transportation. This would be especially important for countries, such as Kenya, where transportation is a major component of total energy consumption.

- For applications, such as grinding and milling, where a substantial amount of power is required on a daily basis for commercial operations, hydroelectric or hydro-mechanical turbines are the only renewable energy systems examined in this assessment that can successfully compete with small-scale diesel systems.

At good sites, with year-round water flow and physical characteristics suitable for a "run-of-the-river" system (such that no dam or other major civil work need be undertaken), micro-hydro systems can provide low-cost energy, in the form of either direct shaft power or electricity, which can then be transmitted to a convenient location. Unfortunately, such locations are scarce in most of Africa, and many of the few available sites are already being exploited or are under consideration for future use. Other renewable energy systems, such as PV, have an initial investment cost that is too high to permit operating a commercial mill which can compete with existing small-scale diesel units or mills with access to an electric grid.

- Solar drying of crops, grains and fish has been successfully tested in a number of locations, but has yet to prove economically feasible or attractive to small-scale farmers and food processors.

There are two reasons for this. First, the traditional drying technique being displaced--sun-drying--has a very low initial investment cost and no operating expenses. No fossil fuel has to be purchased and no firewood collected or bought, except when food is also smoked. Second, improvements offered by solar dryers--reduced spoilage, less insect infestation and more complete drying--are not yet directly reflected in the market value of the final product. For example, there is no separate market for solar-dried fish, and until one exists, there will be little incentive for investing in solar drying systems. Encouraging a differentiated market for solar-dried fish would not only increase sellers' income, but also lower losses and make greater quantities of food available for consumption by individual families and society at large. This may occur in time.

C. Findings on Non-Agricultural Applications

Non-agricultural applications account for the bulk of current energy use in all the countries visited and will continue to do so for the foreseeable future. Cooking alone accounts for 90 percent or more of total energy consumption in many African countries. Other domestic applications--lighting and water heating, in particular--consume small amounts of the total, but are important because they use fossil fuels or electricity directly. Also, they afford opportunities for early, cost-effective substitution with RETs. A summary of the range of non-agricultural applications is given in Table 2, along with technologies being applied to each end-use. The most important non-agricultural applications and performance of selected RETs in supplying energy for them are decribed in Appendix B.

In keeping with Africa Bureau guidance during the past four years (a sample from 1979 was quoted in the Introduction, section II), most of the AID renewable energy projects visited in this assessment place heavy emphasis on domestic applications--chiefly cooking and water heating--and other basic human needs. They are not directed toward providing energy for community centers or markets, a focus which is central to the Africa Bureau's new development strategy. Renewble energy systems have only limited application to some of the most pressing energy needs of market towns, such as electrical or mechanical power for light industry tools and electricity for direct lighting. However, the assessment's findings <u>can</u> be directly applied to supplying energy for market towns. Certain portions of their energy requirements, such as process heat for small entrepreneurs, can be met with renewable energy systems. These end-uses are shown in Table 2 and also noted in each of the following sections on non-agricultural applications.

- <u>Small-scale entrepreneurs and businesses that purchase fuel are among the first to adopt fuel-efficient wood and charcoal stoves.</u>

Individual entrepreneurs who use wood, charcoal, dung or agricultural residues--beer makers, street food vendors, small restauranteurs, potters, laundry operators--require large amounts of fuel on a daily basis. They usually purchase this fuel, rather than gathering it. With a cash income, they have the capital to invest in an efficient stove, oven or kiln, and being substantial fuel consumers, their use of a fuel-efficient device will produce an immediate, measurable decrease in local firewood, charcoal or fossil fuel use. Since they serve the public directly, involving small-scale entrepreneurs also has a salutory demonstration effect--other potential technology users can see the unit in use. For all these reasons, this group is one of the early participants in and logical targets of stove dissemination programs.

Table 2. Potential of Renewable Energy Systems Examined to Address Particular African Non-Agricultural End-Use Applications

END-USE APPLICATION:	Current Technologies	Observed Renewable Energy Alternatives	RET Potential To 1987	RET Potential Long-Term
DOMESTIC APPLICATIONS	Cooking:			
	petrol stoves	improved wood stove	medium	high
	three-stone fire	imp. charcoal stove	medium	high
	recycled food tin	stone paola	medium	high
	metal charcoal/dung stoves			
	Water Heating:			
	three-stone fire	improved stoves	medium	high
		solar water heater	medium	high
	Space Heating:*			
	open fuelwood fire	passive solar	medium	high
	Lighting:			
	open fire	photovoltaics	low	medium
	kerosene lamp			
	diesel generator			
	candles			
CLINICS/ HOSPITALS	Refrigeration/Lighting:			
	diesel generator	photovoltaics	high	high
	batteries			
TELECOM-MUNICATIONS	Radio/Telephone:			
	diesel generator	photovoltaics	high	high
	batteries			

* This applies to all building construction whether domestic or institutional/ commercial.

Table 2. (Continued)

	END-USE APPLICATION: Current Technologies	Observed Renewable Energy Alternatives	RET Potential To 1987	RET Potential Long-Term
REMOTE SCHOOL/ COMMUNITY CENTERS	Lighting:			
	diesel/batteries	photovoltaics	high	high
	Water Heating:			
	fuelwood stove electric resistance	solar water heater	high	high
MARKET TOWN DEVELOPMENT	Small-Scale Industry-Heat:			
	fuelwood stove charcoal stove	efficient wood or charcoal stove	high	high
	Community Lighting:			
	kerosene lamp diesel generator	photovoltaics	low	medium
	Food Cooling/Storage:			
	diesel generator	none	---	---
	Food Drying/Preservation:			
	open-air, sun drying fuelwood smoking	solar dryer	medium	high
	Small-Scale Industry-Power:			
	diesel generators	micro hydro photovoltaics	medium low	high low

- Water heating is a minor energy end-use that is growing rapidly, for while it is not a basic human need, it is a major source of energy consumption for three clearly defined sectors in most African economies--educational and health care institutions (hospitals, clinics and schools), public accommodations (hotels and guest houses) and the urban middle class.

Because of the high cost of electricity and butane gas (the fuels normally used for water heating) in most African countries, solar water heaters have high economic potential. However, heaters installed thus far in the sample countries have not always been well accepted due to various problems, including poor design, improper installation, and lack of follow-up maintenance and trouble-shooting. Where professionally designed units have been carefully installed and maintained, energy savings have been substantial. Hotels examined by assessment teams saved 120,000 to 300,000 kilowatt-hours per year (enough electricity to light 10 to 20 clinics for five hours each night for a year) and constitute a major retrofit market. Domestic solar water heaters find acceptance mostly among expatriate workers and government officials. This may not be a large enough market to support local fabrication or even asembly in each country, but may require a regional distribution network. The quality of local installation, repair and maintenance, regardless of where units are produced, will determine consumer acceptance.

- Initial indications concerning improved building designs and construction show the potential for substantial benefits in Africa.

In areas where space heating and, to some extent, cooling are needed, early results of prototype designs indicate that large amounts of new energy and energy savings can be generated by the use of passive solar designs and other materials and construction techniques. Although work is just beginning in this area and clear results from fieldwork are not yet available, the early data point to this area as having good potential for high eventual impact.

- PV lighting is cost-effective today for individuals and organizations not connected to electrical grids, dependent on small-scale diesel generators and with access to capital.

PV systems are being purchased by expatriate workers, remote clinics, volunteer organizations and rural representatives of government agencies. The rural and urban poor benefit only indirectly from these PV installations, which will remain true for the foreseeable future because of the high initial capital investment required.

- Major U. S. and French PV manufacturers have set up commercial distribution networks in virtually all the countries visited for this assessment.

In these countries, local distributors are aggressively marketing PV systems for a variety of small-scale applications besides lighting--telecommunications, clinic refrigeration, potable water pumping, navigational buoys, and cathodic protection for structures and pipelines. Local dealers normally offer assistance in system design, installation and follow-up maintenance or repair. All these end-uses are very important in the development of rural areas and market towns, and are economic, technically sound applications of PV systems.

APPENDIX A

PROJECT LISTING

MASTER PROJECT MATRIX

COUNTRY: Botswana

PROJECT NAME	IMPLEMENTING AGENCY	DONOR	PROJECT TYPES: Research/Development	Prototype development	Demo/Field testing	Dissemination	Commercial sales	Institution building	ENERGY SYSTEMS: Earthen stove	Metal stove	Charcoal kiln	Wind - fanmill	Wind - electric	Mini-hydro	Hydraulic ram	PV	Biogas	Gasifier	Animal power	Active solar-low	Passive solar	Solar cooker	Solar dryer	END-USES: Agricultural Production: Irrigation	Cultivation	Fert. production	Livestock	Agricultural Processing: Grinding/Milling	Crop drying	Threshing	Cold strg./refg.	Cooking	Water heating	Domestic: Lighting	Food dryg./presv.	Potable water	Space Htng/clng.	Water heating	Commercial/Industrial: Process ht.-low	Motor-shaft pwr.	H'lth clinic refrg.	Fuels from biomass
Windmill Development	RIIC[1] ITDG[2]	USAID	X	X			X					X												X												X							
Indian/Chinese Bio-digesters	RIIC	RIIC			X												X															X		X									
Animal-Driven Pump	RIIC	RIIC			X														X					X																			
RET Project *	MMPWA[3], BTC[4] & ARD, Inc.	USAID			X											X																		X							X	
Photovoltaic Water Pumping	Taurus Batteries, Arco Solar				X		X									X								X										X		X					X	
Solar Hot Water Systems	Solar Power Inc., Gaborone						X													X													X									

[1] Rural Industries Innovation Center, Gaborone
[2] Intermediate Technology Development Group
[3] Ministry of Mineral Resources & Water Affairs, Gaborone
[4] Botswana Technology Center, Gaborone
* Botswana Renewable Energy Technology Project (BRET)

MASTER PROJECT MATRIX

COUNTRY: Kenya

PROJECT NAME	IMPLEMENTING AGENCY	DONOR	PROJECT TYPES: Research/Development	Prototype development	Demo/Field testing	Dissemination	Commercial sales	Institution building	ENERGY SYSTEMS: Earthen stove	Metal stove	Charcoal kiln	Wind - fanmill	Wind - electric	Mini-hydro	Hydraulic ram	PV	Biogas	Gasifier	Animal power	Active solar-low	Passive solar	Solar cooker	Solar dryer	Irrigation	END-USES: Agricultural Production: Cultivation	Fert. production	Livestock	Agricultural Processing: Grinding/Milling	Crop drying	Threshing	Cold strg./refg.	Domestic: Cooking	Water heating	Lighting	Food dryg./presv.	Potable water	Space Htng/clng.	Water heating	Commercial/Industrial: Process ht.-low	Motor-shaft pwr.	H'lth clinic refrg.	Fuels from biomass
Euphorbia Project	Min. of Env. & Nat. Resources		X															X																										X
Renew. Energy Devel. Project	Min. of Energy, EDI[1] & ITDG[2]	USAID	X	X	X				X																							X											
Ndarugu Water Mill Demo.	French Cultural Center				X								X	X									X				X								X								
Kitui Biogas Project	Better Living Institute	U. S. Embassy			X											X															X												
Wind Water-pumping	Bobs Harries Eng'ng Ltd.		X				X				X												X												X								
PV for Electricity Production	Animatics Ltd.						X								X																		X										
Leakey Charcoal Experiment	Mr. Leakey (private indv.)			X						X																																	X

[1] Energy Development International, inc.
[2] Intermediate Technology Development Group

MASTER PROJECT MATRIX

COUNTRY: Lesotho

PROJECT NAME	IMPLEMENTING AGENCY	DONOR	PROJECT TYPES: Research/Development	Prototype development	Demo/Field testing	Dissemination	Commercial sales	Institution building	ENERGY SYSTEMS: Earthen stove	Metal stove	Charcoal kiln	Wind - farmill	Wind - electric	Mini-hydro	Hydraulic ram	PV	Biogas	Gasifier	Animal power	Active solar-low	Passive solar	Solar cooker	Solar dryer	END-USES: Agricultural Production: Irrigation	Cultivation	Agricultural Processing: Fert. production	Livestock	Grinding/Milling	Crop drying	Threshing	Domestic: Cold strg./refg.	Cooking	Water heating	Lighting	Food dryg./presv.	Potable water	Space htng/clng.	Water heating	Commercial/Industrial: Process ht.-low	Motor-shaft pwr.	H'lth clinic refrg.	Fuels from biomass
Biogas Project	Natl. Univ. of Lesotho	UNDP[1]		X	X												X															X											
Rural Technol. Unit (T.T.)[2]	CIDA[3] SIDA[4]			X																X		X										X			X							
T.T. Solar Hot Water Projects	Parry School, Cat'lic Msn.	Government of Lesotho				X	X	X												X													X					X				
RET Project[5]	MCRD[6], ARD & Peace Corps	USAID	X		X				X				X	X							X		X	X	X			X	X			X			X		X					
PV for Lighting & Communications	MTC[7] & Danish Vol. Service				X										X																										X*	
Water-pumping Windmills	many private owners						X					X												X			X								X							

[1] United Nations Development Program
[2] Rural Technology Unit (Thaba Tseka)
[3] Canadian International Development Agency
[4] Swedish International Development Agency
[5] Lesotho Renewable Energy Technology Project
[6] Ministry of Cooperatives & Rural Development
[7] Ministry of Transportation & Communications

* health clinic lighting/communications

MASTER PROJECT MATRIX

COUNTRY: Mali (page 1)

PROJECT NAME	IMPLEMENTING AGENCY	DONOR	PROJECT TYPES: Research/Development	Prototype development	Demo/Field testing	Dissemination	Commercial sales	Institution building	ENERGY SYSTEMS: Earthen stove	Metal stove	Charcoal kiln	Wind - farmill	Wind - electric	Mini-hydro	Hydraulic ram	PV	Biogas	Gasifier	Animal power	Active solar-low	Passive solar	Solar cooker	Solar dryer	Irrigation	END-USES: Agricultural Production: Cultivation	Fert. production	Livestock	Agricultural Processing: Grinding/Milling	Crop drying	Threshing	Cold strg./refg.	Cooking	Domestic: Water heating	Lighting	Food dryg./presv.	Potable water	Space Htng/clng.	Water heating	Commercial/Industrial: Process ht.-low	Motor-shaft pwr.	H'lth clinic refrg.	Fuels from biomass
Mali Renewable Energy Project	Sheladia Assc.[1] Mali Solar Lab	USAID	X	X	X			X	X			X				X	X			X		X	X	X					X			X	X	X	X	X							
Sahores Windmill Project	Catholic Relief Serv.					X						X												X			X									X							
"Fourneau Economique" Proj.	Catholic Relief Serv.					X			X																																		
Windmill for Gardening	Peace Corps & Mali Solar Lab	USAID	X		X							X												X																			
Photovoltaic Water Pumps	Mali Aqua Viva				X	X										X								X												X							
Rural Biogas Project	C.d'A.R.[2] & Min. of R.D.[3]		X	X													X														X												
Solar Rfgr'tn, Li'tng, Pumping	San Hospital, FAC[4] & CES[5]				X											X																	X		X					X		
Sahores Windmills/Pumping	CMDT Village Association	CMDT[6]			X	X		X																X			X								X								
Improved Woodstoves	Peace Corps				X				X																						X												

[1] Sheladia Associates, Inc., formerly Solar Energy Research Institute
[2] Centre d'Animation Rural
[3] Ministry of Rural Development
[4] Fonds d'Aide et de Cooperation
[5] Commissariat a l'Energie Solaire
[6] Compagnie Malienne de Textile

MASTER PROJECT MATRIX

COUNTRY: Mali (page 2)

PROJECT NAME	IMPLEMENTING AGENCY	DONOR	PROJECT TYPES: Research/Development	Prototype development	Demo/Field testing	Dissemination	Commercial sales	Institution building	ENERGY SYSTEMS: Earthen stove	Metal stove	Charcoal kiln	Wind - farmill	Wind - electric	Mini-hydro	Hydraulic ram	PV	Biogas	Gasifier	Animal power	Active solar-low	Passive solar	Solar cooker	Solar dryer	Irrigation	END-USES: Agricultural Production: Cultivation	Fert. production	Livestock	Agricultural Processing: Grinding/Milling	Crop drying	Threshing	Cold strg./refg.	Domestic: Cooking	Water heating	Lighting	Food dryg./presv.	Potable water	Space Htng/clng.	Water heating	Commercial/Industrial: Process ht.-low	Motor-shaft pwr.	H'lth clinic refg.	Fuels from biomass
Biogas Project	Machinisme Agricole		X	X													X															X		X									
Kolokani Hospital PV Project	Elf Aquitaine				X											X																		X							X	

MASTER PROJECT MATRIX

COUNTRY: Rwanda

PROJECT NAME	IMPLEMENTING AGENCY	DONOR	PROJECT TYPES: Research/Development	Prototype development	Demo/Field testing	Dissemination	Commercial sales	Institution building	ENERGY SYSTEMS: Earthen stove	Metal stove	Charcoal kiln	Wind - fanmill	Wind - electric	Mini-hydro	Hydraulic ram	PV	Biogas	Gasifier	Animal power	Active solar-low	Passive solar	Solar cooker	Solar dryer	Irrigation	Agricultural Production: Cultivation	Fert. production	Livestock	Agricultural Processing: Grinding/Milling	Crop drying	Threshing	Cold strg./refg.	Cooking	END-USES Domestic: Water heating	Lighting	Food dryg./presv.	Potable water	Space Htng/clng.	Water heating	Commercial/Industrial: Process ht.-low	Motor-shaft pwr.	H'lth clinic refrg.	Fuels from biomass
Murunda Mission Small Hydro	Belgian Misn. Catholique				X		X							X														X							X*								
Lake Ihema Fishery Project	ORTPN[1] and Belgian T. A.[2]		X	X																		X							X							X							
Akagara Hotel Solar Water Htr.	Belgian Technical Asst.				X		X													X																		X					
Small Livestock Development	UNDP/FAO[3]			X	X												X															X											
Renewable Energy Woodstoves	VITA[4], CEAER[5] & USAID		X	X	X				X																							X											
Renewable Energy Biogas	CEAER & USAID			X				X																								X											
PV Refrigeration & Lighting	Mercuria of Rwanda (pvt.)						X									X																		X							X		

[1] Office Rwandais de Tourisme et Parcs Nationaux
[2] Belgian Technical Assistance
[3] United Nations Development Program and U. N. Food and Agriculture Organization
[4] Volunteers in Technical Assistance
[5] Centre d'Etudes et d'Application de l'Energie au Rwanda

* various electrical uses

MASTER PROJECT MATRIX

COUNTRY: Senegal (page 1)

PROJECT NAME	IMPLEMENTING AGENCY	DONOR	PROJECT TYPES: Research/Development	Prototype development	Demo/Field testing	Dissemination	Commercial sales	Institution building	ENERGY SYSTEMS: Earthen stove	Metal stove	Charcoal kiln	Wind - fanmill	Wind - electric	Mini-hydro	Hydraulic ram	PV	Biogas	Gasifier	Animal power	Active solar-low	Passive solar	Solar cooker	Solar dryer	Irrigation	Cultivation	END-USES: Agricultural Production: Fert. Production	Livestock	Agricultural Processing: Grinding/Milling	Crop drying	Threshing	Cold strg./refg.	Domestic: Cooking	Water heating	Lighting	Food dryg./presv.	Potable water	Space htng/clng.	Water heating	Commercial/Industrial: Process ht.-low	Motor-shaft pwr.	H'lth clinic refrg.	Fuels from biomass
Renewable Energy I	ITA[1]	USAID	X	X																			X						X						X				X				
Ban ak Suf-Program de Dif'sion	Maison Familiale, CERER[2]					X			X																							X										
Agri./Village Water Project	CARITAS				X							X			X								X												X							
Biogas Digesters	CARITAS				X											X															X		X									
Hotel Palm Bch. Solar Hot Water	SINAES[3]						X												X																		X					
Windmill Water-pumping Project	LVIA[4]				X						X												X			X									X							
Soffretes Solar Thermal Pumps	SINAES & Village Councils	French AID			X														X																X							
Improved Cookstoves	Coumla Gueye, Peace Corps	USAID				X			X																						X											
Station Solaire de Mt. Roland	CERER, SINEAS, Catholic Misn.				X										X																		X		X					X	

[1] Institut de Technologie Alimentaire
[2] Centre d'Etudes et de Recherches sur les Energies Renouvables
[3] Societe Industrielle pour l'Application de l'Energie Solaire
[4] Lay Voluntary International Association

MASTER PROJECT MATRIX

COUNTRY: Senegal (page 2)

PROJECT NAME	IMPLEMENTING AGENCY	DONOR	PROJECT TYPES: Research/Development	Prototype development	Demo/Field testing	Dissemination	Commercial sales	Institution building	ENERGY SYSTEMS: Earthen stove	Metal stove	Charcoal kiln	Wind - fanmill	Wind - electric	Mini-hydro	Hydraulic ram	PV	Biogas	Gasifier	Animal power	Active solar-low	Passive solar	Solar cooker	Solar dryer	Irrigation	END-USES: Agricultural Production: Cultivation	Fert. production	Livestock	Agricultural Processing: Grinding/Milling	Crop drying	Threshing	Cold strg./refg.	Cooking	Water heating	Domestic: Lighting	Food dryg./presv.	Potable water	Space Htng/clng.	Water heating	Commercial/Industrial: Process ht.-low	Motor-shaft pwr.	H'lth clinic refrg.	Fuels from biomass
Water Pump for Baback Project	CARITAS				X											X								X			X									X							
Biogas Research	ISRA [5]																																										
Solar Hot Water Heaters Proj.	SINAES		X	X	X															X													X										

[5] Institut Senegalais de Recherche Agricole

MASTER PROJECT MATRIX

COUNTRY: Upper Volta

PROJECT NAME	IMPLEMENTING AGENCY	DONOR	PROJECT TYPES: Research/Development	Prototype development	Demo/Field testing	Dissemination	Commercial sales	Institution building	ENERGY SYSTEMS: Earthen stove	Metal stove	Charcoal kiln	Wind - fanmill	Wind - electric	Mini-hydro	Hydraulic ram	PV	Biogas	Gasifier	Animal power	Active solar-low	Passive solar	Solar cooker	Solar dryer	Irrigation	END-USES: Agricultural Production: Cultivation	Fert. production	Livestock	Agricultural Processing: Grinding/Milling	Crop drying	Threshing	Cold strg./refg.	Cooking	Domestic: Water heating	Lighting	Food dryg./presv.	Potable water	Space Htng/clng.	Water heating	Commercial/Industrial: Process ht.-low	Motor-shaft pwr.	H'lth clinic refrg.	Fuels from biomass
Dori Fuel-Efficient Stoves	Save the Children			X	X				X																								X										
Kaya Wood Stove Project	Peace Corps	VITA			X	X			X																								X										
Tangaye Solar Demonstration	MHER[1] and NASA[2]	USAID			X											X											X			X			X		X								
Apl. of Biogas to Micro-Irrig.[3]	CIEH[4]			X	X												X						X																				
Kaya PV Lighting	private individual				X											X																		X									

[1] Ministere de l'Hydraulique et d'Equipement Rural
[2] National Aeronautics and Space Administration
[3] Application of Biogas to Micro-Irrigation
[4] Centre Interafricain d'Etudes Hydrauliques

APPENDIX B

DETAILED FINDINGS

1.0 AGRICULTURAL PRODUCTION AND PROCESSING END-USES

While teams sought to identify the whole range of energy systems being applied to agricultural applications, only three distinct end-uses were actually observed--water pumping, milling and crop drying. These are listed in Table B.1, along with the technologies used in these applications and the number of projects observed or visited by the teams.

