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The Introduction of Space Technology Power Systems into Developing Countries

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SUMMARY

Between 1978 and 1984, the NASA Lewis Research Center was responsible for the design, fabrication, installation, and operational support of 57 photovoltaic power systems in 27 countries. These systems were installed in locations not served by a central power system and ranged in size from 40 W for powering street lights to 29 kW for providing power to a complete village. Several of the systems projects had social/economic studies components that provided for an assessment of how the introduction of both electricity and a novel high-technology power system affected the users and their society.

INTRODUCTION

The NASA Lewis Research Center has been involved in photovoltaic (PV) cell research and array systems technology since 1960 and is now NASA's Lead Center for PV cell technology. NASA Lewis fielded its first terrestrial PV systems in the early 1970's to test the terrestrial applicability of module fabrication techniques derived from space research. Those first few systems demonstrated the practicality of terrestrial PV systems and provided a small experience base for understanding their problems.

In 1975, NASA Lewis was selected to manage the Remote Stand-Alone PV Systems Applications Project of the National Photovoltaic Program for what was then the Energy Research and Development Administration (now the Department of Energy). In 1976, the U.S. Agency for International Development (U.S. AID) requested that NASA Lewis assist in PV energy programs in less developed countries (LDC's).

Between 1976 and 1980, the Lewis Photovoltaic Project Office designed, fabricated and installed 19 PV power/load systems in the United States including the world's first village PV power system at Schuchuli, Arizona, and one system in Africa. Those first systems provided the NASA Lewis Terrestrial Photovoltaic Project Office with the experience base necessary to direct and manage later systems projects for which the designs, hardware and installation were procured by competitive bidding from U.S. PV systems suppliers. From 1981 through 1985, Lewis procured 57 PV systems which were installed in 27 developing countries.

It is our intent in this paper to describe some of the challenges associated with the introduction of renewable energy systems and new technologies into rural settings of developing countries. The lessons learned from the NASA Lewis PV demonstration project should be instructive as terrestrial applications for future space-based research are introduced into the Fourth World development process.

BACKGROUND

The PV systems projects NASA Lewis implemented for U.S. AID and the foreign systems projects for the DOE were meant to demonstrate the applicability of PV systems in a variety of rural development settings and to introduce electrical energy into the development process. The projects concentrated on applications in the health, education, potable water, and community services sectors. Table I displays the country of location and the load service sector for those systems. The largest project was a field trial project of PV-powered vaccine refrigerator systems conducted with the U.S. Centers for Disease Control (CDC) and the World Health Organization (but funded by the CDC, DOE and U.S. AID (refs. 1 and 2)). Others were: a PV-powered health clinics project (ref. 3), a four village community services project in Gabon (ref. 4), a Pacific island village power project, and a village power project in Tunisia. Table II details the extent of the vaccine refrigerator field trials project.

The NASA Lewis PV projects were initiated in a variety of ways. The Tangaye, Burkina Faso water pumping and grain milling project, the Guyana, Ecuador, Zimbabwe and Kenya medical clinic systems project, and the Indonesian earth station project were initiated by the Office of Science and Energy Technology at U.S. AID/Washington. The Tunisian village systems project was initiated by the U.S. AID mission in Tunisia. The Gabon Village PV-powered Community Services project was initiated by the Government of Gabon. The Utirik project was initiated by the people of Utirik through the Government of the Republic of the Marshall Islands, and the PV-powered vaccine cold chain refrigerator project was initiated by the U.S. Centers for Disease Control.

All projects were established on a government-to-government basis and were implemented in cooperation with appropriate ministries within the host countries. Typically, a memorandum of understanding and an implementation plan between NASA and the host country ministry provided the framework within which a project was carried out. In every case, the host country government participated in the formulation of the project. In all cases, except for some of the vaccine refrigerator field trial sites, NASA Lewis' project office personnel visited the host country to perform a site inspection and to work with ministry personnel to draft the memorandum of understanding and implementation plan. NASA's intent was to involve host country personnel as much as possible in the complete project process.

The Tangaye system was designed and built by NASA Lewis engineers. NASA provided performance requirements and specifications for all other foreign systems. For all those systems, system design, fabrication, installation, documentation, preparation of training materials, and user training was provided by U.S. companies under competitively bid contracts.

To measure the development significance of these projects, NASA Lewis built socio-economic impact research into all except the vaccine refrigerator field trial project. This research was performed by non-NASA personnel in cooperation with host governments. While positive results were obtained, the successes of this research varied widely depending on a several factors, most of which were out of control of the NASA Lewis project office, (e.g., difficulty in gaining access to the local people during necessarily brief visits by anthropologists, withholding of results from research performed by in-country personnel, and studies performed by researchers with bias and lack of background information).