Table B.1. Summary of Agricultural Production and Processing Application Installations

End-Use	Energy System	Number of Systems Observed
water pumping*	major: PV arrays	16
	wind fan-mills and wind electric turbines	11
	minor: hydraulic rams, solar thermal, anaerobic digesters	6
grinding/ threshing	PV, anaerobic digesters, small-scale hydro	5
community-scale crop/ fish drying	solar dryers	5

*Includes irrigation, provision of potable water and livestock watering.

Because this assessment only included RETs, many foreign donor-sponsored agricultural projects using small-scale diesel pumps, mills, cultivators and threshers were excluded from consideration. Consequently, this analysis places greater emphasis on domestic applications, such as cooking. Nonetheless, a number of valuable lessons were learned about the field performance of certain technologies and the "fit" between

individual power sources, auxiliary equipment and the final need for energy in these three end-use applications. Each end-use is discussed in turn, and an effort made to compare and contrast technologies in terms of their reliability, durability, match of output with demand pattern and cost-effectiveness.

1.1 Water Pumping

Major Technical Findings of the Field Teams

- A lack of easily obtained spare parts and trained repair personnel contributed to long periods of non-operation or system abandonment for all pumping systems, both wind and PV.
- Insufficient attention to routine maintenance and operator training were the chief causes of pumping system failure for all technologies, closely followed by poor matching of system components and lack of pump protection from low water levels.
- Of the energy systems examined, PV arrays have the highest reliability for pumping, but overall PV system reliability was hampered by poorly matched and unreliable pumps and motors.
- Wind system reliability and durability varies widely, according to the type of design and local wind regime. Many systems were poorly designed to withstand periodic high winds and storms.
- Anaerobic digesters appear to be ill-suited for most small-scale agricultural applications, but may hold promise for the provision of irrigation and stationary power for large-scale farms and feedlots. The application of hydraulic rams is severely limited by a lack of appropriate sites.
- For irrigation pumping, only locally manufactured, site-built, wind fan-mill pumps have a capital investment cost as low or lower than small-scale, diesel generator sets, but both require constant repair and maintenance. The wind units also have low water flow rates at many sites.
- Many donors and PVOs felt that the reliability of PV for remote sites offsets its higher capital cost (relative to diesel units) for small, critical, electrical loads, such as potable water pumping.

Nature of the End-Use

Field teams found that the normal distinction in development planning between potable and irrigation water supplies simply does not apply in the countries visited. Regardless of the water's end-use, the pumping systems examined were medium- to high-head (15 to 60 meters), low-volume tube-wells. Only one example of pumping large amounts (over 100 cubic meters) of inexpensive water from surface or shallow underground sources was seen, though this is common in parts of Asia and Latin America. Except for traditional, rain-dependent grain production, the planting of cash crops by small farmers is planned only after a supply of irrigation water has been assured through the digging of a well. For all these reasons, water pumping for irrigation, livestock and human consumption is be treated as a single subject in this section. If the pumping system was designed to function only during the growing season, rather than year-round, this will be noted in the text.

Africans do not consider all water sources to be of equal value. In a number of the seven countries visited, the value attached to the source (whether for potable water or irrigation) was reported to be dependent on three factors:

- Year-Round Availability -- This is a highly prized feature. It is, in turn, dependent on a number of interrelated factors, including seasonal fluctuations in well depth, the aquifer's recharge characteristics, daily and seasonal demand for water, reliability of the pump's power source, pump durability, cost and availability of any fuel required, and amount of water storage.

- Geographical Location -- What is important here is not only how close the well is to users, but also where it is located relative to other water sources. People will use shallow wells close to their homes for potable water until those sources are exhausted and then will walk the extra distance to the diesel pump for their daily supplies. Thus, even wells with mechanical pumps, if located in areas with dispersed populations and numerous shallow wells, are often used only seasonally.

- Water Quality -- There is a value attached to water's cleanliness and taste, but consumer preferences are difficult to measure. Deep tube-wells, particularly when they are cased and have a tight-fitting cover, normally provide much cleaner and more sanitary drinking water than shallow wells, which often suffer from animal fecal contamination and serve as a breeding ground for insects and parasites. There is often a clear trade-off in the minds of water-bearers between a hand-dug well nearby and

a distant borehole--it may require more time and effort to obtain cleaner water.

At most of the 33 pumping installations examined for this study, water was of high quality, centrally located and available year-round. These characteristics make the water very valuable to local users, although it is difficult to assign a monetary value to it, particularly when it is used for human consumption. In Africa, water is usually a major constraint on all aspects of life--population growth, health services or agriculture.

Energy Technologies Applied to Pumping

Pumping can be accomplished by a variety of energy technologies. The most common conventional systems encountered in the seven African countries visited were: small-scale diesel engines powering surface-mounted mechanical pumps, diesel generator sets driving surface-mounted or submersible electrical pumps, and grid electricity powering a variety of electrical pumps. All these systems tend to be quite small by world standards, rarely topping 20 horsepower, due to the limited recharge capacity of many African wells, which results in a drop in water level during pumping. In addition, there have been significant efforts in the countries visited to install, test and distribute small-scale, renewable energy-powered systems, both for irrigation and potable water applications. Of the 33 renewable energy-powered pumping units examined,* the range of technologies used in the field or laboratory tests included:

- PV arrays of French, Belgian and U. S. manufacture--16 instances,
- wind turbines of the site-built, fan-mill type or imported, manufactured variety--11 instances,
- anaerobic digesters, being tested to power modified gasoline or diesel pumps--three instances,
- hydraulic rams--one instance, and

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*It is important to note that field teams did not see all, or even a representative sample, of renewable energy systems in the countries visited. For example, one report noted that 30 wind pumps were installed in Senegal, but the team only had time to visit five. More than 35 PV-powered pumps have been installed in Mali, but the team had time to examine only eight. This problem of partial coverage applies to all end-use applications. A listing of the technologies to be found at each project is given in Appendix A.

- solar, thermal, flat-plate collectors powering Rankine-cycle engines--two instances.

Three summary notes should be made about pumping system sizes and configurations before discussing lessons learned from the field visits. First, the systems examined, whether applied to irrigation or providing potable water, are small in size and limited in output. Of 33 systems, only two produced more than 50 cubic meters per day (50 cubic meters being 13,200 gallons). The average daily output for the typical, 1300-watt, "Mali Aqua Viva" PV system was 40 cubic meters when pumping a 20-meter head. The average water output of the wind fan-mills observed in Senegal and Mali is believed to range from two to eight cubic meters per day, although it was not directly measured.

Second, most of the renewable energy pumping systems have been in place for only a short while, relative to their expected life. Three PV pumps were installed between 1976 and 1978, nine from 1979 to 1980 and the remainder from 1981 to 1982. Virtually all the wind pumps examined were installed between 1979 and 1982, although some commercial sales may have occurred before then in Lesotho. All the anaerobic digesters are laboratory prototypes, still under development, while the single hydraulic ram was installed in 1982. The only exception is the ill-fated, French SOFRETES solar thermal pumps, which were installed in West Africa (primarily Senegal, Upper Volta and Mali) from 1974 to 1980. Most of these are now broken down and abandoned, although some did function resonably well for three to five years. For the PV and wind systems, many more hours of operation are required to provide the needed information on system reliability and durability. Nevertheless, some of the problems encountered thus far and possible solutions are discused below.

Third, many installations were undertaken without any attempt, or even intent, to calculate economic or social viability. In a number of instances, systems examined by the teams had been installed as experiments, designed to try out a new technology under field conditions--as a philanthropic service, missionary outreach program or some combination of these activities. Even where feasible, cost and performance data collection had a low priority at most of the projects visited. Thus, information was not always available on the real cost of installations, including design, labor, site acquisition, etc. While some preliminary economic analysis appears in a subsequent section, the unreliability and incompleteness of the data should be kept in mind constantly.

Reliability of Renewable Energy Technologies

The sustained delivery of water from a field pumping installation is a function of the reliability of two different systems:

- energy production technology--does it produce electrical or mechanical power output when required; and

- auxiliary power-conditioning and power-consuming equipment--whether pumps, controls and motors function when the power is delivered to them.

Because field experience with these two system components is so different, they will be treated separately below. Also, the following section will examine whether the combined outages or failures of the energy and auxiliary systems have affected water availability when it is needed, or if the reliability of the water supply, including water and electricity storage, has been adequately matched to local requirements.

As mentioned before, three different energy technologies were used or being tested for pumping water in the countries visited--PV arrays, wind fan-mills and anaerobic digesters. In general, PV arrays experienced the fewest problems and had the highest percentage of energy availability. The reliability of PV arrays was superior to other available decentralized power systems, including diesel generator sets and batteries. This is not surprising, given that PV power systems are basically manufactured, solid-state devices, with no moving parts and limited local field adaptation. There were three instances of performance degradation reported, all in systems installed between 1976 and 1979, but these appear to be problems with early production runs and inferior-grade encapsulants that have largely been corrected in arrays manufactured since 1980. Even these degradation problems did not lead to an interruption of power, but rather a reduction in systems' electrical output. Energy availability from arrays observed in the field was reported as five to eight hours per day (except in the rainy seasons), with uninterrupted pumping of four to six hours per day. The AID-sponsored project in Tangaye, Upper Volta, reported that the pump was available for operation 97 percent of the time when the sun was shining during the first two years of operation, and a similar level was achieved in the 18 months following alteration and doubling of array size.

Wind systems had a more mixed reliability record than PV arrays. They ranged from factory-produced systems (usually from South Africa, Italy, Australia or France, although units are now produced in Kenya and assembled in Senegal) to low-cost, site-assembled units fabricated from wood, recycled machine parts and other local materials. Factory-built, "Kijito," wind water pumps, produced in Kenya using a local adaptation of the ITDG model, appear to be reliable and virtually maintenance-free. Site-built systems require frequent attention and often ingenious local improvisations to keep them operating. Examination of the daily log kept by a cooperating PCV on a series of locally fabricated, "Sahores" windmills in Mali showed weekly or even

daily repairs that had to be made to the windmill/pump assembly, usually due to breaking, cracking, or bending of different wooden and iron pieces of the drive-train assembly. The same log noted that many of the required repairs for the transmission and power train could be made on the spot by local mechanics and operators, or at most, required service by a nearby welding shop.

A second problem with the wind systems examined was faulty design, often due to inexperienced staff and a lack of accurate, site-specific, wind data gathered prior to installation of the unit. While this led to some difficulties caused by insufficient wind speeds, a much more serious problem is the lack of adequate built-in protection against periodic storms and high winds. In two instances, it was reported that towers were damaged or knocked over by wind gusts. In addition, systems to feather the blades and brake the turbine during periods of high wind were sometimes ineffective in preventing damage to the drive system. At one site, the windmill was taken down during the rainy season to prevent damage from storms. While designs have been altered in the field to accommodate these conditions, many are still in a phase of adaptive research and development rather than being widely disseminated, despite some favorable economic indications from early installations.

Experimental anaerobic digesters (bio-gas generators) were being tested for water pumping in Botswana, Upper Volta and Mali. In all cases, they were more prototype development exercises than field demonstrations. No data on the amount of water pumped could be found for any of these installations, and little can be said about the long-term reliability of the systems, either in terms of the amount of gas produced, its availability when pumping is required or quality as a fuel for a modified diesel or gasoline engine. It should be noted that Indian-style bio-gas systems seem to have very limited application for any end-use in colder regions of Africa, particularly mountainous regions, as in Lesotho. It has been observed at these sites that cold evening temperatures year-round and low daytime temperatures during the winter months strongly inhibit gas production, even with good design and operation. Chinese-style digesters may have greater success, if they can be buried in the ground or insulated in some other way. High-cost construction and operation would probably be required for success.

Materials and Component Degradation

The overall performance and durability of the renewable energy systems examined was high, given adequate maintenance. In all the irrigation and potable water pumping systems observed, pumps and motors (if electric) were the weakest system components, just as they are for diesel systems. There appeared to be four different reasons for pump degradation or failure, the most important being the use of inferior components or units not

originally designed for the particular renewable energy technology. For example, from 1976 to 1979, existing pumps were often coupled to early PV arrays although the motor/pump's technical characteristics were not well-suited to the daily fluctuations in input current from the array, peak amperage, etc. Certain European systems had particularly unfortunate matches between the PV array's output characteristics and motor's operating requirements. As a result, pumps failed with less than 2,000 hours of operation. Even when these early pump-sets did not completely fail, they were less efficient and/or durable than other commercially available units, thus reducing the amount of energy produced by expensive PV arrays that was actually available and used for water pumping.

Second, spare parts and routine maintenance materials were often not provided by the manufacturer, resulting in long outages in water supply even for minor problems (seals, brushes, etc.). Some pumps were out for two to three months awaiting a replacement pump or part, and waits as long as six months were reported.

Third, routine maintenance for pump and motor is essential if the system is expected to last, whether it is powered by PV, wind or bio-gas. Many moving parts of surface-mounted motors require weekly greasing or oiling, while seals, belts and mechanical connections require adjustment and checking on a semi-monthly or monthly basis. The most successful pump installation programs--such as Mali Aqua Viva or the CARITAS program in Senegal--have professional installation and maintenance teams plus trained local operators who perform routine cleaning and lubrication. The Sahores windmill program in Mali carries this one step further by teaching future owners not only how to operate the system, but also how to construct them and fabricate spare parts. Without this attention, small problems quickly lead to excessive wear and pump failure.

Lastly, three pumps failed prematurely because the water level in the well fell below the pump, leading to a loss of lubrication and overheating of the pump. This was due to either poor system design (not allowing for annual fluctuations in well levels) or over-pumping of the aquifer when too large a motor/pump set was installed. With the exception of the PV installation at Tangaye, Upper Volta, early pumping systems examined had no low-water, shut-off mechanism to automatically stop the flow of power to the pump when the water fell below safe levels. In fact, one French firm threatened to void its warranty if the user in Mali installed his own low-water, shut-off sensor, despite the fact that none was provided with the unit.

While pumps were the major cause of system failure, there were also material and component problems for each of the energy technologies. As already noted, early PV arrays, manufactured before 1980, had problems with discoloration and loss of

transmissivity of the encapsulant surrounding the cells. Most major manufacturers have now substituted glass for the earlier resin and polymer encapsulants, solving this problem. One major U. S. manufacturer had difficulty with a loss of power from arrays due to thermal stressing within the modules and a subsequent lack of electrical contact. This was rectified in subsequent production runs by using a different substrate material.

Wind systems naturally have problems of frictional wear and heat-induced degradation since they derive power from moving air via spinning and rotating parts. Bearings, rotor blades and drive shafts appear to be particularly susceptible to early fatigue and failure. However, these problems are well understood, and wind turbines built today have long life expectancies, if care is taken in design and installation.

Bio-gas plants, examined in Mali, Senegal and Botswana, displayed a number of problems even when installed in a laboratory setting. Indian-style digesters, with floating steel gas-holders, show rapid corrosion of the steel and subsequent gas leakage, if the holder is not sealed initially with a heavy, asphaltic, rust inhibitor or scraped and repainted every year. Chinese digesters have other problems--principally gas leakage, if the dome is not carefully constructed and tightly sealed.

Matching Output to Demand

For irrigation, the ideal pumping system uses the water as it is lifted by the pump, thus eliminating any storage of electricity or water and the costs associated with such storage. With diesel and small, grid-powered, electrical pumps, matching can be achieved simply by operating the unit during the morning hours. The total elimination of storage was rarely attempted with the renewable energy systems examined.

For PV systems, particularly deep-well models, some battery storage is normally included to generate the initial amperage required to start the pump in the morning. As many analysts have noted, the incidence of sunshine in most arid African countries corresponds quite closely to the period when irrigation is needed most. Barring a breakdown in the pumping system or a loss of power from the PV array, there appears to be an excellent match between the amount of water needed for irrigation and the output of this energy technology. Nonetheless, storage tanks or ponds are often installed to ensure continuously available water, despite system failure, cloudiness or abnormally high demand.

For PV-powered, potable water pumping systems, a good fit between demand pattern and water availability can usually be ensured by using an "on-demand" supply system, as was installed at the AID-sponsored unit in Tangaye, Upper Volta. People draw

water, normally from a supply tap connected to a storage tank, and the pump or battery is activated to refill the tank when the water falls below a preset level. Water is available to consumers whenever they want it. There is also some flexibility in expanding or contracting the available supply on a daily or seasonal basis, within limits imposed by the well's recovery rate and the maximum daily power output of the PV system.

For wind pumping systems, matching the amount of water produced to the demand pattern, whether for irrigation or human/livestock consumption, is much more site-specific than for PV or diesel systems. In addition to being governed by characteristics that affect all pumping installations--total static head, pipe diameter, well recovery rate, etc., output depends greatly on the daily and seasonal pattern of the local wind regime. If wind is consistently available each day, or even several days a week at a sufficient velocity, a combination of water storage and direct pumping can provide the water required for irrigated agriculture. Because of the critical nature of water availability in potable applications, wind installations often combine water storage for a day or more with a back-up unit, such as a hand pump. This assures a ready supply even if there is an extended calm period or failure of the wind turbine or pump.

Normally, continuous feed bio-gas digesters (such as the laboratory models observed in Botswana and Mali) have enough stored gas, accumulated in the gas-holder over 24 hours or longer, to permit several hours of operation of an irrigation pump upon demand. However, this is dependent on a continuous supply of fresh manure and water, commodities that are often in short supply in African farming districts. Since most bio-gas driven pumps run on a mixture of diesel fuel and bio-gas, less fossil fuel is displaced than with wind or PV units. All the systems observed were still in the prototype development stage, and thus, were not actually pumping water on a regular basis. Batch digesters, such as the French prototype installation observed in Upper Volta, have the additional problem of large variations in gas output during the course of producing each batch, normally a period of 50 days. This requires substantial storage capacity for either gas, as in the Upper Volta case, or pumped water to smooth out the dramatic changes in gas production. Either storage solution, employed to make gas available when needed for irrigation, is very capital-intensive and increases the system's cost and complexity drastically.

Rate of Utilization

Regardless of technical performance and durability, technologies cannot be considered disseminated if they are not being actively used, maintained and repaired. Technology implants, "parachuted" in by government agencies or foreign donors with no local involvement, local capital investment and

trained operators in the area, last only so long as the donor provides the required maintenance, spare parts and fuel, if any. The system is used until the first problem arises and then abandoned, if outside assistance is not continued. To avoid this problem, some organizations, such as CARITAS in Senegal and Aqua Viva in Mali, provide all the maintenance and repair staff required for their PV and wind units. The most famous examples in West Africa of the problems created by a lack of attention to repair and maintenance are the French SOFRETES solar thermal pumps. Inherently complex and difficult to keep in operation, they were also plagued by a lack of in-country spare parts and training for local repair personnel. Six of the seven systems in Upper Volta were not functioning, and many had been out of commission for periods of three months to two years.

Second, an energy system can function admirably and be well-maintained, but still not produce a service considered necessary or valuable by local users. In such cases, the system will probably be under-utilized relative to its potential output. As mentioned, water is an extremely valuable commodity in most of Africa, and pumping systems are kept running and in heavy use. Some wells received two to three times the estimated demand during the dry season, although there was no evidence that water was ever being wasted. It should be noted that a number of PV systems designed for potable water could have produced more, if they pumped steadily throughout the daylight hours into additional storage tanks or ponds rather than functioning on a "demand" system. Such extra water could be used for livestock watering or the irrigation of high-value crops, such as vegetables, near the well. Another possibility is that the electrical power produced when the pump is not running can be stored and used for other applications--lighting, small-scale cottage industry, etc. This multi-purpose approach has been tried in several recent PV installations with great success.

Cost-Effectiveness

Given the limited data collected in the field on the water output and costs of operating wind, PV and anaerobic digester systems, only broad generalizations can be made about the comparative economic viability of the various renewable energy technologies. Where there are good wind regimes, fan-mills appear to be cost-competitive with conventional technologies available for irrigation pumping, such as diesel pump-sets. Low-cost, site-built windmills, such as the Sahores units in Mali, have initial capital costs as low or lower than diesel units, but the field team could not locate reliable data on their daily water output. Thus, no cost per cubic meter of water pumped could be calculated. Given actual capital costs from 1978 to 1981, water pumped by PV systems cost 40 to 60 cents per cubic meter in Mali and approximately 30 cents per cubic meter in Senegal, even when capital costs were amortized over 10 years at

10 percent interest and systems were assumed to operate 365 days a year with no maintenance costs.* No field data were available for pumps powered by anaerobic digesters, although projections for the large experimental unit in Upper Volta, designed to power perimeter irrigation, indicate higher values per cubic meter of water than for existing PV systems.

The true proof of the cost-effectiveness of technological alternatives for irrigation pumping is that wind systems are being commercially built and sold in Kenya, imported units are being sold in Lesotho, and elsewhere, active workshops for constructing site-built units are in operation in Mali and Kenya. Neither PV systems nor anaerobic digesters are being sold to commercial farmers, rather private volunteer groups and foreign assistance agencies are purchasing them.

On the other hand, the demand for PV systems to provide small-scale, potable water pumping appears to be strong. Funding agencies that paid for the initial two dozen installations in Mali, Senegal and Upper Volta are quite satisfied with performance and plan to purchase dozens of additional units in the near future. It is difficult to calculate economic returns for this application, since the water is not sold--its provision is a function of government or private volunteer organizations, rather than any market transaction. However, as already mentioned, the value of clean water, conveniently located and available year-round is very high to local people in many of Africa's drier regions, as evidenced by the distances they will travel to use wells and the physical labor they will expend digging them.

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*For Mali, a capital cost of $30,000 to $40,000, amortized over 10 years at 10 percent interest, yielded a yearly investment of $6,000 to $8,000. Water output averaged 40 cubic meters per day or 14,600 cubic meters a year. For Senegal, at Samane village, a capital cost $64,000 gave an annualized investment of $12,800; water output is 117 cubic meters a day or 42,700 cubic meters per year.

1.2 Grinding and Milling

Major Technical Findings of the Field Teams

- The reliability of the renewable energy-powered milling operations examined compares favorably with commercial mills run on diesel fuel and grid electricity.
- Commercial millers in Africa are experienced in machine operation and maintenance, and have no difficulty transferring these skills to mills powered by renewable energy systems.
- Non-economic factors, such as fineness of the flour output and the mill's ability to grind a variety of foodstuffs, often had as much to do with high utilization of the mills observed as low milling prices.
- It is difficult to assess the economic viability of the systems observed for two reasons--the renewable energy systems were usually gifts from outside donors, so capital costs were not considered in local financial calculations; and prices for milling services were often established arbitrarily by local leaders or project managers, without regard to capital costs, operating expenses or the need for future system replacement.

Nature of the End-Use

Grinding is the process of reducing a substance to smaller pieces, generally by the friction of two or more revolving plates or stones. Milling is a specific type of grinding that involves the reduction of grain to flour. According to millers interviewed by field teams, the factors most important to the design of milling or grinding systems are:

- nature of the grain or other foodstuff (nuts, seeds, etc.),
- desired fineness of the end product, and
- desired grinding rate.

These three factors are highly interdependent. For example, the moisture content of the grain feedstock directly affects the maximum milling rate. Similarly, the finer the end product or flour desired, the slower the grinding rate. For this assessment, it is important to note that the finer the grinding or milling, the more energy is required per kilogram of final

product. This energy must normally be in the form of high-torque, rotary motion.

Grinding is essential to the preparation of many staples in the African diet. Without it, certain common foods and grain varieties would be virtually inedible due to their protective shells or the extremely dry state in which they are stored. When grinding grain such as millet, a high value is assigned to very fine flour, and consumers are willing to pay an extra 25 percent or more for this particular service.

Technologies Used for Grinding and Milling

Grinding and milling can be powered by a variety of energy sources. In African commercial operations, diesel units, electrical motors using grid power and draft animals are typical power sources. Generally, power is fed into a burr mill, which crushes the grain or other foodstuff between rotating millstones or metal grinding plates. However, burr mills cannot produce very fine flour without excessive wear on the grinding plates. Hammer mills, which employ cutting knives that rotate rapidly, can accomplish a variety of tasks too difficult for burr mills, including very fine grinding and the de-hulling of certain grains. Unfortunately, hammer mills are more expensive than burr mills, usually imported and consequently, found less frequently at small-scale, African operations. For instance, there were no such mills in the area around the Tangaye PV milling operation.

Several renewable energy systems can be used to power milling systems. Outside Africa, windmills have been used for centuries to grind grain directly into flour, as have several types of water wheels and turbines. Only four grinding projects were observed in the field by assessment teams, including three water-driven mills--one each in Kenya and Rwanda, and one under construction in Lesotho. In addition, there was a large PV-powered unit in Upper Volta. Laboratory prototypes were also being developed, including an internal combustion engine fueled by bio-gas in Mali.

Reliability of Renewable Energy Technologies

The water-mill demonstration project in Kenya was the only project observed that is designed to use direct mechanical power from a renewable energy source. Fabricated almost entirely from local materials, the original unit was in operation for 23 years until 1981, when several worn wooden components were replaced with steel parts. At present, the system operates 28 days per month. Since there is no electricity available in the area, the only alternatives to the mill are hand-grinding or a five-kilometer trek to the nearest other mill. The mill has become an

important asset to the village, especially because it benefits small-scale landowners and lower income households.

In Rwanda, the Murunda Belgian Catholic Mission has set up a small hydro system for the generation of electric power, a portion of which is used by a grain mill. A small grid distributes power from the 75-kilowatt, cross-flow turbine at a rate of 11 cents per kilowatt-hour (the price of electricity from the national grid is 13 cents per kilowatt-hour). The milling services are widely used and have achieved general acceptance in the area. Private, personal use of electricity from the mini-grid is low among local citizens due to high hook-up charges.

The small hydro system at Thaba Tseka, Lesotho is designed to produce 3.8 kilowatts of electricity from a Pelton wheel turbine. The power will be directed exclusively to a local grain mill, half a kilometer away, via an overhead line. The Pelton wheel, generator and controls are in place, but at the time of the site visit, the grinder had not been delivered, so no reliability data were available. At present, the system can operate at only 50 percent of its rated capacity due to inadequate information from the electrical equipment manufacturer. Other problems, such as a lack of technically qualified personnel and electrical equipment breakdowns, have resulted in project delays. There are indications that local people have given up on this unit--the chief of a neighboring village believes it will never be finished.

The large PV installation at Tangaye, Upper Volta has been thoroughly studied and documented. The 3.6-kwe system provides power primarily for a three-horsepower hammer mill, as well as a village water supply and lighting for the mill. Of the total 3,848 kilowatt-hours produced from March 1, 1979 to March 29, 1981, 2,838 or 74 percent were used by the milling machine, 440 by the water pump and the remainder for lighting, distributed as 120-volt DC power. Since early technical problems with the PV array were solved and the system expanded to double its original size, the mill has been available for grinding over 90 percent of the time and for longer periods to meet the strong local demand for the fine flour produced.

In grinding, the reliability of the total system hinges on the durability of the grinding devices employed, which is linked, in turn, to both the product's initial design and the frequency of cleaning and maintenance. The initial design and siting may be a constraint in certain countries because of the specialized skills involved. For example, the siting and construction of even small-scale hydroelectric generators requires a thorough understanding of hydrology, geology and civil engineering. The initial design, based on commercial milling considerations, may also affect long-range economic viability. Mills are usually located on a main road or near a major commercial center. Hydroelectric sites, on the other hand, are often inaccessible,

particularly for the constant transportation of commodities as bulky as grain and flour. Therefore, waterpower is converted to electricity and transmitted to the mill site. This process results in some inefficiencies in the conversion and transmission process, requires additional expense and introduces sources of system failure in the added electrical components.

For both PV- and hydroelectric-powered systems, the long-term reliability of the milling operation depends partly on the availability and affordability of spare parts and replacement units. In most cases, all of the power system is imported from the industrialized world, often over very long and circuitous supply routes. This can mean long delays in making the system operational again after a part gives out unless prior arrangements are made for an in-country stockpile of parts.

Most African milling operations are operated by teams of experienced, skilled professional millers who have a vested interest in keeping the machinery operating. They know how to perform preventive maintenance and replace parts to keep producing flour. Millers at the sites visited had no difficulty managing renewable energy-powered units and found them as easy or simpler to run than small-scale diesel mills.

Matching Output to Demand

The output characteristics of the two commercial technologies used for grinding--PV and hydroelectric turbines--vary widely, both on daily and seasonal bases. PV systems only produce power during the daylight hours and may have reduced output levels during periods of cloud cover. Storage, in the form of batteries, may be included to increase the daily length of system service, but they greatly increase system cost, by as much as 40 percent, and introduce a major potential source of unreliability. With its expensive battery storage, the PV system installed in Upper Volta can continue grinding well into the evening hours until the millers shut down to preserve the battery charge or allow continued operation of other higher priority devices, such as the potable water pumping system. Hydro power is subject to major seasonal variations, and there may also be short-term variations in water flow due to sudden rainfalls. Large hydroelectric installations solve this problem by storing water in reservoirs or ponds, allowing excess water to spill out harmlessly when there is an oversupply and acting as a buffer during short dry spells. None of the three systems examined had such reservoirs.

Rate of Utilization

Since grinding is normally a commercial operation, the demand upon a particular installation depends on its cost to

users, perceived reliability and quality of service. Economic issues are discussed in the following section. Besides these three key factors, institutional and organizational variables also affect the extent to which grinding facilities are used. In Lesotho, the water-powered system is run in batch mode, producing up to 400 kilograms a day. The decision to use batch mode was based on customers' desire to receive flour ground from their <u>own</u> grain, rather than just a commensurate amount of flour.

Another important factor in the utilization of a renewable energy technology is the overall belief in or acceptance of the system by local users (i.e., does it provide something useful). There are indications that local people in Lesotho have given up on the small hydro unit after repeated delays caused by technical difficulties. In contrast, the milling unit at Tangaye has been integrated into the life of the local community. According to the NASA report of February, 1982, "A great deal of credit for the successful and prosperous operation of the system has to be attributed to the pride the villagers have in the (PV) system." The grain mill powered by electricity from a small hydro system in Rwanda has also achieved general acceptance in the area, even though few residents can afford to use the electricity produced by the same turbine in their homes.

Cost-Effectiveness

Limited cost and performance data were available for only three of the five grinding projects--the hydro systems in Lesotho and Rwanda, and the PV system in Upper Volta. A general discussion of these systems' capital costs would be misleading because all three were gifts from donor countries or PVOs and their costs may not be comparable to those an African buyer would find in a competitive market.

The charge of seven cents per kilogram for grinding in Lesotho was based on comparable local prices. In Upper Volta, the price of five CFA (1.4 cents) per kilogram was selected by the village council. The criteria for setting this price were not clear to the assessment team, since it is about half that charged by a local miller who uses a diesel-powered mill. Still, the main attraction of the Tangaye mill is not just its low cost, but also its ability to grind unhulled grains and produce a high-quality, finely ground product. The price of grinding at this mill is apparently unrelated to capital or operating costs. In contrast, the hydroelectric mill in Rwanda is financially self-sustaining, including salaries and the amortization of capital, at a price of four cents per kilogram, which is considered affordable by most users. However, it would be inappropriate to draw sweeping conclusions from just these three cases, especially in economic terms.

1.3 Crop and Fish Drying

Major Technical Findings of the Field Teams

- As solar dryers are still at an early stage of prototype development in Africa, there is no good information available on future economic viability, durability or even acceptance by potential users.
- Laboratory testing and initial demonstrations of solar dryer prototypes in Africa indicate potential economic viability in projects designed to produce cash crops, chiefly dried fish and fruit, for commercial markets.
- Many research prototype solar dryers were developed with little effort to define potential users or consult them on important parameters, such as allowable investment costs, market product differentiation, consumer taste characteristics, etc.
- Consumer acceptance of the final dried product is often as important as the unit's technical performance.
- Higher market value, increased marketable yield and lower insect infestation are the major benefits perceived by end-users of successful prototypes.
- Since the traditional alternative drying technique--open-air, sun drying--has no capital costs, solar-drying systems must either be very low-cost or perceived by users to have substantial economic and/or social benefits.

Nature of the End-Use

The drying of agricultural crops, fruit and fish is practiced in all the African countries visited. Normally, produce is spread out on racks or mats in direct sunshine to dry, lowering the moisture content of the food to the point where spoilage and rot are significantly retarded. There are several problems with sun-drying that can lead to post-harvest losses and serious health hazards. First, food may begin to rot or spoil during sun-drying, thus reducing the final amount of food, seeds or fish that can be stored for later use or sold. Second, the market price of each remaining unit may drop because of product degradation that occurs during sun-drying, especially when sunshine is intermittent. Third, sun-dried produce often suffers from serious insect and vermin infestation. This is a particular problem with fish and meat, with vermin transmitting a number of serious diseases and parasites to consumers. Fourth, post-

harvest losses can also occur when animals eat or wind scatters the exposed food.

Technologies Applied to Drying

Sun-drying, salting and smoking are the techniques usually employed to preserve food in Africa. In addition, commercial operations may employ large-scale, enclosed dryers that use hot air and/or smoke, produced by the combustion of wood, agricultural residues, coal or possibly petroleum products. The combination of techniques used in any given application is governed largely by the local availability of fuel(s), the value added by the drying or preservation process, and local tastes. Consumer preference is a particularly important factor. For example, smoking normally alters the taste, color and texture of the foodstuff. This is considered desirable for certain products, such as fish, some meats and a few fruits, but it is unacceptable for other crops and in other locales.

There have been a limited number of renewable energy systems applied to the problem of drying fruits and fish in Africa. The field teams examined, or at least discussed, four different solar drying projects--two in Senegal and one each in Lesotho and Rwanda. Other projects were studying the possibility of burning bio-gas or agricultural wastes for drying, but no prototypes or field installations had been made. The solar dryer prototypes examined varied in size and configuration, ranging from a commercial-scale system planned for fish and vegetables in Senegal to small, family-sized, fruit-drying units being field-tested in Lesotho. Most of the systems, even those developed by the long-standing, solar-drying project run by CERER (Centre de Recherche sur les Energies Renouvelables) in Senegal, are still only in the development stage.

Reliability of Renewable Energy Technologies

The durability and reliability of solar food dryers is directly related to materials used. Unfortunately, this in turn directly affects cost--the more durable the system, the higher the front-end capital cost. This is a problem primarily because the standard for comparison, traditional drying techniques, require virtually no initial investment. In Lesotho, the first solar dryer prototypes were built with metal frames. While extremely durable, the units were too expensive--even the smallest systems cost more than $35. At the time of the team's visit, experiments were underway to evaluate the performance of less expensive materials (including cardboard) for the unit's frame. In other cases, the reverse occurred--the project moved to <u>more</u> expensive materials to improve performance. For example, sawn lumber was substituted for sticks to improve the seal between the frame and plastic covering. Also, the polyethylene

that had been used as glazing was to be replaced by more expensive Tedlar to reduce the progressive loss of solar transmissivity due to discoloration from ultraviolet radiation. In all cases, solar dryers are still in an experimental stage, so little can be said about long-term system reliability and durability in the field.

Cost-Effectiveness

In the countries visited, there is a demand for techniques/ devices that can reduce the loss of crops during processing. Regrettably, field teams did not observe projects that were generally analyzing benefits or reduced losses in a clear, methodical manner. In general, benefits from drying vary widely, as a function of both seasonal differences in sunlight and harvest, and the market value of the food being dried. For example, in Senegal, there was a major institutional problem in the lack of market differentiation for solar-dried produce. While consumers and local observers clearly preferred fish dried in solar units because of its freedom from spoilage and insects, merchants sell the traditionally processed and solar-dried fish mixed together, so consumers cannot choose the solar-dried product, even for a premium price.

Similar mixed results occurred in Lesotho and Rwanda, and local development workers were divided over the perceived value of solar food dryers. Some felt that any device which increases food production is of great value, while others argued that the benefits do not justify the costs incurred. Solar food dryers must undergo substantially more field-testing and marketing analysis before their potential value can be accurately estimated.

2.0 NON-AGRICULTURAL END-USES

In the seven countries visited during the assessment, five distinct non-agricultural end-uses were served by technologies examined on site visits. (Potable water supply pumping is discussed in section 1.1.) Table B.2 lists those end-uses in order of frequency, giving the number of projects addressing each end-use and the specific technology options being employed.

Table B.2. Summary of Non-Agricultural Application Installations

End-Use	Energy System	Number of Systems Observed
cooking	bio-gas, metal/earthen biomass cook stoves, solar cookers	156
water heating	active and thermo-siphon solar systems	22
lighting	bio-gas, PV units	13
food drying	family-scale solar food dryers	8
space heating/ cooling	passive solar construction	2

This section discusses each end-use and compares the relative success of renewable energy systems in meeting the requirements of each. Overall, non-agricultural applications of renewable energy systems have received more attention than agricultural applications in the projects visited. In large part, this is a reflection of the important role of domestic energy supply for the people of these countries. In addition, it reflects the determination of many major public and private foreign assistance donors in Africa to target projects on the basic human needs of the rural and urban poor. Energy for food preparation and other domestic chores is a basic, irreducible need of all Africans. It also has implications for a host of other concerns that interest government agencies, foreign donors and social service organizations.*

*These include the causes and consequences of deforestation and desertification; effects of gathering fuel on rural women and children; opportunity costs to individuals and communities of gathering fuel; availability of capital to invest in new energy systems; secondary, non-energy related qualities of traditional energy systems; rural vs. urban implications of energy scarcity; and seasonality of energy demand.

2.1 Cooking

Major Technical Findings of the Field Teams

- Very simple, site-built cook stoves without chimneys are often rapidly accepted in rural areas where they have been introduced because of their low cost, ease of construction and insensitivity to minor fabrication errors.

- Laboratory and field tests have found fuel savings of 30 percent or more for improved cook stoves. However, consumers may adopt a technology for other reasons--freedom from smoke, decreased cooking time or as a symbol of modernity.

- People who purchase, as opposed to gathering, fuel are more likely to invest in a fuel-conserving cooking device. The more they spend on fuel each month, the more likely they are to seek an energy-conserving unit.

- Characteristics considered desirable in a cooking stove vary drastically from location to location, based on the foods being cooked, manner of cooking and/or stirring, fuels available and customary location of cooking chores.

- Earthen and metal cook stoves have been successfully adapted and disseminated in a number of locations, while there has been little dissemination or even successful field testing of anaerobic digesters (bio-gas) for cooking. The high capital cost of bio-gas units makes them prohibitively expensive for individual families.

- Some solar cookers performed well technically, but were not observed to have overcome a host of social, cultural and practical problems to achieve any good level of social acceptance.

- Since current cooking systems in all the countries visited--"three-stone" cooking pits or recycled, tin, food containers--have no capital cost, new fuel-efficient stoves must have either virtually no purchase price or obvious fuel and time savings to gain wide acceptance.