In looking back over the various NASA Terrestrial Photovoltaic Applications projects, however, these shortcomings add to the sense gained from the social impact research that was successful that, as frequently as not, the ultimate success of new technology demonstration and application in LDC's depends as much on social factors as on the excellence of the technology being introduced. Observed critical social factors include: proper extension service for rural people meant to benefit from the technology; cooperative management and oversight by both the provider and host countries; and the evaluation and follow-up from one project being inputted to the next project. It has often been said that technology cannot exist in a social vacuum and the NASA PV projects affirmed this important rule. Unfortunately, lack of emphasis on the importance of the social factors during project planning and implementation has meant that in a number of cases PV technology has not received a proper field test because of failures in the human support system.

Overall, the program proved to be valuable for understanding the process necessary to introduce both electrical energy and new renewable energy technology into developing countries (ref. 5), for the need to create the necessary infrastructure in host country ministries to accommodate the new energy technology, and for understanding the impact on rural people in LDC's of the introduction of electricity to serve critical human needs.

PROJECT BRIEFS

All of NASA's projects resulted in the introduction of a technologically advanced energy system providing electrical energy and services to rural people in LDC's. NASA provided the PV system and in most cases the electrical appliances (loads) to be powered from the PV system. Most of the projects had higher order (primary) objectives that were served by the availability of electricity (see table III). The effect of each of these projects on the people served had to be measured against the resources and background of each host population. Table IV displays the baseline energy and socio-economic background for some of the projects.

PV TECHNOLOGY AND EQUIPMENT SUITABILITY AND PROBLEMS

Photovoltaic power systems are ideally suited to application in developing countries because:

(1) PV systems may be "high-tech" in nature and manufacture, but they are "low-tech" in installation, maintenance, and operation and can be easily operated by people having little or no formal technical education, but who are trained in the operation of the systems;

(2) PV modules are inherently reliable and have a lifetime of over 20 years;

(3) Of system design flexibility; (i.e., the same modules may be used singly for small distributed systems or in larger numbers for larger or centralized systems);

(4) Small PV systems consisting of a single module and battery producing sufficient energy for one light or other small appliance can be introduced for individual purchase, use and care as catalysts for microenterprise or other programs of "percolate up" development (as opposed to the often unsuccessful, large scale "trickle-down" programs);

(5) PV systems are humanly portable allowing for easy transport, off-loading, and assembly in remote locations where materials handling equipment cannot be made available;

(6) System capacity can be easily increased (or decreased) as load requirements change;

(7) There is a paucity of single point failure modes - a PV array may get "sick" (i.e., some cells or modules may fail), but rarely fails completely. Failure modes are almost always downstream of the PV array in controls (effects of failures in the control system can be minimized by the use of redundant subsystems), energy storage, distribution, and loads;

(8) The PV system itself has no moving parts to service or to wear out--experience has shown that inadequate maintenance is the single greatest threat to longevity of mechanical systems in developing countries;

(9) PV systems have a benign (if any) environmental impact;

(10) PV systems are very safe at low voltages, but require standard safety procedures and practices at high voltages;

(11) PV systems are silent and so do not intrude on the cultural environment.

As appropriate as PV systems are from a technological point of view, experience has shown that there is one major problem relating to their actual use, and that is the vulnerability of the energy storage subsystem to mismanagement of the electrical loads. Depleted energy storage has been the most common problem related to the use of stand-alone PV systems. As a minimum, the system controls must have provisions for disconnecting loads if energy storage (i.e., battery state-of-charge) becomes so low as to threaten the integrity of the batteries. The concept or reality of a dead battery is easily understood, but effective and appropriate management of energy consumption in a renewable energy system is less well understood and often reluctantly and ineffectually put into practice by people in rural areas of LDC's.