- The economic pay-back on stoves for users varies according to the cost of fuel. In most cases, especially in urban areas, the pay-back period is relatively short, in some cases as little as three months. However, in rural areas where available capital is extremely scarce and wood is gathered, stoves must be built primarily of low-cost, locally available materials with subsidized or free labor.

- Even when functioning properly, improved wood stoves may not greatly reduce total fuel consumption. Users may opt for more cooking, water heating, etc. and consume the same amount of fuel, thus improving life in ways besides reduced fuel gathering or purchase.

- Even using the same stove design in the same area of a country, different organizations had varying success in their dissemination efforts. The strategies and organizations found to be most effective include:

  -- programs that included continuous follow-up with stove owners;

  -- nongovernmental and private volunteer agencies, sometimes linked with a government program, that had previous consumer extension experience;

  -- projects that involved people from the village in building the stoves; and

  -- project staff involved with the stove work living permanently in the village or area.

- Projects that have active user involvement have a greater probability of widespread technology adoption, partly due to proper operation and maintenance.*

Assessment teams found that every country visited had RET projects aimed at using biomass fuels (wood, charcoal, dung, crop residues) more efficiently or directly displacing fossil fuels (kerosene, propane gas, butane) used for cooking. More projects (21) are oriented toward cooking-related end-use problems than any other single domestic activity, and over 75 percent of the renewable energy systems observed are used for cooking. Information brought back by the assessment teams does offer some perspective on the nature of cooking as an end-use and problems that arise when matching different energy systems to cooking needs. The data also provide some indication of whether certain energy systems can favorably affect energy use in cooking applications.

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*In Senegal, village women trained to build stoves for their own use had a 25 percent higher rate of stoves "built-and-still-in-use" compared to those built by professional male masons who received the same training.

Nature of the End-Use

In the seven countries visited, cooking technologies being developed must respond to a variety of cooking needs. Specifically, there are four sets of factors which the assessment found to require attention during the development of cooking technologies and that can drastically affect public acceptance of individual units. These are briefly outlined below.

Current Cooking Technologies

Throughout the countries visited, the traditional cooking system is either the "three-stone" method or a recycled metal food container. In either case, the "system" is usually free. Fuel availability and price, rather than the cost of the traditional cooking system, is the biggest concern of families and small businesses. Thus, in order to be widely adopted, new cooking systems must be very inexpensive, while at the same time, promising obvious fuel savings.

Food Types and Special Cooking Considerations

Certain foods in these African countries require long cooking times (for example, beans and maize). Some staple foods require active stirring during preparation and are commonly cooked in large metal pots, such as toh made from millet in Upper Volta and Mali. Thus, cooking technologies must be durable, stable and capable of providing substantial heat for long periods. This is especially true for larger units and commercial systems--for example, when making beer or peanut oil, village women keep a fire going most of the daylight hours. On the other hand, cooks may also want a stove that can warm small quantities of food or liquid quickly for rapid cooking at certain times of the day, such as breakfast tea in many rural areas. The design problems in creating a single unit that can handle all these constraints are formidable. Some projects have begun successful work on developing separate stoves for a single family, each serving a different purpose.

Cooking Fuel Availability

The range of fuels used in these seven countries includes dung, wood, crop residues (e.g., millet stalks, rice husks), charcoal, kerosene, butane, coal and propane gas. In every country visited, wood, charcoal or dung is the principal fuel. Petroleum-based and fossil fuels must always be purchased, often at high prices. Thus, projects have attempted to either displace the petroleum-based and fossil fuels now used (five out of 21 projects) or increase the combustion efficiency of biomass conversion systems--wood stoves, for example (16 of 21 projects).

Indoor/Outdoor Use

In locations with a change of seasons, consumers place a higher value on stoves that are portable, as they can be used indoors when it is cold or rainy and outdoors when hot or dry. In addition, there is a comfort issue in terms of both space heating/cooling and traditional cooking practices. It also points to the secondary benefit of traditional cooking systems that provide heat as well as light.

Technologies Applied to Cooking

The range of technologies for cooking applications examined by field teams includes:*

- earthen stoves for burning wood, dung, crop residues, etc.--126 instances;
- bio-gas units of Chinese, Indian, Zairian and other modified design--26 instances, most of which were in laboratory settings;
- solar cookers--three instances; and
- metal stoves for burning charcoal--one instance.

Based on data collected in the field and an analysis of local cooking requirements, the performance of a number of different cooking technologies up to the date of the site visits (November, 1982) can be reviewed. However, the ability to assess the success or failure of these projects in meeting African cooking needs is limited by:

- the fact that half the projects are in the very early stages of implementation (10 out of 21), and in many instances, the technology being used is a prototype (six cases); and
- a lack of data regarding:

  --actual fuel savings of installed systems in the field,

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*These represent a very small sample of the number of installed systems in the seven countries. According to CERER, more than 5,000 "Ban Ak Suuf" wood-conserving stoves have been installed in Senegal alone, and over 1,000 modified Lorena stoves in Upper Volta. Low-cost, commercially available, charcoal stoves also received little attention from field teams, partly because they are not being developed or disseminated by foreign assistance projects.

--actual energy system costs, exclusive of extraordinary, one-time charges, and

--the value of labor and opportunity costs, when, for example, a female head-of household spends one out of every four days collecting fuel for cooking.

Earthen and Metal Stoves

In general, efforts to disseminate earthen and metal cook stoves that burn wood, charcoal, crop residues (e.g., millet stalks) and animal dung are underway and presently experiencing a fair degree of success. Conclusive evidence that any of these energy systems markedly lowers domestic fuel consumption in the field is available only for earthen stoves in Senegal at this time.

A detailed energy survey recently conducted by the U. S. Peace Corps found dramatic differences for Senegalese families whose fuel consumption was being monitored. For example, in the village of Ndieye Sefour, seven families who were already involved in the energy survey, built and adopted Ban Ak Suuf stoves. Average wood consumption for the seven families (a total of 82 persons) dropped from 139.7 kilograms per day to 63.3 kilograms after the stoves were installed. While this decrease does include some seasonal variation (villagers use more wood during the coldest winter periods for space heating), the change is dramatic. If a fuel savings of 30 to 40 percent is assumed, rather than the higher figure found in Ndieye Sefour, each of the 5,000 Ban Ak Suuf stoves has the potential to save .5 to .7 kilograms of fuel per person per day. The total fuelwood saved by the initial stoves would amount to 25 to 35 metric tons per day, assuming 10 persons per household. In addition to the Senegalese studies, there is evidence that secondary benefits, including the creation of jobs and easier cooking procedures, have resulted from several earthen cook stove projects in Upper Volta, Senegal and Mali.

Earthen and metal stoves have been the centerpiece of projects in Mali, Rwanda, Senegal and Upper Volta. In these countries, 72 percent of the stoves examined by field teams were being used, and a total of over 8,000 had reportedly been built by the projects. In Lesotho, Botswana and Kenya, considerable work is now being done on stoves, but primarily in prototype develompent and testing. The following tentative lessons can be drawn from the earthen and metal stove projects visited.

- The construction quality of all stoves is directly related to the level of training and follow-up assistance given construction personnel. Poorly constructed stoves deteriorate quickly, yet even well-built stoves often

need repair--thus, the importance of continued technical assistance for repair and use.

- Poorly built and protected earthen stoves typically have a very short life span, usually less than one rainy season. A damaged or poorly constructed stove may consume as much or more fuel than a "three-stone" cooking arrangement.

- Average fuel savings documented by this assessment range from 10 to 30 percent in the field and 20 to 50 percent in the laboratory. So far, too little effort has been made to document the overall impact of stove projects on users and the environment. This should change as projects mature.

Numerous dissemination strategies are available for fostering widespread stove adoption or purchase--government extension programs, voluntary agencies, local village organizations or councils, and the private sector via individuals, stores and companies. It appeared to teams that variations on all these alternatives will likely be tried over the next few years, but it was too early to determine any clear trends.

Commercial and industrial applications of energy-efficient earthen, concrete and metal stoves appeared quite promising in several of the countries visited, despite the relatively high capital cost of large units. Commercial users generally purchase fuel and have access to the funds required to make capital purchases. For example, the Peace Corps project in Kaya, Upper Volta had sold 23 large concrete "dolo"--commercial beer-making stoves--at $60 to $80 per unit and had requests for more, as the women who operate small breweries purchase large quantities of wood and can recover their investment in a few months. Besides breweries, other large-scale wood and charcoal consumers that might be willing to invest in fuel-efficient devices include bakers, potters, commercial laundries and restaurants.

Solar Cookers and Bio-Gas

The other two energy systems applied to cooking--bio-gas and solar cookers--are at a much earlier stage of prototype development, and units installed thus far are uneconomical or poorly matched to this end-use. For example, solar cookers work best at noon when there is ample sunshine, while most domestic users cook early in the day or in the evening. This is praticularly true in rural areas during the planting and harvesting seasons, when adults work in the fields all day and may not return home at noon. In general, solar cookers have not met with much success.

Bio-gas units typically have high construction costs, and require dependable supplies of dung and water, which are not readily available in most African countries in the amounts needed to fuel such systems adequately. Thus, a major issue with bio-gas is the scale of units in terms of both user costs and fuel supplies. Limited diffusion potential may exist for large-scale units of commercial size (e.g., for large farms).

2.2 Water Heating

Major Technical Findings of the Field Teams

- Locally built solar water heaters have not been a major success in the countries visited for a variety of technical and economic reasons. Commercially installed and/or imported units have often been received quite successfully.
- Domestic solar water heaters displace substantial amounts of imported oil or electricity, since they are installed primarily as replacement units by affluent residents and expatriate foreign assistance staff.
- In many cases, locally produced solar water heating systems have been unable to compete with imported systems in cost or quality.
- The success of any individual domestic solar water heating system depends on the components' quality (lack of design and manufacturing defects), care taken during installation and availability of qualified maintenance and repair personnel during subsequent operation.
- Large-scale, institutional, hot water users (e.g., schools, hospitals, clinics and hotels) are interested in purchasing solar systems but require ease of operation and reliability equivalent to current water heating systems, which are primarily electrical.

Most appliances designed for cooking may also be used to heat water for domestic use, including such devices as traditional cookers ("three-stone" arrangements or metal paolas, used in Lesotho) and modern substitutes (e.g., Lorena stoves, stone paolas, solar cookers). The issues surrounding the use of traditional cooking devices for heating water are much the same as those discussed previously for cooking--high fuel use, deforestation, time required for gathering fuel, etc.--except that the economic and social values of domestic hot water are lower than those associated with the provision of cooked food.

Only four projects (in Mali, Lesotho, Botswana and Senegal) were observed where devices were being employed solely for domestic water heating. The domestic units observed are used primarily by high-income local households, government officials and expatriate workers. Low-income people typically heat water on stoves, also used for cooking, and thus, generally produce less hot water than solar heaters, since it is a secondary result of cooking.

Two major experiments in institutional-scale applications of solar water heating were observed, each with very different results. In Rwanda, Belgian Technical Cooperation sponsored a 150-square meter installation on the Akagara hotel. Installed in April, 1979, the system is running well, displacing 120,000 kilowatt-hours of electricity each year by producing an average 14,500 liters of hot water per day. It is locally regarded as "successful," and other hotels have expressed interest in acquiring a similar system. In contrast, a very large system (520 square meters), installed on the Palm Beach hotel in Senegal in May, 1981, was temporarily out of order when visited. Assembled locally, the system displaced 300,000 kilowatt-hours per year. However, there design problems and no good program for routine maintenance and operation had been set up, so required repairs were taking a long time.

Nature of the End-Use

Hot water is used in African homes primarily for bathing, making beverages and washing clothes. It is generally considered a second-order energy need in that it can be reduced, deferred or eliminated, as required. The exception is brewing tea or preparing other hot drinks--a nightly ritual after the main meal. In low-income homes, the traditional method for heating water is the same as for cooking and uses the same fuel (dung, wood, crop residues or kerosene). High-income households and institutions usually employ electricity for water heating. Thus, any RET designed to provide household electricity (small-scale hydro, PV, wind power) is also a potential source of heated water, depending on the electricity's cost and other demands for it in the home.

In institutions, hot water has a variety of uses, including bathing, washing clothing and dishes, and food preparation. For sanitation reasons, many African schools and hospitals require large quantities of hot water. In some commercial applications, such as laundries, hot water is central to the operation of the business. This hot water is currently provided by the combustion of wood or charcoal, or in a few instances, electrictiy.

Reliability of Renewable Energy Technologies

Some design and manufacturing problems were evident in several of the solar hot water systems examined. In Lesotho, for example, several units developed leaks when the seal between the panel and inlet or outlet pipes corroded. These units were manufactured by a well-known, reputable, foreign firm. Still, a large number of properly designed, built and installed systems were giving satisfactory service in this country. A distributor in Botswana, who originally manufactured solar water heating systems locally, is now importing them. In Rwanda, a local energy research center installed several solar systems for commercial and institutional use, many of which malfunctioned shortly after becoming operational. This center was also underbid on a recent installation of a solar hot water system for a nearby hotel by a Belgian corporation using imported collectors.

Cost-Effectiveness

The domestic solar hot water systems observed typically displace electricity as the energy source. Therefore, cost-effectiveness is a function of the local cost of electricity and average amount of hot water used. Sometimes, domestic systems are built in newly constructed homes, so the cost of the system alone is difficult to determine. Solar water heating systems visited in Botswana cost at least $1,000, and the government is actively promoting their use in middle-income housing. However, an attempt to install these units on low-income, government-sponsored housing failed when residents objected to an additional monthly rent charge of five dollars to cover the cost of the systems. In Lesotho, electricity is inexpensive--only five cents per kilowatt-hour. There is, however, a high political cost since all electric power is imported from the Republic of South Africa and subject to disruption or interruption.

In Senegal, units costing $1,400 are estimated to save 1,800 kilowatt-hours per year. At the lowest block rate of 10 cents per kilowatt-hour, the simple pay-back period is eight years. However, this price for electricity is partially subsidized. The true cost is estimated to be about 20 cents per kilowatt-hour, so the pay-back period in terms of social benefits and costs is only about four years.

High initial costs, long pay-back periods and a low level of perceived need for hot water have put solar water heating systems out of reach for low-income households. However, in the countries visited, high-income homes generally consume more energy than low-income households. Reducing their demand should make more energy in conventional forms available to low-income people while lowering the balance of payment requirements for imported energy.

2.3 Space Heating

Major Technical Findings of the Field Teams

- Where the climate is appropriate, the provision of space heating by passive solar building design and improved, fuel-efficient stoves addresses a high-priority energy need.
- Initial information on performance, economics and user acceptance seems promising for these technologies.

Space heating is an important energy end-use in two of the countries visited--Lesotho and Botswana. Electric resistance heaters and coal-burning metal stoves are used by urban residents in both nations. Although reliable data on current use levels of these relatively expensive conventional fuels are not available, teams were informed that such space heating is becoming more frequent. Rural residents use dung or wood for heating at certain times of the year. At present, many poorer urban and rural people have little space heating due to either a lack of readily available traditional fuels or money to buy commercial fuels. However, recent survey data from both countries indicate that people strongly perceive a need for space heating and would prefer to have warmer living spaces during the winter. Summer cooling is not expressed as a strongly felt need.

In both Lesotho and Botswana, AID-funded projects are the main source of activity aimed at improving space heating, although stores carry South African coal stoves at what are considered high prices by local people. The AID projects are mainly concerned with passive solar housing design and secondarily with using stoves as cooking/heating devices, though the high costs of coal, wood and dung, combined with the low per capita income, indicate a rather limited role for increased use of heating fuels among the majority of the population.

Prototype passive solar buildings and a variety of standard housing designs have been produced by AID's RET projects in both Lesotho and Botswana. Initial calculations based on these designs show potential fuel savings for space heating ranging from 40 to 95 percent, with a much higher comfort level (an important benefit in itself). Estimated pay-back periods for the additional costs of insulation and passive solar design run from four to 17 years, depending on the design. Buildings are currently under construction by both projects, but the final determination of feasibility and economic viability will have to wait for several years of adequate data monitoring and assessment of user acceptance. Based on field teams' review of designs, and given positive field tests and acceptance, passive solar

buildings could have a significant long-term impact on comfort and energy savings in these countries.

2.4 Lighting

Major Technical Findings of the Field Teams

- Small PV lighting systems are commercially viable in virtually all the countries visited. They are cost-effective alternatives today for small institutional users and expatriate workers, not connected to an electrical grid, when other alternatives are diesel generators or storage batteries.
- Properly designed and installed PV lighting systems have records of power availability that approach 100 percent. Their record for reliability is being used as a major marketing tool by private-sector PV distributors and manufacturing representatives.
- In remote locations, PV lighting systems are more reliable and trouble-free than other options, despite the need for batteries and control devices. For this reason alone, they are the system of choice for health clinics and other emergency services.

Energy for lighting is considered a second-order need by most low-income rural residents in the seven countries visisted. Light is provided primarily as a byproduct of the evening cooking fire, although kerosene lamps and candles are used to some extent in more affluent areas. Urban residents, expatriate workers, government officials and major institutions are the major users of evening lighting, both electrical and kerosene. Hospitals that have emergency clinics, maternity services and evening hours also require reliable lighting systems. Rural schools and community centers actively seek lighting equipment so they can conduct adult literacy and extension classes in the evenings.

One surprising finding of the assessment was that PV systems are already commercially available throughout Africa for a numer of low-demand, remote, electrical applications, including telecommunications, cathodic protection of structures and pipelines, microwave repeaters and refrigeration, but especially lighting. Purchasers of the lighting systems examined were mainly small-scale health clinics, schools, government stations, PVOs and resident foreign assistance specialists or expatriates. While most owners were enthusiastic about using a renewable energy system, their decision to invest was largely economic.

First, operating costs for a small-scale diesel generator or kerosene lamps were prohibitive. Second, local supplies of petroleum products were unreliable, thus requiring expensive stockpiling to ensure lighting availability. Third, lamps and generators require substantial maintenance, repair and spare parts--major problems at remote sites.

3.0 FINDINGS ON TECHNOLOGIES

Thus far, all the information presented has been organized by end-use application. Since the renewable energy systems examined were installed to provide energy for particular end-uses and a variety of technologies were being tested to meet especially crucial energy needs (cooking, water pumping, etc.), this organization seemed to fit the information needs of decision-makers best. It was recognized, however, that some readers might like to focus on how particular technologies have fared in the field, regardless of end-use, as well as desiring information on which applications of individual technologies appear most promising, cost-effective or best received by local consumers. Thus, this section reorganizes the information already presented by technology for the four multi-application, renewable energy systems most commonly installed in Africa--PV arrays, wind energy conversion devices, anaerobic digesters (bio-gas units) and solar thermal water heaters. In addition, findings on fuel-efficient wood and charcoal stoves are discussed, as this was the most prevalent RET examined by field teams. In each case, the teams' findings on technology performance will be explained briefly along with trends in technology development and adaptation that were evident from the assessment, and applications that appear particularly promising in African settings. It should be noted that a number of RETs are not discussed in this section because first, some were never observed by field teams and so were not part of this assessment. Second, there were too few instances of other technologies (see Figure 1, section III) visited by teams to provide adequate information for firm performance conclusions.

3.1 PV Arrays

PV panels installed in Africa have excellent records of field reliability, even in hostile environments. Teams observed that the servicing required by PV cells is minimal, although frequent washing does improve energy output, especially in locations with a lot of air-borne dust. There were some problems reported with encapsulant degradation and substrate delamination, generally for systems installed before 1980. In each case, the manufacturer or installer replaced defective units with newer ones. However, PV-powered systems have not been without problems, primarily in the failure of auxiliary equipment that uses the array's energy output. Small-scale, surface-mounted, DC

pumps frequently needed repair or replacement because of problems ranging from premature brush wear to burn-out of water-lubricated shaft bearings. In one or two cases, the electronic control box malfunctioned, interrupting system output. Surprisingly, there was little discussion at the sites visited of problems with storage batteries.

Most PV system development in the past five years has been in matching auxiliary equipment to array output. As a result, commercial firms are now producing and selling pre-packaged, modular units for most applications and a range of energy demands. This development work has greatly lowered the need for a professional engineer's services when making procurement decisions, so PV systems are accessible to a wider clientele.

Today, PV systems are commercially competitive with storage batteries and diesel generator sets for a variety of remote, small-scale applications in Africa. Chief among these are telephone communications, microwave repeaters, cathodic protection for pipelines and structures, medical refrigeration, lighting for private dwellings and clinics, and educational television. PV units for these end-uses have been distributed primarily by commercial sales from local African representatives of U. S. or French manufacturers. In addition, teams collected secondary data on more than 30 PV water-pumping installations, mostly in Mali and Senegal, and a few large-scale systems applied to grinding, village lighting and other larger loads. These systems have been installed by foreign assistance groups or PVOs for testing and are not economically competitive with other technologies, such as diesel generator sets.

The future of PV systems in Africa looks bright for three reasons:

- the quality of the solar resource base,
- the lack of centralized electrical grids in many locations, and
- the small, but highly valued, electrical loads found at remote sites.

In recognition of this fact, PV firms are setting up substantial distribution and installation networks, and are aggressively marketing systems to private individuals, philanthropic and foreign assistance organizations, and local government agencies.

3.2 Wind Energy Conversion Devices

Of the 13 wind systems examined in the seven countries, 11 were installed primarily to pump water for human and animal consumption, while two were to generate electricity. Excepting

Lesotho, Botswana, and other scattered locations along Senegal's coast or in mountainous regions, wind regimes are not sufficiently strong and reliable for most commercial, high-speed, wind-electric generating systems. Low-cost, site-built wind-pumping systems have been promoted and distributed in Mali, but because of problems encountered in keeping these systems operating, it is uncertain whether they will achieve widespread dissemination without improvements in their underlying design and construction materials. The Kenyan "Kajito" wind water pump is a local adaptation of a proven European design. Produced at a factory in Kenya and locally maintained, it has great promise, if marketing and financing can be arranged. Factory-built, imported fan-mills have also been installed, mainly through the intervention of PVOs, but it is not clear whether the price of these units can be reduced enough for them to be economical, given the moderate wind regimes in much of Africa. There are more interesting possibilities for wind pumps in southern Africa, particularly Lesotho and Botswana, and prototype development is underway for low-cost machines that can be mass-produced in these countries.

3.3 Anaerobic Digesters

As noted at various places in this report, anaerobic digesters (bio-gas generators) have not been successfully operated on a continuous basis for significant periods of time, much less disseminated, in the countries visited. For the amount of energy produced, anaerobic digesters are inherently complex and capital-intensive, particularly for small-scale applications, such as a single family's cooking. Even without the high capital cost, the daily inputs of water and dung required for continuous operation are scarce in many African locations, and the daily filling of the digester and effluent removal are time-consuming.

Most initial experimentation was done with Indian-designed digesters. Recently, under the guidance of technical experts provided by AID and other foreign assistance donors, successful experimental systems using the Chinese, fixed-dome design have been built, as well as Taiwanese bag digesters. These new systems may overcome some of the major problems of the Indian design, including corrosion of the metal gas-holder and scarcity of materials needed for construction.

Anaerobic digesters are of great interest to laboratory scientists and specialists, but have yet to be coupled with end-users who find the system's output worth the capital expense and operating difficulties. The problem is partly one of scale--laboratories and universities have been experimenting with small systems to learn how to build and operate them within capital constraints, while the few African organizations or individuals with money to invest and access to required feedstocks would be interested in large, commercial units. A digester may make

economic sense for large-scale farmers, livestock raisers or feedlot operators, but there is no information available on how many individuals in these categories would be willing to invest the necessary capital and manpower to build and operate a system.

3.4 Solar Thermal Water Heaters

Active and thermo-siphon solar water heating systems have been installed throughout Africa--field teams observed examples in Botswana, Lesotho, Mali, Rwanda and Senegal. System performance and reliability varied widely, depending on the quality of design, fabrication and installation. While many initial installations were domestic water heating systems for expatriate workers and government officials, there are now large-scale installations on hotels and hospitals that can displace significant quantities of electricity.

One positive trend is that solar water heating is becoming a commercial operation at a number of locations visited. Rather than systems being built one at a time by university researchers or government laboratory technicians, commercial installations are factory-built and guaranteed. More important, private firms' installation crews are better trained and available for follow-up visits in the event of breakdowns. One major complaint about initial systems installed by government laboratories, even when systems were sold, was the lack of subsequent service.

3.5 Fuelwood and Charcoal Stoves

The findings on fuelwood and charcoal stoves have been reviewed at length in the section on cooking (2.1), so only the main points will be highlighted here. Fuel-efficient stoves have functioned well in both laboratory and village settings, showing fuel savings of up to 40 percent. The main problem is that the traditional cooking devices being displaced, while unquestionably inefficient, have no purchase price and require little or no maintenance. In addition, cooking practices are adapted to the traditional, "three-stone," cooking pit. Thus, to be readily accepted, new units must offer the same conveniences, be low-cost, durable and save fuel.

Some initial designs were derived from units built and disseminated in other developing countries, the best examples being the "Lorena," high-mass stove borrowed from Guatemala and Hyderabad "chulas" from India. While offering significant fuel savings, as well as secondary benefits such as external smoke venting, these units have had mixed success in the field in Africa. Some are time-consuming to construct and require material inputs (e.g., cement) that are beyond the means of rural families. Field teams also found that subsequent follow-up is

essential to ensure that stoves are being operated correctly and repaired when they crack from cooking heat.

Widespread experimentation is now underway in Africa on simple wood and charcoal stoves without chimneys. The modified Jiko charcoal stove in Kenya is an indigenous design that is starting to be mass-produced. The "Ban Ak Suuf" design from Senegal and low-cost units developed by AID-sponsored projects in Upper Volta are fuelwood stoves that offer moderate fuel savings with a lower capital investment and easy construction. What is crucial, however, is not the design, but the dissemination program that introduces these units to consumers. If the units work well and women perceive immediate benefits without a great deal of additional work, dissemination can be quite rapid in a village or neighborhood.

It is worth noting that there appear to be two types of successful, efficient fuelwood stoves evolving in Africa. The first, just described, is aimed at low-income, rural consumers, primarily village women who gather their fuelwood. The second is a more expensive, but far more durable, stove with a chimney, constructed by skilled masons of materials such as concrete and steel reinforcing bars. Despite the higher initial cost, these units are being sold to urban households and small businesses that use wood to generate process heat (beer-makers in particular). Purchasers of these stoves normally buy their fuelwood and can finance the initial cost with savings from reduced fuel consumption.

4.0 RELEVANCE OF OBSERVED RETS TO NATIONAL ENERGY NEEDS

In organizing this assessment, one central question to be answered was: what is the potential of renewable energy systems presently installed in Africa to provide significant portions of the energy consumption projected for the countries examined and the whole sub-Saharan region by the years 1990 and 1995? Of the five questions guiding the assessment, this proved the most difficult to answer. In the initial design, it was determined that five separate sets of information had to be gathered to answer this question:

- resource data--available local resources and how they matched the renewable energy systems observed;
- significant need--whether the technology's output met a significant end-use demand;
- critical fuels impact--whether the energy system significantly reduced the use of fuels in critically short supply, such as firewood and diesel fuel;

- development potential--the potential impact of each energy system and the whole set of technologies on the accomplishment of long-term national development objectives; and

- contribution to long-term national energy supplies--which technologies could be expected to contribute to national energy supplies, based on economic viability, technical performance and social acceptability.

During the short period of time allotted for this study, assessment teams were not able to collect the information required for each category. In particular, data on local resource bases and patterns of energy needs has not yet been collected. To fully address all these issues would require comprehensive collection of primary data--a task beyond the scope of this project. Still, this assessment was able to develop aggregate country energy profiles, based on existing statistical data. Summaries of these supply and demand profiles are presented in Appendix C. This section presents general findings for the seven sample countries on the potential role of the renewable energy systems observed in the field. These generalizations should only be considered indicative of the role each RET might play in the future. It was decided not to speculate on other technologies and techniques that are potentially useful, but not yet in use in Africa.

4.1 Resource Match

Before considering the applicability of an energy conversion system, an adequate resource base to power it must be assured. The renewable energy systems observed by field teams in the seven countries used a variety of local resources. Direct solar radiation was the resource base for the solar thermal and PV units examined. In all cases, solar insolation was excellent throughout the year, except for some limited cloudiness during the rainy season. While the collection of insolation data is still underway in most countries, there is little doubt that the success of installed solar systems to date has not been limited by the availability or quality of solar radiation.

Experience with wind systems has been much more mixed. Wind regimes in equatorial Africa are often limited and seasonal, with the exception of individual sites, such as the mountains of South Africa and coastal areas. Therefore, good site data are essential, and the lack of good wind monitoring has led to incorrect system design and sizing. Field visits found several instances of systems sited at locations with insufficient wind regimes that had to dismantled. Also, some systems were not properly designed to withstand periodic high winds and were damaged by gusts.

Anaerobic digesters (bio-gas generators) have to be matched to the availability of several different resources. They require a convenient, reliable water supply that is mixed with animal dung to form the slurry which fuels the digester. Dung should also be easily collected, but local herding practices have a great deal of influence on the availability of sufficient, easily collected animal waste. In Kenya, Mali, Rwanda and Upper Volta, the practice of allowing animals to graze freely during the day and bringing them into a pen only at night means that dung is generally scattered and difficult to gather. In Botswana, there is a greater tendency for animals to collect around watering holes, so dung is more easily collected. It should be remembered that these generalizations are based on limited field observations. Nevertheless, it appears that bio-gas units may not be readily applied without a good water supply and centralized animal feeding and/or watering area.

Water turbines were observed in Kenya and Rwanda, and were effectively matched to local stream conditions. However, adequate, year-round stream flow is a principal condition for installation and greatly limits the number of potential systems. The issue of matching to available resources was not applicable for other systems visited.

4.2 End-Use Demand Match

In determining whether a particular technology is addressing a significant end-use demand, "significant" can have two meanings. Such a demand may be one that currently accounts for (or can be expected in the future to require) a large portion of energy consumption, or serves an important need though it is not quantitatively very large.

Of the systems reviewed, fuelwood and charcoal stoves and water pumping units (powered by wind, PV, animal power and low-temperature thermodynamic units) addressed the most pressing needs in the countries visited. Cooking is a basic human need and accounted for a majority of fuelwood consumption in all the countries visited. (In a number of countries, it accounted for a majority of total energy consumption.) Water pumping is a primary concern in Sahelian countries, but is important in others as well. In quantitative terms, water pumping is not a major energy user, but its contribution to human and animal survival and food production is extremely important.

Some PV units (excluding those used for pumping) provided electricity for important public uses. A clinic in Botswana used PV to provide electricity for refrigeration of medical supplies and lighting. Other units charged batteries and electrified fences. None of these uses are large in purely quantitative terms, but are significant because they meet important needs. Water turbines were being used for grinding grain--an end-use

that would otherwise be accomplished by hand or mills using imported diesel fuel.

Several applications of renewable energy systems to secondary or "convenience" end-uses were observed. Solar water heaters are used in private homes to satisfy demands for hot water for bathing and laundry. Some institutional (e.g., schools, hospitals) applications were oriented toward more basic uses of hot water.

On the surface, solar crop dryers address an important need--to reduce crop losses by reducing spoilage and vermin infestation. However, the importance of this need was lost on consumers who could not distinguish between air- and solar-dried produce. It appears that the economic impact on farmers and fishermen will dictate the acceptability of this technology.

Insufficient information is available to judge whether the allocation of resources to different types of RETs is consistent with the importance of the end-use demand satisfied. It can only be stated that some of the projects observed focused on critical demands while others dealt with convenience end-uses.

4.3 Impact on Use of Critical Fuels

In five of the seven countries visited, three fuels are of primary concern--fuelwood, charcoal and petroleum. (In Botswana and Lesotho, there is a signficant amount of coal use in addition to petroleum.) The concern about fuelwood and charcoal arises from the depletion of available resources and impact of deforestation. In the case of fossil fuels, concern is due to the need to use foreign exchange to purchase these supplies. RETs visited had, and were projected to have, direct and indirect effects on the use of critical fuels.

Efficient fuelwood and charcoal stoves can have the largest direct effect on critical fuel use, both now and in the future. In some countries (e.g., Mali, Rwanda, Upper Volta), fuelwood accounts for over 90 percent of all energy consumption and cooking for the majority of the wood consumed. Anything that improves the efficiency of fuelwood use will have a direct impact. Although none of the technologies examined have yet been widely disseminated, the potential for major impact exists.

Solar water heaters have also had a large impact on critical fuel use. Heaters being installed are generally displacing electric units, and since most electricity is generated using oil (or coal in Lesotho and Botswana), solar units are reducing the demand for fossil fuels.

Various water pumping systems displace fossil fuels directly and indirectly. In many instances, units are located in areas

with no existing pumps and thus, are providing a new service. In some cases, however, renewable energy-powered pumps were displacing diesel sets. Since water pumping does not yet constitute a quantitatively large energy demand, the impact on critical fuel use is small. But, the extensive use of renewable resource-driven pumps can forestall or reduce the widespread use of diesel pumps in the future. While this benefit can be realized, any reduction in total petrolem consumption would lie mostly in the future.

The renewable energy systems examined in this assessment will have little direct impact on several major current uses of imported fossil fuels--crop cultivation and harvesting, transportation, generation of grid electricity and low-cost residential lighting. However, other RETs are already being demonstrated in Africa which may have widespread application to some of these critical needs, such as field to market transportation, cultivation, plowing and farm-scale mechanical shaft power. Chief among these systems is animal traction, which is having preliminary success in increasing agricultural productivity at several locations. Energy conservation programs aimed at drastically reducing fuel consumption per mile of vehicle travel also have great potential for directly affecting the future import and consumption of petroleum products.

Without the benefit of a detailed energy supply/demand balance for each country, benefits to be gained from future utilization of the RETs observed cannot be quantified. It is possible to infer that fuelwood and charcoal stoves have the potential to significantly lower the growth rate of demand for biomass fuels. Water pumping systems have modest potential to reduce the need for diesel units in the future. Solar water heaters may directly displace electricity for urban dwellers and some institutions. The quantitative analysis to substantiate these inferences cannot be done given available data.

4.4 Impact on Development Objectives

In addition to the effects that each renewable energy system might have on the energy supply/demand balance, the potential effects or contributions to overall country development goals must be considered. In the case of water pumping technologies, it is easy to see how increased water for irrigation can improve crop production and enhance the food supply. In addition, some units offer the opportunity to create local industries to manufacture, market and maintain systems. In Kenya, the "Kajito" wind turbine and "Tikko" stove have already shown the potential to create jobs, and other labor-intensive facilities are under development in other African countries.

For fuelwood stoves, there are a number of direct and indirect effects on development. Improved stoves with increased

efficiency reduce the time and effort required to gather wood, thus making time available for other activities. The potential for involving the private sector in cook stove installation is discussed in section 6.0, "Role of the Private Sector." It is clear that for these development benefits to be realized, improved stoves must be widely disseminated. None of the projects visited had yet achieved a high level of market penetration.

The benefits of PV as a reliable energy source have already been discussed. PV systems are meeting well-defined needs at a clinic in Botswana, water pumping stations in all the countries visited, and in applications to battery charging and fence electrification. However, most parts of every PV unit are imported, and it does not appear that any of the seven countries will have the capability to manufacture PV cells in the near future. Thus, while this system does not require imported fuel, it does demand imported technology. The development benefits derived must be weighed against the foreign exchange it requires.

Solar water heaters on individual homes provide convenience benefits to middle- and upper-income residents. Units installed on institutional buildings have benefits that are more widely distributed, and may contribute directly to national goals concerning the provision of public health and educational services.

The extent to which anaerobic digesters (bio-gas units) can meet development goals is not clear. The most promising area appears to be in commercial animal and food processing. In these applications, waste is easily collected and the gas has defined uses. Village-level applications have less potential because of difficulties in gathering waste and finding appropriate uses for gas which is continuously produced.

Because of limited sample size and the fact that many of the technologies visited were in an early stage of development, the generalizations in this section regarding potential development benefits of renewable energy systems can only be considered as preliminary speculations. One important point to remember is that while various RETs can be shown to provide such benefits, alternative systems must also be considered to best judge the configuration that will maximize benefits.

4.5 Projection of Technology Use

The final issue to be addressed is whether the RETs observed in the field can be expected to make a major contribution to the countries' energy supplies, given the systems' technical performance, economics and social acceptability. The details concerning these considerations have already been presented for each technology.

It can be inferred that the cook stove projects visited have the potential to become significant contributors as energy systems. In the five countries where such projects were observed, the stoves demonstrated acceptable performance, at least under laboratory conditions. The economics appear to be attractive, although there is very little field data to corroborate this conclusion. Wood or charcoal savings easily outweigh the cost of an improved stove, but acceptability can be a problem simply because of the consumers' inertia. It appears that those who are accustomed to buying both stoves and fuel from commercial vendors will accept new units more readily than those who gather wood and cook using three stones. Nevertheless, improved stoves have the potential for significant impact.

Wind turbines have had mixed performance results. In all the countries where such project were observed (not Rwanda or Upper Volta), steps are being taken to maintain and/or increase the use of these systems. The government of Kenya has been especially supportive. Since there are many examples of the successful application of wind systems, it can be expected that they will make contributions where the wind regime is adequate. One important qualification is that there is very little economic data available to weigh the performance of wind systems against alternative technologies.

PV units enjoy a high level of performance and acceptance, in which minimal maintenance requirements seem to be a big factor. All seven countries had PV units in operation and reported acceptable performance. It has been generally agreed that the economics of PV units do not compare favorably with alternatives at present, but no detailed economic analysis has been conducted to verify this assumption. Also, since PV units appear to be most feasible in remote, micro-load situations, the total amount of energy produced, even with many installations, may be quite small in the context of national energy demands.

Solar water heaters were observed in five countries (not Kenya and Upper Volta). With the exception of Rwanda, the units appeared to be performing well and are being accepted by middle- and upper-income residents. The performance difference between locally designed and manufactured systems and imported units has already been noted. A reasonable projection is that solar water heaters can have measurable market penetration since they displace electric units, which tend to be more expensive to operate.

Bio-gas units do not appear to have much potential, except for certain large-scale applications. The laboratory unit in Botswana was the only one reporting good performance. In Mali and Senegal, results were mixed, while they were disappointing in Rwanda and Upper Volta. One inhibiting factor may be the relatively high skill level required for operators to keep units

functioning properly. Cattle-grazing habits may also work against general dissemination.

Water turbines observed in Kenya and Rwanda were performing nicely (for 30 years in one case) and are well accepted. One exception was the steel unit in Kenya which had presented repair problems. The economic viability of these systems is unknown since the equipment was donated.

Two other technologies functioned well, but may experience problems with acceptability--solar cookers and solar crop/fish dryers. In Lesotho, early morning and evening cooking habits did not coincide with solar cookers' capability. Widespread dissemination would require changes in basic life-style patterns. In the case of solar dryers, producers would not easily be able to pass the unit's cost on to customers. For this system to be widely used, it would have to demonstrate a large enough increase in output (via reduced losses) to justify the expense.

It would be desirable to present some conclusions about the appropriate mix of technologies for each country's energy situation. However, there was insufficient available information to permit such generalizations.

5.0 PROJECT MONITORING, EVALUATION AND MANAGEMENT

Since the first renewable energy projects and technologies were initiated four to five years ago, the major focus has been on developing feasible technologies for site-specific conditions in African countries. Given this situation, the role of good monitoring and evaluation is extremely important. Thus, the examination of monitoring and evaluation systems was a key part of this assessment.

As most of the projects and sites visited by teams were pilot projects, the vast majority of activities and technologies were in a research and development phase. Those which had moved to demonstration in the field were generally still under development in that further adaptations were being made to both the technology and dissemination strategies. Even when a technology had been proven or established elsewhere in the world, changes in design for local conditions and to address end-use issues are usually essential. At only 23 percent of the 78 sites visited were the particular technologies in a dissemination phase--some of the cook stove programs, for example, as well as certain windmills and solar water heaters.

In pilot projects, monitoring and evaluation needs to be "feasibility"-oriented, which means employing real data from projects' technical output, supplemented by socioeconomic data and supported by strong reliance on users' opinions. Naturally,

laboratory development work requires sound scientific procedures, as well as thorough testing and evaluation.

Project management also plays a critical role in determining the success or failure of any energy project. Even programs with abundant resources and the greatest potential for success can falter as a result of poor management practices. This assessment was not intended to evaluate projects themselves, but rather to examine the performance of specific energy systems applied to various end-uses, besides the fact that time and resource constraints prohibited an in-depth assessment of the adequacy of project management. Thus, general management information was obtained for only about 20 percent of the 78 sites (a fact which must be kept in mind before attempting to generalize from these results), compared to evaluation and monitoring information, gathered for over 90 percent of the projects visited.

Major Technical Findings of the Field Teams

- Of the projects (sites) that seemed to be progressing in the development of successful technologies, all were engaged in some form of ongoing monitoring and evaluation.
- Over half the sites did not report or evidence substantial technology development. Of these, 89 percent did not have any type of monitoring or evaluation activity.
- Energy laboratories and prototype development workshops carried on the most extensive monitoring and evaluation of technology performance.
- Laboratories making the most progress in technology development were also using some kind of systematic monitoring and evaluation system.
- Laboratories that had a good working relationship with a field-oriented organization had the highest percentage of successful demonstrations.
- The formal acquisition and consideration of user/client opinions was a key element in making good design changes in technologies.
- Most projects used only ad hoc financial/economic information and assessments when making decisions about technologies.
- Formal financial or market evaluations were generally not used in decision-making.
- Although dissemination activities are at an early stage, all those visited (except most commercial sites) had some form of monitoring and evaluation effort.
- Good, dynamic project leadership was always found in conjunction with functional monitoring and evaluation systems.