There were other problems associated with the introduction of PV systems in developing countries that may be indicative of what may happen with the introduction of other space-age technologies. Specifically:

(1) The success of new technology demonstration and application projects in rural areas of LDC's depends heavily on identifying and training local people who show an interest in the technology and who have some basic skills that can be adapted to the immediate need. Often such people show remarkable dedication and skill in managing systems, but unless these people are well trained

and disciplined to follow maintenance, troubleshooting, and repair directions, they can become tinkerers with the system and may cause more harm than good. Inadequately trained users and/or technicians exacerbate problems with installed systems because they do not recognize problems in their formative stages, because they do not recognize the need to report the problems up the line of support, or because they are not able to identify and report problems accurately, thus rendering the higher level support function ineffective. A successful technology demonstration program must identify these people in the local community and train them to operate and maintain systems and when to report difficulties to higher-order support staff. To do this sort of training well requires a degree of dedication to the training process rarely found in contemporary development programs, whether they be of American or other initiation. (An example of the consequences of the lack of properly trained people was case of a loose PV array power plug to a PV-powered vaccine refrigerator that resulted in the batteries constantly being discharged and which took one and one-half years to diagnose and correct. In another case, a very remote village level PV system was managed by a local person with some electrical skills. When elements of the system failed, he took it upon himself to make modifications to the system which ultimately caused serious problems with the system.)

(2) People in the rural sector trained in the operation and maintenance of new technology often gain in social status and political-economic power. Such social advancement often results in their moving to more responsible positions in the government or to urban locations thus leaving a void in a fledgling rural support infrastructure. Filling such a void requires that there be an on-going training program to bring new people into the support infrastructure. No country we dealt with instituted such a program during our association with them and the process of new technology application we initiated was often inhibited to the detriment of the particular project and broader program goals. (During the medical clinics systems project, for instance, medical interns trained to use and maintain the PV systems were soon transferred elsewhere with no overlap and no one on-site who could train their replacements.)

(3) Most developing countries lack a support infrastructure for newly introduced technologies. Such infrastructure should include informed and involved government people, trained technicians and users, a spare parts inventory, a facility for maintaining a spare parts supply line, and an extension service to ensure that the users properly integrate the technology and services into their lifestyle. Creation of such a support infrastructure requires investment of considerable time and effort by donor agency staff, especially those located in-country. Problems in any bureaucracy must be recognized from the start, including the difficulty of communicating between one office within a ministry and another within that same or a different ministry. The constraints of present organization of in-country foreign assistance by U.S. AID and other agencies often preclude this.

(4) The problem of the lack of a technology support infrastructure is not and will not be unique to PV systems. Any new technology or product introduced into a developing country will have the same requirements for a support infrastructure and the same initial problems stemming from the lack of such an infrastructure. A technical infrastructure can either be maintained by the government or, more preferably, by a commercial organization. A commercial organization is preferable because it can offer an immediate opportunity and facility for growth of use of the technology. Factors relevant here would

include access to international supply sources and even more important, the possibilities for warehousing and distribution of parts or add-on components matched by centralization of technically trained, field-experienced staff. Participation by private enterprise contributes to host country economic development and may well be the best way to ensure a secure future for the technology in a country.

(5) There may be a reluctance to accept new technology in the form of new systems. This is a social, not a technical problem (although it must be remembered that technology cannot exist in a social vacuum). In some cases, when the new technology affects or replaces earlier ways of doing things, users may either choose not to use the new system, adapt the system to their needs as they understand them and prioritize them, or misuse the system leading to its damage or destruction. Ideally, social impact research should begin before project design is complete so that it can be modified to reflect the users' own expressed needs. The research should be continued during the project period to identify user reluctance or aversion to the project or technology, and it should be evaluated after the project to understand shortcomings or unforeseen benefits of the project that can either be avoided or built into the next project. (Women were found avoiding use of water from a tank filled by a PV-powered pump because it was not associated with ancestral spirits as is stream water. In another case, farmers were provided with a PV-powered pump and drip irrigation system for fruit trees. Instead, they used the pump for trench irrigation as they were previously accustomed to doing because they were not sufficiently trained to understand that drip irrigation requires far less water because it wastes far less water. They then complained that the PV-powered pump was inadequate for their needs. As an example of a positive adaptation, men adapted a PV-powered grain mill to accommodate the grinding of damp, fermenting grain used to brew beer.)

(6) There is often a lack of appreciation by U.S. planners for the difficulty of installing and servicing equipment in rural settings of developing countries. Equipment is often not packaged for ease of handling and security. Installation tools are often inadequate or inappropriate, especially in terms of their own need for a power source (e.g., electric drills). Sufficient and appropriate spare parts to cover those damaged or lost during installation are often either not included in the installation kit or are provided in inadequate quantities. Without a prior site survey or good knowledge of the local conditions, it is often difficult to anticipate site-unique conditions or requirements. In other words, it is a long and expensive way back to the shop.