The feasibility of renewable energy projects and technologies can be evaluated in terms of:

- technical performance,
- economic performance,
- social adaptiveness,

- organization stucture and management, and
- dissemination requirements.

A technology or strategy is not ready for widespread dissemination until there is strong evidence that satisfactory solutions have been found for any problems in the first four of these five areas. Most RETs observed by the teams are in an early stage of development for at least two, if not all five, areas. Hence, at the project level, the need has been for field-testing and feasibility analysis in an iterative evaluation process.

The assessment's evaluation effort in the seven countries focused on two questions:

- what mechanisms currently exist in ongoing AID and non-AID African development projects that allow for "real-time" monitoring and evaluation of installed renewable energy systems; and
- what means are there to permit modifications of technologies or project elements to take advantage of lessons learned from the monitoring and evaluation of the economic, technical, institutional and social performance of installed energy systems.

The first question probes the extent to which formal monitoring and evaluation is intended to be part of ongoing projects and is, in fact, being carried out. Teams observed highly mixed results for this question. Of 72 project/technology site visits, 62 percent had formal monitoring and evaluation systems designed into the project, 24 percent had informal monitoring systems by design, and 14 percent had no system at all.* In the formal systems, analysis was being carried out on a systematic basis and written reports produced. For the informal systems, data were gathered in a systematic manner and decisions made based on that information, but evaluative reports were not written, nor was a pre-designed, systematic, analytical method used.

The second question concerns whether lessons are being learned and incorporated into projects to assist in the development of technologies and project strategies--is progress

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*Six other sites visited could not be classified with regard to monitoring and evaluation. These were either projects in a very early stage of development (e.g., a single bio-gas unit under construction) or technologies observed by evaluation teams that were not part of formal projects (e.g., the use of a PV system by an individual).

being made? For purposes of this assessment, "progress" was defined as a situation where the design and performance of technologies and projects evidenced change with a greater probability for success. Progress also implied good decision-making. For example, when a project or technology activity was stopped because it was not going anywhere or began to look unattractive, the decision was viewed as positive.

In order to measure progress, teams gathered data on changes in designs and activities made by research and development, field demonstration, and dissemination projects. Of the 55 research/development and field demonstration sites, 41 percent had made design changes as a result of their monitoring and evaluation. Of the 17 dissemination projects, 35 percent had changed aspects of their strategies based on monitoring and evaluation data. No changes were reported or observed for research and development, field demonstration or dissemination projects that did not have monitoring and evaluation systems.

One cautionary note--data brought back from the field concerning changes in technology design and project activities may be incomplete. That is, changes may have occurred that were not seen or discovered by the field teams. However, although recorded information on project changes was not available for all the sites visited, there were adequate data to establish a relationship between monitoring and evaluation activity and positive project changes/developments.

Based on data from the site visits, 72 percent of the projects that appeared to be making progress had formal monitoring and evaluation systems, and 27 percent had informal systems. These projects were systematically attempting to learn and, thereby, advance through decision-making and research and development to succeed in technology dissemination. On the other hand, 89 percent of the projects that did not evidence progress had no formal or informal monitoring and evaluation system or activity, and the remaining 11 percent had only informal systems. If they were learning or progressing at all, they were doing so in disconnected, ad hoc ways.

One clear conclusion is that a monitoring and evaluation system is important to maximize progress. The extent to which progress was due to good project managers versus monitoring and evaluation systems is unclear, but both are probably requisite elements for progress. The assessment also found that the existence of a monitoring and evaluation system did not necessarily mean project personnel were using it. However, the reasons for such situations lie in project design and management--issues beyond the scope of this assessment.

In general, it is clear that the most dynamic projects have been consciously collecting and recording findings, and using what they have learned to choose and improve technologies, and

develop dissemination strategies. Informal systems, while not as useful in providing outsiders with information, often seemed to supply project staff with sufficient data for technology development and progress to continue.

In considering both formal and informal systems, field teams attempted to evaluate the degree to which information was being used and integrated into the decision-making process, thus leading directly to project learning and development. Four key areas were chosen for close examination to determine whether monitoring was occurring and the resulting information was being used:

- field-testing or performance monitoring of installed technologies,
- design changes in technologies,
- financial and economic evaluation of technologies, and
- dissemination strategies.

The following discussion presents field teams' findings on monitoring and evaluation in these critical areas.

5.1 Performance Monitoring and Field-Testing

Assessment teams found that field-testing and performance monitoring were most thoroughly executed by renewable energy laboratories and projects having a research mandate. Sometimes this involved an effective combination of a research laboratory and another organization that gathered data while working in the field on demonstration/dissemination. Such cooperative efforts seemed to work well and show promise for addressing the major weakness of laboratory or research projects, which work well in controlled settings, but do not focus adequately on field activities, occasionally to the extent of engaging in research/prototype development activities that are theoretically interesting but have little relevance for country-specific applications. Of the energy laboratories that were demonstrating or disseminating technologies in the field, all had a good relationship with a field-oriented organization. Conversely, of the laboratories which were not successful in the field, even though they might have developed interesting technologies, none was reported to have a working alliance with a field-oriented group.

Only half the research and development projects, including most of those funded by AID, were using field data from systematic monitoring efforts as an important element in making progress with technologies. Many improved designs and demonstration/dissemination strategies were based on data from

systematic performance monitoring. In instances where progress did not appear to be occurring, it was due in most cases to three interrelated factors:

- inadequate available field data,
- no systematic evaluation procedure in place, and/or
- no analysis of technology performance.

5.2 Design Changes

As already mentioned, design changes in both laboratory prototypes and field-testing/dissemination efforts are clearly related to systematic monitoring and evaluation. Occasionally, design changes occurred based on informal observation or analysis. But, in the opinion of the assessment teams, projects/sites demonstrating the greatest degree of design innovation and adaptation evidenced a strong analytical and monitoring component in their management. However, there is no question that monitoring and evaluation procedures are only part of what is required for successful design development--competent project personnel are needed to implement those procedures.

A key element of successful technology design adaptation/change is the degree to which user opinions are incorporated into design development. Thus, one aspect of project management that affects the implementation of development programs is the extent to which clients are consulted on matters affecting their lives. Regardless of the importance assigned a program by foreign donors and project planners, it will meet with little success if those for whom it is designed do not feel it is needed.

With this in mind, project personnel were interviewed by assessment teams concerning whether their project had a formal means of soliciting user opinions. Of the projects for which information was available, 73 percent (14) did have a formal systems for this purpose--26 percent (five) did not. Of particular interest is the degree to which those 14 projects were also making design changes and progressing. All were in the group of 29 projects making design changes, and they had based these changes, in part, on user opinions. In other words, of the 29 projects making good design changes, 14 (48 percent) were using a formal process to gather user opinions.

5.3 Financial and Economic Evaluation

Assessment teams found the financial and economic evaluation of technologies to be a weaker area than the two already discussed. Informal, ad hoc assessment seemed to characterize much of the evaluation on the financial and economic

attractiveness of technologies under development. Teams found that although donor and site personnel were aware of the importance of technologies' economic attractiveness, project decisions about which technologies or designs to pursue or disseminate did not usually take economics (in the sense of solid analysis) into account. Much more needs to be done in this area, but over half of recent AID projects (e.g., the Lesotho RET project) are clearly beginning to base decisions on data from more rigorous financial analysis and are attempting to develop economically attractive energy systems. In part, the dearth of good financial/economic evaluation may stem from most project personnel's lack of training in economics/marketing, as well as their oft-stated uncertainty that such formal analysis can provide information they seek on the general attractiveness and desirability of technologies, and predicted future market behavior or potential consumers.

5.4 Dissemination Strategies

Dissemination strategies are only beginning to be used by some of the projects visited. In most cases, projects are in a stage of development that is too early for them to be undertaking much dissemination. However, where dissemination was occurring, teams observed monitoring and evaluation efforts. Of the 17 projects reporting dissemination activities, 12 (71 percent) had formal monitoring and evaluation systems, while the other five (29 percent) had informal systems. Of particular interest was that AID stove projects often had good monitoring programs. (It is important here not to confuse good technical maintenance programs with monitoring and evaluation--they are completely different.)

The potential importance of monitoring and evaluation systems for effective dissemination can be drawn from inferences about the lack of follow-up, maintenance, and monitoring and evaluation observed at the failed projects and unusable, installed technologies visited. There usually had been no systematic attempt during the project's life to analyze the situation at these sites. A good monitoring and evaluation effort might have produced information to permit learning and successful changes in dissemination strategies, or even earlier, in technology design or choice. For example, teams observed a monitoring and evaluation effort for 35 percent of the 17 dissemination programs, which allegedly had produced key modifications in dissemination strategies. As previously stated, many of these 17 projects are just beginning dissemination, and hence, it is too early to determine the effects of their monitoring and evaluation systems.

5.5 Summary

Assessment teams found wide differences in the degree to which various projects, donors and government organizations were learning and using monitoring and evaluation systems. Nongovernment projects often lacked monitoring and evaluation of dissemination efforts. For example, two Catholic mission groups in Senegal (CARITAS and LVIA) and one Mali (Mali Aqua Viva) had good maintenance and follow-up programs for technologies they had installed in villages. However, none had set up any technical or socioeconomic monitoring which would later allow for rigorous technical and economic evaluation of the energy systems' attractiveness. Systematic evaluation, with the aim of locally financed technology diffusion, does not appear to be a stated objective of their field efforts. This approach tends to result in technology installations that work well but have no core component designed to encourage self-sustaining, non-donor supported dissemination in the near term (three to five years).

Whether the result of monitoring and evaluation systems, institutional competence or good management, the most learning occurred in situations that included formal monitoring and evaluation efforts. In general, the eventual degree of success for AID projects could not be determined because of projects' newness. However, for all those projects (both AID and other programs) that did not appear to be learning much, the chance for any systematic analysis of presently installed systems is rather doubtful, unless improvements are made in how data are gathered and organized. Without such improvements, analysis in these projects will continue in an ad hoc, informal, impressionistic manner, and an adequate level of learning will probably not be achieved.

6.0 ROLE OF THE PRIVATE SECTOR

The current and future role of the private sector in renewable energy systems varied significantly across the countries visited and technologies reviewed. There are five potential areas of involvement:

- manufacture--design and fabrication of units by either local firms or joint ventures of a local firm and foreign partner;
- marketing and distribution--sale of renewable energy systems to private and/or government customers;
- installation, maintenance and repair;
- purchase of units--commercial purchase by private users, with or without subsidy; and

- commercial utilization--system use in commercial enterprises.

For the first three areas, the private sector acts as a technology supplier. The latter two involve private, as opposed to government, technology use.

6.1 Manufacture

Local, private-sector manufacture of renewable energy systems has had mixed success in the seven countries visited. Since many of the systems observed are in the experimental or prototype stage, the following generalizations are based on limited information.

Solar water heaters have been the focus of a great deal of local manufacturing attention. Systems observed in Botswana, Lesotho, Mali and Senegal have all been manufactured locally to some degree, but the results have not always been successful. Often, locally designed and fabricated units did not function very well. There have also been some attempts to manufacture windmills locally. Simple models, such as the Kajito machines fabricated in Kenya, seemed to work quite well, while more elaborate ones did not, although this may be more a function of ease of repair. Indications are that locally produced solar water heaters and windmills can operate successfully. Concentration on efficient fabrication techniques and quality control will further enhance system reliability while lowering unit cost.

Fuelwood and charocal stoves are being manufactured locally throughout Africa. Units observed in Senegal and Upper Volta are currently being produced there. In Kenya, an interesting situation is developing with regard to the use of ceramic stove liners, as metal stove manufacturers are concerned that the use of liners will increase stove life, thereby cutting into sales. An integrated manufacturing operation of stove and liner is conceivable, but has not yet been tried.

Bio-gas and passive solar systems have some potential for local manufacture, but the systems examined are not ready for mass production. None of the other systems observed had any significant local manufacturing component.

While there appear to be opportunities for local manufacture of all or part of various renewable energy systems, there was no evidence of concerted efforts to establish indigenous manufacturing capability. The failure of some early local design and fabrication attempts (as in the case of solar water heaters) may have discouraged further efforts in this area. It is often easier for distributors to use imported equipment that performs reliably than to invest in local production capacity.

6.2 Marketing and Distribution

The countries visited all had some privately owned marketing and distribution operations for one or more of the renewable energy systems studied. PV units used for pumping, communications, battery charging and electric fencing seemed to be most actively marketed--in every country, there was at least one local distributor of PV units. No information was available on the distribution of sales between private and government customers, but there were at least some sales to private concerns reported in Botswana, Kenya and Upper Volta.

Solar water heaters are also privately marketed and distributed to some extent, with distributors handling both local and imported units. In Botswana and Lesotho, private operations controlled the entire market. Wind turbines, both locally and foreign made, were also being handled by private distributors. None of the other systems examined provided sufficent data to warrant generalizations.

It appears that the marketing and distribution of RETs is becoming an active business opportunity in the countries visited. Some dealers are local people that have worked out arrangements with foreign manufacturers, while others are foreigners operating as in-country representatives. In order for the distribution business to have a larger role, markets have to mature. This will occur as various units are used more widely.

6.3 Installation, Maintenance and Repair

Installation, maintenance and repair of RET systems were accomplished in different ways. Units that were locally distributed (e.g., solar water heaters, PV systems, etc.) were installed and maintained by the distributor. However, for systems purchased by a donor agency and installed by agency personnel, the donor often provided routine maintenance. In some instances, the user was left to cope with maintenance problems after system installation.

As already noted, proper installation and maintenance is a key factor in the performance of some of the systems examined. Yet, apart from service operations affiliated with a distributor, there were no privately operated maintenance and repair businesses. Without this type of service infrastructure, systems were not properly maintained unless the user or donor performed the required repairs. The potential market for private-sector repair and maintenance businesses seems tied to the rate of penetration for various technologies. Whether separate repair services, not affiliated with distributors, are economically viable is not known at this time.

6.4 Purchase of Units

The purchase of RET systems by private (i.e., nongovernment) users is an important measure of business potential. Of the systems observed, PV units, solar water heaters and windmills all had sales to private users. In Kenya, 40 percent of wind system sales were to private customers.

No data were available on the terms of sale in different countries. Thus, it is not possible to determine the role of government subsidies in encouraging private purchases. In the case of PV, there is some government resistance to widespread technology use because these systems are wholly imported, which results in a demand for foreign exchange.

Cook stoves offer one of the biggest opportunities for commercial sales since they are designed for indvidual households. To date, however, commercial sales have been limited, as many systems are still in the testing and prototype stages. In only Senegal and Upper Volta were commercial stove sales reported, and there, only on a limited basis. The solar cookers observed in Lesotho had not had much success with commercial sales, primarily due to the units' limitations in meeting the cooking needs of consumers.

6.5 Commercial Utilization

It was evident from the systems observed that many were being used in commercial operations. This was true for units sold commercially, bought by the government and donated by various agencies. As would be expected, systems with good reliability and performance were more likely to be integrated into commercial operations.

PV systems to provide electricity for lighting, refrigeration, grinding, pumping, battery charging and fence electrification enjoyed a high rate of utilization. Their reliability seemed to be a major factor in their acceptance. Windmills are widely used to increase water availability for irrigation, and some operators noted improvements in their crop yields as a direct result of these units. Solar water heaters for institutional buildings were accepted where reliable performance was demonstrated. Water turbines observed in Kenya and Rwanda were part of commercial operations, though the equipment had been donated. Solar dryers also have potential for commercial use. The other systems examined were not generally observed as part of commercial operations.

It is evident that a number of renewable resource technologies have been accepted as practical elements in commercial enterprises. The energy they deliver has been demonstrated to be of sufficient commercial value and reliability

to warrant continued use. At this point, it is not possible to determine the commerical acceptability of these units at free market prices as economic data are insufficient to draw firm conclusions.

6.6 Projections

It was obvious from the field visits that the private sector is currently involved in some aspect of RET use in each of the seven countries. This implies that there is a commercial market for at least some of the systems, and the demand generated by that market can be met, at least in part, by private entrepreneurs. The role of government in the successful marketing of various technologies was not systematically evaluated, although it was evident that various mechanisms (e.g., subsidies, direct government purchase, regulatory requirements, research funding) were sometimes being used to enhance market penetration.

Two important issues arose in considering the potential role of the private sector in establishing RETs--economic viability and financing. As indicated in the discussion on project monitoring, evaluation and management (section 5.0), economic assessment and evaluation were clearly the weakest part of monitoring and evaluation efforts. This is not necessarily critical because many of the projects visited were research or demonstration programs with little or no economic evaluation component. However, without some indication of a payoff for a specific system, it will be impossible, in most cases, to increase private-sector participation in that technology. It is clear that demonstrating profitability will enhance the likelihood of private-sector participation, and proven economic viability is a prerequisite for substantial private-sector investment.

For low-cost technologies, such as improved wood stoves, government or private financing is generally not needed. But, for many RETs, such as windmills, PV systems and bio-gas, some sort of external financing will be necessary for successful dissemination. For example, even if large, PV water-pumping systems prove economical, the probability of commercial development of these systems is low without adequate financing. African villages simply do not have the capacity to either save the capital investment required or borrow it from existing financial institutions. So, if PV water-pumping systems (and other similar expensive, capital-intensive technologies) are to become commercialized, some policy changes will be needed in most countries.

Economic viability and credit availability will largely determine the extent to which the private sector becomes involved in the extension of renewable energy systems. Of course,

government policies can have an important impact on both factors. For instance, if it is perceived that a government subsidy of limited duration would help establish private companies that could continue without the subsidy after it expired, something like the U. S. solar energy subsidy might be useful. Also, programs for low-interest or guaranteed loans, such as the rural electric cooperative program or Federal Land Bank in the United States, might be worth considering. Clearly, there are many government policy options which could facilitate private-sector involvement in renewable energy development, and future examination of these options should focus on the two key issues identified by this assessment--economic viability and access to credit.

In summary, it can be safely stated that as various renewable energy systems are used more widely in each of the seven countries, there will be an increasing role and opportunities for private businesses. It is conceivable that small, medium and large operations can be built around the systems. One serious gap, however, is evident in countries' ability to take advantage of these opportunities. In the countries visited, there were no programs oriented toward building indigenous manufacturing, marketing or maintenance capability. Rather, all the projects were aimed at demonstrating technologies with no emphasis on the supporting business infrastructure. This perceived gap may be the result of the limited duration of field visits. If verified by more detailed evaluation, it represents a significant opportunity for projects to put some effort into the development of this important infrastructure.

APPENDIX C

FIELD DATA COLLECTION AND ANALYSIS METHODOLOGY

Introduction

The findings, conclusions and recommendations presented in the body of this report are derived from a major field data collection and analysis effort. Four teams of specialists visited more than 75 project sites in seven countries, gathering a wide variety of technical, social, economic and institutional data on the performance of renewable energy systems installed in the field. Unlike most previous AID-sponsored data collection efforts, this study's focus has been on technologies and technology diffusion strategies, rather than projects and a summative evaluation of their impacts. Because of the ground-breaking nature of this work, special care was taken to document the methodology used, practical problems encountered, solutions developed and data collection instruments employed.

Associates in Rural Development, under a grant from the Office of Energy of AID, has already published a major follow-on field data collection guide (see McGowan, Ashworth, Burrill, and Donovan, Data Collection Handbook for Energy Systems Installed in Developing Countries, Burlington, Vermont: ARD, February 1984). The original methodology for the African RET study was presented in a 1982 ARD report, "Assessing Renewable Energy Technologies and Renewable Energy Project Elements in the African Context: A Study Design and Methodology." This appendix provides a distillation and refinement of that publication, eliminating most of the step-by-step instructions for field teams, since these are given in great detail in ARD's recent workbook. More importantly, this appendix includes revisions in the methodology necessitated by constraints encountered during field data collection--manpower limitations, time pressures, budgetary restrictions and, above all, data availability.

The study's methodology was designed to answer five basic questions, developed by senior management personnel of AID's Bureau for Africa and Office of Evaluation, as part of their effort to provide policy guidance to AID's Assistant Administrator for Africa on possible future directions for the agency's Africa energy program.

- What has been the observed technical performance of renewable energy systems currently installed in terms of AID African countries?

- What problems have been observed with renewable energy systems installed in the field in Africa, in terms of social acceptance, institutional compatibility and required technology delivery systems?

- What has been the comparative performance of alternative renewable energy systems in the provision of usable, cost-effective energy for specific African end-use applications in the areas of agricultural production, domestic consumption, agricultural processing and food preservation, and small-scale commercial and industrial operations?

- What mechanisms currently exist within ongoing AID and non-AID African development projects that allow for "real-time" monitoring of installed renewable energy systems and modification of technologies or project elements to take advantage of lessons learned from technology monitoring?

- What is the potential of renewable energy systems presently installed in Africa to provide significant portions of the energy consumption projected for the countries examined and the whole sub-Saharan region by the years 1990 and 1995?

Methodology Approach and Initial Design Constraints

Introduction

From its inception, this assessment focused on providing accurate, up-to-date information for senior-level, decision-makers in AID and interested African national governments. This emphasis on "information for decision-making" is reflected in the study design and methodology in four major ways:

- its comparative focus looks across technologies and sites to draw common lessons;

- the mixture of technology-specific and end-use driven information sets recognizes that decision-makers need reliable data from both perspectives;

- the relative weight accorded technology characteristics that are important to project success--reliability, durability, ease of maintenance, economic viability, etc.--and lesser value placed on strictly technical performance parameters; and

- in the plan for data analysis, the stress on information sets having pivotal significance for the allocation of scarce financial and manpower resources among alternative energy systems.

In addition to its emphasis on "decision-making," it was essential that the methodology take into account three key contraints:

- short time frame of the entire assessment--four months from initial conceptualization to completion of data analysis;
- limited time available for fieldwork, requiring that separate assessment teams work simultaneously in widely scattered locations; and
- final data analysis and report writing to be accomplished by both AID and ARD personnel, working in parallel at different locations.

These three limitations spawned a major challenge--to incorporate in the study design a series of cross-checks to minimize the margin of error for field data collection and data handling problems during analysis.

The gathering of data by different teams, as opposed to one team visiting all 78 sites, was of prime concern to the designers of the assessment methodology. Three major strategies were employed to ensure acceptable levels of comparability among project data items:

- a very detailed data collection handbook was distributed to every field team member;
- an intensive training session on data collection was conducted; and
- a comprehensive decision tree for making in-country decisions, such as selecting which non-AID funded projects to visit, was prepared.

The data collection workbook contained more than 80 required data elements for all projects, ranging from technology performance to the match of system output with local demand patterns to users' reactions about the installed system. To ensure data comparability, additional questions were included for each end-use application and energy technology. Common data units were specified, and alternative methods for converting from one set of measurements to another provided for use by field data collectors. (ARD's forthcoming handbook on field data collection will provide general guidance on organizing such a data gathering effort.)

Once the data collection workbooks were completed, all assessment team members were assembled in Abidjan, Ivory Coast for a two-day training session on the collection of field data, handbook use and technology-specific guidelines. This meeting

also included discussions on making in-country decisions. Particulars of the training and other parts of the overall planning analysis are presented in greater detail below.

During the development of the study design, a number of other important, yet time-consuming, issues had to be addressed, including:

- specifying and standardizing units of measurement;
- establishing a hierarchy of data elements, based on their importance to AID staff and other concerned parties;
- drawing up a set of criteria for selecting non-AID projects to be included in the sample for field data collection;
- clarifying data requirements, given diverse project types--for example, institution-building versus research and development versus technology dissemination; and
- integrating data gathered in the field with information collected in Washington, DC.

The resolution of each of these issues led to the creation of five different "modules" to guide study team members as the assessment progressed. These are presented graphically in Figure D.1 on the following page.

Non-AID Project Selection

The selection of projects to be visited bears directly on the breadth and comparative nature of the final analysis. Projects were chosen not only for their physical accessibility, but also based on their goals and objectives, types of institutional mechanisms used in implementation, success in technology demonstration and dissemination, and technologies employed. The project selection process was designed to provide a good mix within and across these characteristics. Those chosen reflected a wide variety of initial objectives. The study design attempted to ensure that the non-AID projects selected would complement the AID programs visited. Whereas AID projects are aimed largely at institution-building and prototype-testing (Mali is an example), the non-AID projects chosen for field visits place systems directly in the hands of end-users or entrepreneurs. Similarly, projects were closely analyzed regarding the technologies employed, so that sufficient data would be collected on specific technology/end-use pairs to permit comparative analysis.

The design for the selection methodology is presented in Figure D.2. Final project selection often did not occur until

Figure D.1

OVERVIEW OF DATA COLLECTION AND ANALYSIS METHODOLOGY

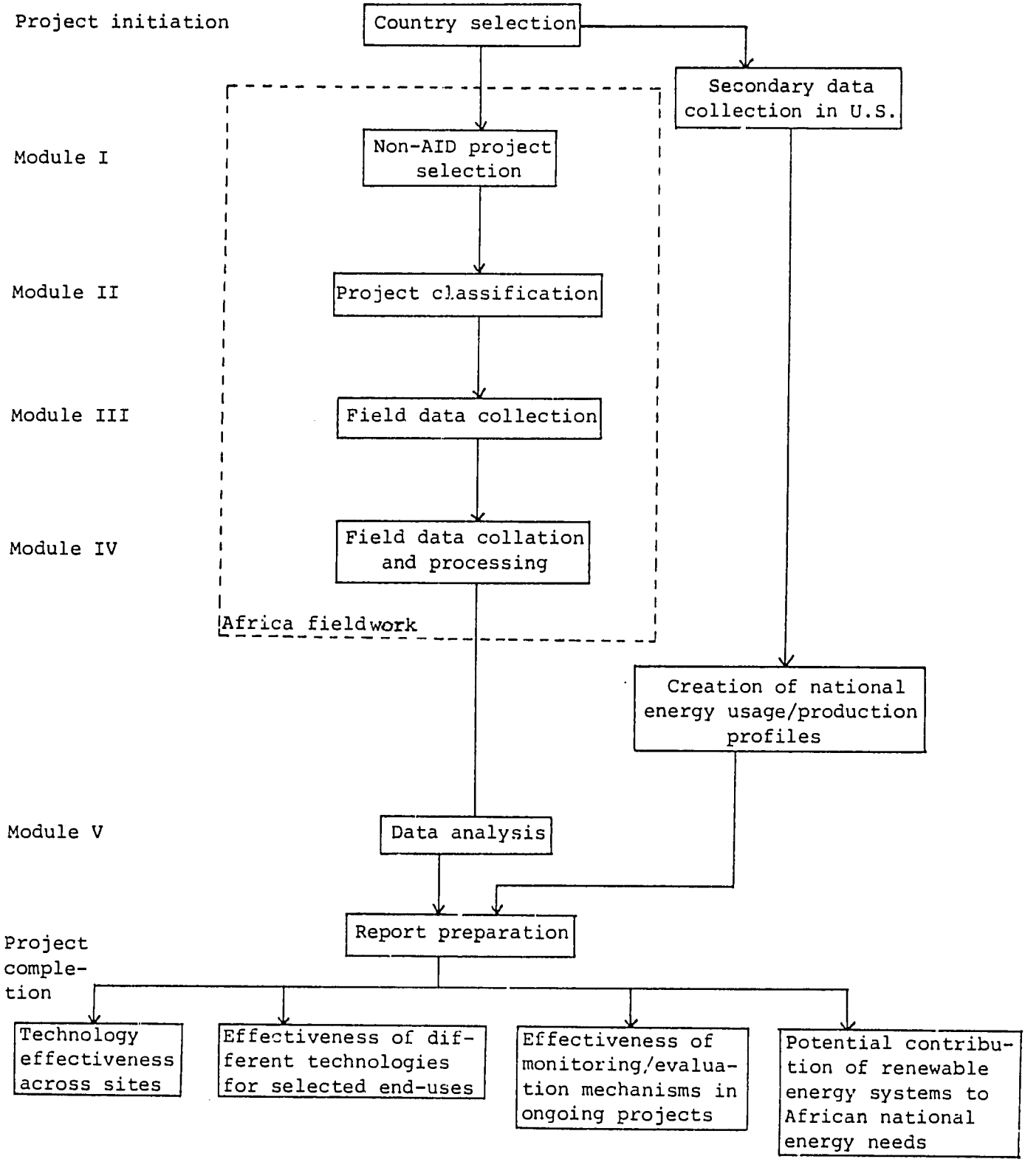
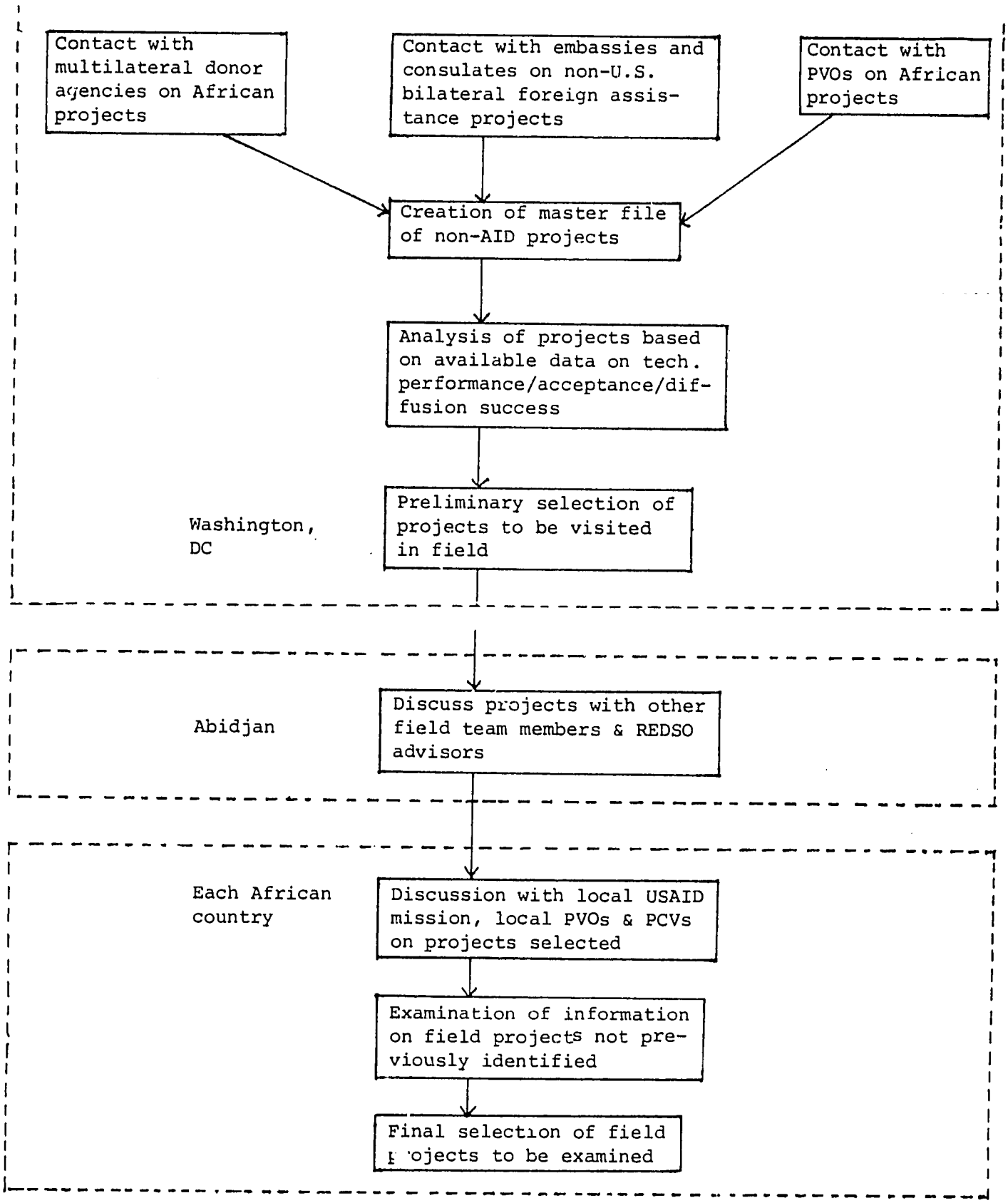


Figure D.2

DATA COLLECTION/ANALYSIS MODULE I:

NON-AID PROJECT SELECTION



the assessment team was in-country. Local AID missions, other donors, Peace Corps volunteers and cooperating private volunteer organizations assisted in choosing additional projects for field visits. The actual process of non-AID project selection varied greatly from country to country, based on assistance from the local mission and the initiative of individual field team members. However, the key factors precipitating a site visit were the availability of transportation and distance to be traveled--few sites were visited that were more than a half-day of travel from the capital city. This proved to be a problem only in some of the larger countries (e.g., Kenya and Upper Volta).

Project Classification

Project classification was a logical extension of the selection process. This step attempted to:

- ensure that field teams gathered sufficient information through both examination of project design documents and interviews;
- determine exactly what each project sought to accomplish; and
- define the program's hierarchy of goals, if it had more than one purpose.

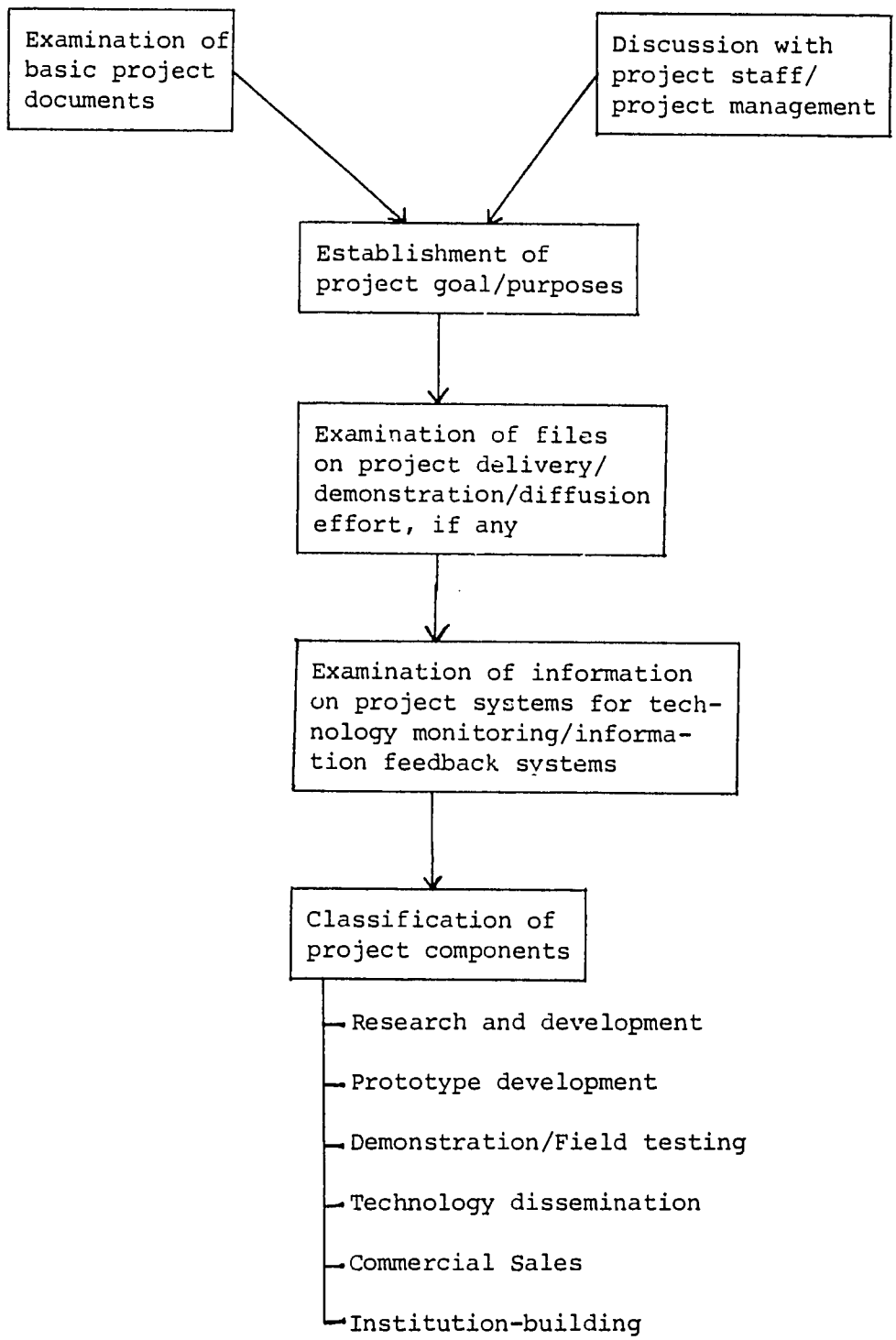
Figure D.3 shows that the project classification process specified not only what programs set out to do, but also what was accomplished. Many renewable energy projects that donor organizations intended as widespread dissemination efforts (e.g., for solar cookers; low-cost, efficient, fuelwood, cook stoves; or solar crop dryers) became just prototype development and testing efforts, with no field tests outside the laboratory. There are several sets of queries in the project classification module aimed at determining if any real efforts at technology demonstration and dissemination in the field have been made and, if so, how successful they have been.

The project classification module provided guidance for the main thrust of the fieldwork--data collection. There are different sets of data requirements and different priorities in the collection of data elements for technology demonstration/ diffusion projects versus applied research and development/ institution-building projects. Clearly, economic data (e.g., cost per million BTUs of energy output or thousand liters of water pumped) are important for actual field installations, but far less so for laboratory prototypes or systems installed solely for manpower training. This division between the two sets of project types carried through all phases of data collection and analysis.

Figure D.3

DATA COLLECTION/ANALYSIS MODULE II:

PROJECT COMPONENT CLASSIFICATION



During data collection in the field, the distinction between the two types of projects was not as crucial as had been expected because of the general lack of detailed economic data for all types of installations. Exceptions were the few commercial installations of PV lighting systems, solar water heaters and some wind units being used for water pumping. Nonetheless, the distinction was maintained during analysis so that data for prototypes or other experimental laboratory systems and field-tested units would not be mixed.

Field Data Collection

Field teams were given detailed instructions about gathering preliminary data, classifying projects according to their objectives and proceeding with the use of the field data collection workbooks. This process is shown schematically in Figure D.4 on the following page.

Primary Data Collection Techniques

The principal sources for new data developed by each field team were unstructured interviews and direct observation. Both are discussed briefly and then related to the other major field task--gathering existing secondary data and reports.

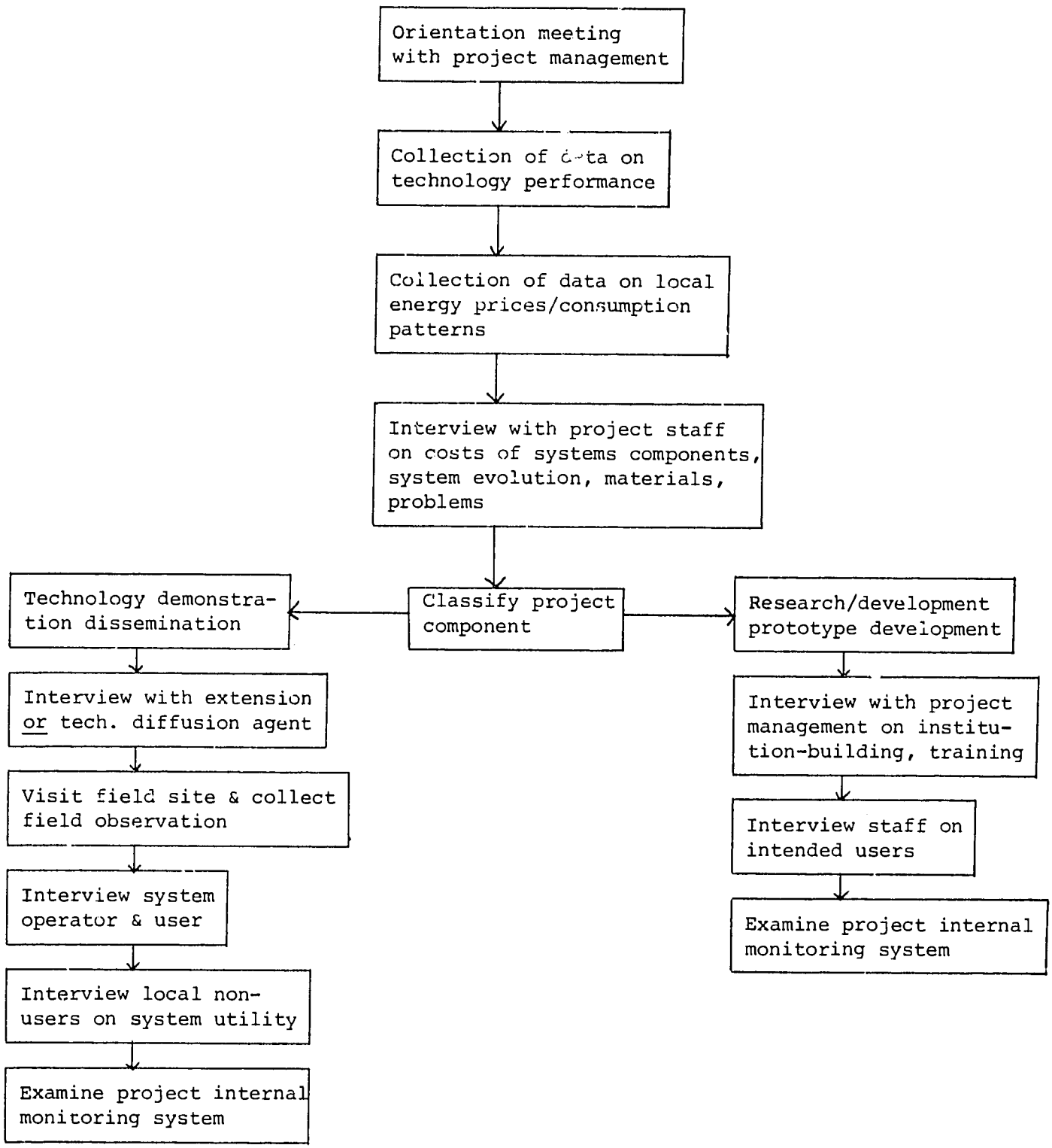
Unstructured interviews were chosen as the primary means for technology and project component assessment because they offer a reasonable compromise between the complete, though unwieldy, nature of a formal survey instrument and total reliance on easily acquired, but often incomplete, secondary data in official published reports. Field teams often had but a few hours to visit a project site; gather existing data on the resource base, technology performance and costs; and conduct short interviews with selected project participants. In such situations, formal interview documents would have been counterproductive, serving as a real barrier between the field team member and individual recently met or contacted. Further, it would be difficult for assessment team members to use such an instrument for the variety of respondents at a single site, since different questions need to be addressed to each person, according to their involvement with the installed energy system and/or project.

Team members were asked to gather certain types of information on the condition of the energy system, construction materials, physical environment in which it functions, location relative to the point of the energy's end-use, availability of certain renewable resources at the project site and cost of various fuels in the local marketplace, if feasible. However, team members were not asked to engage in technical observations,

Figure D.4

DATA COLLECTION/ANALYSIS MODULE III:

FIELD DATA COLLECTION



but to rely instead on measurements already taken at the site or in existing project documents.

Secondary Data Acquisition in the Field

During the course of site visits, unstructured interviews and orientation meetings, team members were to locate and acquire published documents or internal field notes that could provide portions of the data needed to answer the assessment's five key questions. This included any and all information available on renewable energy systems installed by the project, such as technical performance; reliability and durability problems encountered and solutions developed; operation and maintenance requirements; training needed for fabricators, operators and maintenance personnel; feedstock demands; and compatibility with end-use. If primary or secondary data were availably only in raw form, thus requiring further interpretation, teams were instructed to get copies for the project files.

Assessment teams were asked to collect all publications containing up-to-date national energy consumption and production figures, and include them with the national energy data sheets. Information on resources of biomass fuels, small-scale hydro power and wind energy were of particular interest, but did not prove to be readily available in many of the seven countries visited. Secondary reports containing detailed information on the energy required to satisfy local end-use needs were also gathered and appended to the end-use data sheets.

Field Data Elements

The specific data elements were presented in detail in the data collection workbook, which also provided specific directions on the information to be gathered as well as other important, though lesser, considerations, such as appropriate units of measurement, procedures for transforming data from one type of measurement to another, data to be gathered if the information sought was never collected or was unavailable, and what data to request from particular sources within a project or organization.

Figure D.5 shows the basic data elements that field teams were instructed to collect. However, it should be noted that far more detailed information was contained on the data sheets than can be indicated in this simple summary. For example, under the single data element of technical reliability, information was sought not only on how often the technology was in service, but also which components of the overall energy system caused the most problems; the frequency of part replacement; and major environmental hazards presented by the severest difficulties with the technology. In addition, there were special questions for certain individual technologies and end-use applications.

Figure D.5

DATA CATEGORIES AND ELEMENTS

DATA CATEGORIES		DATA ELEMENTS				
		TECHNICAL	TECHNOLOGY PROFILE	SOCIAL & CULTURAL	INSTITUTIONAL	ECONOMIC
ENERGY SYSTEMS EFFECTIVENESS	1. Technical 2. Technology profile 3. Social 4. Institutional 5. Economic 6. End-use fit	1. Performance 2. Reliability 3. Durability 4. Materials problems 5. Output vs. resource base	1. Components 2. Inputs 3. Outputs (units/amt./time period) 4. Operating sched. 5. End-use applications	1. Formal acceptance 2. Cultural issues confront/solutions developed 3. Replicability 4. Intended impact 5. Unintended impact	1. Formal acceptance 2. Host country institutions' • prior experience • goals vs. project goals 3. Policy redirections/changes 4. Resources apportioned	1. Costs: extraordinary, capital, maintenance, fuel, training, environmental 2. Benefits: outputs (monetized, non-monetized), environmental
END-USE APPLICATIONS	1. Agricultural Production 2. Agricultural Processing 3. Domestic 4. Commercial/Industrial	AGRICULTURAL PRODUCTION 1. Irrigation 2. Cultivation 3. Fertilizer production 4. Livestock	AGRICULTURAL PROCESSING 1. Grinding/Milling 2. Crop drying 3. Threshing 4. Cold storage/Refrigeration	DOMESTIC 1. Cooking 2. Water heating 3. Lighting 4. Food drying/Preservation 5. Potable water 6. Space heating/cooling	COMMERCIAL/INDUSTRIAL 1. Water heating 2. Process heat-low 3. Motor-shaft power 4. Health clinic refrigeration 5. Fuels from biomass	
PROJECT-SPECIFIC INFORMATION	1. Project objectives/goals 2. Sub-sector involvement 3. Observed technology development 4. Other changes within project 5. Internal project learning mech.	PROJECT OBJECTIVES AND GOALS 1. Project type 2. Project genesis 3. Project goal 4. Project purpose 5. Major project components 6. Expected outputs	SUB-SECTOR INVOLVEMENT 1. Implementing agency/organization: • name • type 2. Private-sector involvement 3. Delivery mechanism at village level	OBSERVED TECHNOLOGY DEVELOPMENT 1. Baseline design/configuration 2. Changes in: • materials • mfg. process • end-use focus • tech. choice • tech. design	CHANGES WITHIN THE PROJECT 1. Project focus, expected outputs, goals, purpose 2. Staffing 3. Funding changes: • level • type (grant, loan) • direction (priorities, training, materials	PROJECT INTERNAL LEARNING MECHANISMS 1. Formal monitoring activities 2. Formal evaluation 3. Information monitoring activities 4. Corrective process

Figure D.5 (continued)

DATA CATEGORIES AND ELEMENTS

	DATA CATEGORIES (con't.)	DATA ELEMENTS (continued)			
		ENERGY CONSUMPTION: 1970/1980/1990	ENERGY RPODUCTION: 1970/1980/1990	ENERGY IMPORTS: 1970/1980/1990	TREND ANALYSIS
NATIONAL ENERGY PROFILES	1. Energy consumption by fuel & sector 2. Energy production by fuel 3. Energy imports by fuel & by final end-use 4. Trend analysis of the above	1. Crude oil (BB) 2. Residual fueld oil 3. Gasoline 4. Natural gas 5. Diesel 6. Kerosene 7. Propane/butane 8. Coal 9. Fuelwood 10. Agric. residues	1. Crude oil 2. Coal 3. Forest wastes 4. Fuelwood 5. Natural gas 6. Geothermal 7. Wind 8. Solar 9. Peat	1. Crude oil 2. Coal 3. Residual fuel oil 4. Gasoline 5. Kerosene 6. Jet fuel 7. Other refine petroleum products	1. Dependence on imported fuels over time 2. economic implications of foreign fuel dependence 3. Bio-fuel production vs. sustainable local production 4. Consumption 5. Production

APPENDIX D

FIELD DATA COLLECTION GUIDE

for the Assessment of
Renewable Energy Systems Installed
in Selected African Countries

Key Data Collection Questions and
Workbook Data Element Sets

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INTRODUCTION

This pocket guide follows the same format as the data collection workbook. It is intended to be used in the field to remind the data collector of key areas related to the field site visit.

At the beginning of each visit, it will be necessary to explain the purpose of the visit and the project. The purpose is to gather information on the performance of renewable energy systems in several African countries. We are visiting their project or installation because it is an example of an installed system that is of interest. We are also interested in the way(s) the project, company or other institution has disseminated and otherwise supported the development of the energy system.

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GENERAL PROJECT INFORMATION

Basic and necessary data:

- project name,
- implementing agency,
- project goal,
- project purpose,
- project outputs (quantify where possible, e.g., number of units in place, number of trained technicians),
- major project components (e.g., training, small business, nutrition, fuelwood),
- private-sector involvement, and
- delivery mechanism at village level.

ENERGY SYSTEMS EFFECTIVENESS

Key question: What have been the observed economic, institutional and social problems and performance of renewable energy systems currently installed in selected AID countries in Africa?

1. SYSTEM PROFILE

A. Energy System Description

Basic:
- system type, sub-type, make and model.

Secondary:
- dimensions and type of installation.

B. Inputs

Basic:
- nature and origin of principal components.

Secondary:
- nature and origin of principal routine replacement parts, and
- nature and origin of principal operating materials.

C. Operating Schedule

Basic:
- planned number of hours of daily operation and daily/seasonal variation in number of operating hours.

Secondary:
- planned life of energy system in months or years.

1. SYSTEM PROFILE (continued)

D. End-Use Applications

Basic:
- direct and indirect end uses of energy system.

Secondary:
- occasional or unplanned uses for energy produced.

2. TECHNICAL

A. Technical Performance

Basic:
- type of energy produced,
- system output of final product, and
- hours of operation required to produce output.

Secondary:
- amount of energy produced daily,
- quality of energy produced,
- daily/seasonal variation in output, and
- other alternative technologies considered.

B. System Reliability

Basic:
- actual versus scheduled hours of operation per month, and
- longest period of unscheduled downtime.

2. TECHNICAL (continued)

B. System Reliability (continued)

Secondary:
- number of hours of scheduled and unscheduled maintenance monthly.

C. Durability/Material Problems

Basic:
- materials and/or component substitutions that had to be made due to premature degradation, breakage or design changes, and
- reasons for those substitutions.

Secondary:
- design changes made to limit or eliminate durability and material problems, and
- results of design changes.

D. Operation and Maintenance

Basic:
- number of hours operator is in attendance monthly,
- frequency of system fueling and/or cleaning, and
- frequency and duration of major scheduled overhauls.

Secondary:
- frequency and duration of scheduled lubrications/maintenance, and
- frequency and duration of spare parts replacement.

2. TECHNICAL (continued)

E. Output versus Resource Base

Basic:
- specific figures on energy output given a particular amount of input, in units appropriate to the energy system.

3. ECONOMIC

A. Costs

Basic:
- operation and maintenance--currency conversion rate, price of raw feedstock, amount of feedstock used, fuel costs for back-up system, price of routine spare parts and lubrication, training costs for operation, maintenance and repair personnel, and wages for operators and/or maintenance staff,
- capital expenses--the energy system itself, power conditioning and/or end-use auxiliary equipment, and energy storage devices; whether equipment is locally produced and/or assembled or imported,
- other costs--local prices for fossil fuels, biomass and grid electricity, initial cost of diesel electric generating set and its monthly fuel consumption, extraordinary one-time costs and costs to train end users, and

3. ECONOMIC (continued)

A. Costs (continued)

Basic:
- affordability to user in terms of percentage of income to buy and maintain/operate.

B. Benefits

Basic:
- increased output of final product or value added to current output due to additional energy and its value per unit of time,
- amount of fossil fuel or fossil fuel-fired electricity displaced at site by renewable energy system per month and cost of fossil fuel delivered to site, and
- types of employment created and number of full-time equivalent jobs per month or year for number of units produced.

Secondary:
- secondary stimulation of the economy, such as new services or businesses established due to the introduction of the new energy system(s) and other services or businesses attracted by higher incomes in agriculture.

4. INSTITUTIONAL

A. Project Support

Basic:
- support by central government via policies, legal or institutional revisions, manpower, financing and practical help, and
- support by regional/local government in terms of manpower, legal/institutional revisions and practical help.

B. Experience

Basic:
- experience of personnel connected with energy system, including owner/operator, manager, maintenance and support staff, and government technicians.

C. Capability

Basic:
- central, regional and local governments' capabilities to support energy system in terms of technical competence and manpower,
- training and manpower needs of central and regional/local governments, and
- capabilities and training needs of owner/operator and maintenance personnel.

5. SOCIAL AND CULTURAL

A. Beneficiaries

Basic:

- profile of beneficiaries, such as landowners, entrepreneurs, traditional and government officeholders, male and female household heads and residents, and groups, in terms of income, history of innovation, length of residence, education and training, employment status and age.

B. Acceptance

Basic:

- general acceptance of system, things in particular people like about system and general problems,

- specific problems, including:
  --mismatch between need(s) and type or quantity of energy output,
  --system differs from preferred type,
  --system excessively complex,
  --difficulty obtaining replacement parts,
  --technical support overwhelms government services,
  --system violates cultural norms,
  --local dealer/government agent not trusted,
  --system operation interferes with social/community life or is poorly matched to rhythm of agricultural or other operations,
  --system type fits poorly with local climatic or other environmental conditions,
  --system incites social jealousies,

5. SOCIAL AND CULTURAL (continued)

B. Acceptance

Basic:

- more problems...
  --system is perceived as being too expensive, imposed by the government or displacing local labor,
  --system is too unwieldy, heavy or inflexible,
  --concern about durability and maintenance,
  --traditional system perceived as superior in performance, and
  --water pumping seen as interfering with traditional water rights.

- solutions, including:
  --users need more training or subsidies/tax breaks,
  --potential users need more demonstrations,
  --strengthen extension service,
  --system needs redesign,
  --revision of system operation,
  --improve after-sales service,
  --greater local participation in planning new energy systems,
  --greater local control over management of collective systems,
  --greater local input in system design,
  --local entrepreneur as less intimidating diffusion agent,
  --show users alternative uses of same energy,
  --clarify system ownership, and
  --clarify or reorganize system management.

END-USE APPLICATIONS

Key question: What has been the comparative economic, technical, social and institutional performance of alternative renewable energy systems in the provision of usable, cost-effective, energy-specific, African end-use applications in the areas of agricultural production, agricultural processing and food preservation, domestic consumption, and small-scale commercial and industrial operations?

1. ALL END USES

Basic:
- type of output required,
- production level sought/needed,
- technology currently used to meet end-use requirements and price per unit,
- limitations and advantages of technology currently in use,
- commercially available technologies that meet end use,
- advantages and disadvantages of commercially available technologies,
- key use considerations for technology design,
- key fuel considerations for technology design, and
- key production materials considerations for technology design.

2. AGRICULTURAL PRODUCTION

A. Irrigation Pumping

Basic:
- crops being irrigated,
- hectares irrigated per day,
- water output per use per day,
- pumping lift,
- type of pumps installed, and
- current conventional pumping units installed locally.

Secondary:
- number of days per year of output above normal use, and
- seasonal fluctuations in water demand.

B. Cultivation

Basic:
- crops being tilled, and
- number of hectares being tilled.

Secondary:
- general soil and terrain types,
- type and depth of cultivation, and
- energy form used.

2. AGRICULTURAL PRODUCTION (continued)

C. Fertilizer Use

Basic:
- crops being fertilized, and
- amounts of fertilizer required per season.

Secondary:
- nutrients required,
- seasonal fluctuation in fertilizer demand, and
- method for applying fertilizer to field.

D. Space Heating/Cooling

Basic:
- monthly heating/cooling requirements,
- type and number of seedlings to be produced each year,
- seasonal fluctuations in temperature and solar insolation, and
- size of space to be heated or cooled.

E. Transportation

Basic:
- engine to be run and type of fuel required,
- distance to be traveled, and amount of fuel required per kilometer, and
- volume and weight of load to be carried.

2. AGRICULTURAL PRODUCTION (continued)

E. Transportation (continued)

Secondary:
- steepness and roughness of terrain to be covered, and
- frequency of trips.

3. AGRICULTURAL PROCESSING

A. Harvesting

Basic:
- average tons per hectare per day,
- persons working per hectare, and
- equipment used.

Secondary:
- mobility of equipment desired, and
- duration of peak harvesting period(s).

B. Threshing

Basic:
- person(s) doing threshing,
- crop(s) to be threshed, and
- amount to be threshed per day.

Secondary:
- moisture content of crop, and
- portability requirements.

3. AGRICULTURAL PROCESSING (continued)

C. Crop-Drying

Basic:
- type and volume of crop to be dried per day,
- percentage of residual moisture desired, and
- monthly or seasonal fluctuations in temperature, rainfall and insolation.

D. Cold Storage/Refrigeration

Basic:
- product to be stored/refrigerated and space required, and
- necessary temperature change and seasonal, day/night or monthly fluctuations.

Secondary:
- seasonal fluctuations in storage needs,
- available refrigeration back-up units, and
- access requirements.

4. DOMESTIC USES

A. Cooking

Basic:
- foods to be cooked,
- maximum number of pots used simultaneously, pot capacities, and fluctuations in use,

4. DOMESTIC USES (continued)

A. Cooking (continued)

Basic:
- fuel availability and costs,
- indoor or outdoor use, and
- hours of daily use.

Secondary:
- portability requirements,
- need for rapid heating, and
- cooking used for simultaneous space heating.

B. Water Heating

Basic:
- necessary temperature change and baseline temperature,
- liters per day required, and
- typical daily demand pattern.

Secondary:
- maximum and minimum annual temperatures.

C. Lighting

Basic:
- number of bulbs and wattage to be powered,
- hours per day required, and
- maximum distance from power source.

Secondary:
- portability.

4. DOMESTIC USES (continued)

D. Potable Water Pumping

Basic:
- liters per day required,
- size of group using water,
- head and distance being transported, and
- storage need.

Secondary:
- water source.

E. Space Heating/Cooling

Basic:
- seasonal variation in heating/cooling requirements,
- temperature change required,
- volume of room/building, and
- exposure of room/building.

Secondary:
- dimensions of room/building.

5. COMMERCIAL/INDUSTRIAL

A. Low-Temperature Process Heat

Basic:
- temperature and amount of energy available.

B. High-Temperature Process Heat

Basic:
- temperature and amount of energy available.

5. COMMERCIAL/INDUSTRIAL (continued)

C. Space Heating/Cooling

Basic:
- volume and dimensions of space to be heated/cooled,
- materials room/building is made of,
- seasonal variation in heating/cooling requirements, and
- temperature change required.

Secondary:
- people's daily habits related to indoor comfort needs.

D. Water Heating

Basic:
- use for heated water,
- temperature change needed and baseline temperature,
- daily hot water requirement, and
- daily demand pattern.

E. Motor Shaft Power

Basic:
- type of motor to be run,
- size of motor,
- daily duration of demand at what load level, and
- fuel available.

PROJECT-SPECIFIC MONITORING AND EVALUATION

Key question: Is there a formal monitoring and evaluation system; and is there an informal system that provides assessment and direction for the project, while not formally evaluating it?

1. PROJECT MANAGEMENT

A. Decision-Making Structure

Basic:
- formalized process for integrating opinions and information from all institutions/groups involved into decision making,
- who makes decisions, and
- how decisions are reached.

B. Project Changes

Basic:
- key management decisions that have changed the project's elements or direction,
- were these decisions result of formal or informal monitoring and evaluation, and
- are the project's purpose, strategies, etc. periodically reviewed and discussed formally.

2. TECHNICAL

A. Performance

Basic:
- performance monitoring procedure for each set of technologies, and
- observable technology development due to these procedures.

B. Design

Basic:
- changes in baseline design of technologies, and
- reasons for changes.

C. Economic

Basic:
- financial and economic assessments for each technology, and
- actions taken based on these analyses.

3. DISSEMINATION

A. Institutions

Basic:
- institutions deeply involved in dissemination and basic strategy/delivery mechanism for each technology, and
- any changes in strategies.

Secondary:
- institutions doing better than others and reasons, and
- new dissemination strategies developed.

3. DISSEMINATION (continued)

B. Users

Basic:
- how user needs are determined by project,
- major changes in perception of user needs since beginning of project, and
- how users are integrated into design, testing, demonstration and dissemination.

C. Barriers and Constraints

Basic:
- barriers and constraints that were not recognized during project design,
- how were such barriers discovered, and
- strategies to address those constraints and how they were developed.

Secondary:
- evidence that unexpected barriers and constraints will be overcome by present project strategies.

STANDARD DATA NOTATION FOR WORKBOOK ENTRIES

Length: meters (or decimals thereof) -- m
or
kilometers -- km

Area: hectares -- ha
or
square meters -- m^2

Volume: cubic meters -- m^3
or
liter -- l

Weight (mass): kilogram -- kg
or
metric ton(1,000 kg)

Energy: kilowatt-hour -- kWh
or
megajoules -- MJ, per m^2 per day in the case of solar radiation

Power: kilowatt -- kW (10^3 watts)
or
megawatt -- MW (10^6 watts)

Heat: kilocalorie -- kcal (10^3calories)

Pressure: atmosphere

Temperature: degrees Celsius