RESULTS FROM INTRODUCING PV-GENERATED ELECTRICITY INTO DEVELOPING COUNTRIES

The introduction of electricity into just four use sectors in rural areas of developing countries (water pumping, lighting, refrigeration, and communication), can have a significant impact on users' lives; e.g.:

(1) PV pumped water versus water lifted by hand can increase water availability and the time spent lifting and hauling water both for human and animal consumption can be freed for other purposes. Potable water, if provided from deep wells, can be cleaner, thus reducing the incidence of intestinal diseases. Irrigation is made easier and more efficient when drip irrigation is incorporated with pumped water. New crops can be introduced, additional land can be cultivated and/or less labor is needed for farming.

(2) PV-powered refrigerators for vaccine preservation allow the vaccine "cold chain" to be extended into the most isolated rural locations. This eases the outreach burden on rural vaccination programs, increases vaccine potency, lowers nurse workload at administration sites vis-a-vis having to maintain kerosene fueled refrigerators, and ultimately lowers disease and the associated human misery. PV-powered food refrigerators, especially for fish and similar perishables, extends markets and marketing time, increases productivity, improves the local economy and can contribute to improvement in the national nutrition.

(3) PV-powered lighting can allow for evening markets, studying opportunities for students, adult literacy and health care classes, better medical services, added opportunities for cottage industry, changes in home life, and increased community activity.

(4) PV-powered communication can facilitate medical diagnosis and evacuation, help minimize the effects of predictable natural disasters and mitigate the negative effects, and increase commerce and tourism. PV-powered TV can facilitate education and bring people into closer touch with others in their country and the wider world.

In some measure, all of these benefits were observed during the NASA program. There are, however, technical and social risks associated with the introduction of technology and energy into rural areas of developing countries. Some could be associated with the introduction of any new technology, others resulted from the introduction of PV systems. For instance:

(1) There may be reluctance to embrace the technology and or some of the benefits it brings into society because these are contrary to tradition. The new technology is then either used in an inappropriate fashion (e.g., PV-powered pump for drip irrigation used instead for trench irrigation) or abandoned.

(2) PV generated electricity and supported services, especially TV, may raise expectations above realistically achievable levels.

(3) Failure of new technology or services provided therefrom can have a long-term negative impact. We have noticed a tendency of users to associate the failure of a load device with a failure of the PV technology (e.g., vaccine refrigerator failure is a failure of the PV system and associated technology). If that same refrigerator were powered from an electrical grid, failure of the refrigerator would be taken in stride. In a similar vein, failure of any new technology is often accepted with fatalistic attitude by the users; i.e., "we did without it before and we can do without it in the future."

(4) When technology introduced by the government languishes due to lack of government support the users feel that they have become the victim of another failed government experiment in bringing them into the 20th Century and become disinterested in the new technology and cynical toward future introductions of new technology.

(5) New technology projects may fail if the community is not involved in every aspect of the project, from planning through operation. Such involvement fosters interest, cooperation, care and pride, and a sense of ownership vital to system longevity. Without community involvement, the introduction of a new technology could be doomed to failure.

A summary of the social-economic results of those NASA PV projects for which there was socio-economic research is as follows:

Tangaye, Burkina Faso (refs. 6 to 10)

People. - Tangaye residents quickly made the PV system and loads (station) their own, exploiting its services and adapting certain of its features to meet their own needs. However, the extent of positive social impact as originally planned and expected was not realized because; (a) Tangaye hamlets are so widely scattered that it is impractical for those living farthest from the station to use its services regularly; (b) the size and output of the mill was less than what was needed, causing long delays and frustration, especially early in the project; and (c) some baseline assumptions about the division of women's work were unsubstantiated (e.g., there is a much lower frequency of flour production by any given woman in a living unit in which a number of women share such tasks). As a result, a few Tangaye women benefited from the PV system regularly, most did so occasionally, and some never at all.

Social patterns. - By 1982, people had begun to concentrate certain activities around the PV station creating a village center where none had existed before. A church, bar, and permanent store were built nearby; the house originally built for use during the anthropologist's study was converted to serve multiple village needs as an occasional dispensary, literacy center, meeting facility and warehouse; and people driving along the main road used the station as a stopping place. The station co-operative was one of several founded or existing in Tangaye. With minimal guidance, Tangaye residents organized upkeep of the station and the running of the PV-powered grain mill.

Economy. - The grain mill generated a profit from fees set and collected by the station co-operative. After some resistance due to unfamiliarity with urban practices, villagers learned to bank these in the provincial capital. The co-op disbursed funds to finance social events accompanying regular station clean up, to purchase seedlings for a local reforestation effort, and for similar purposes that they themselves deemed appropriate.

Local government. - The station co-operative worked closely with the hereditary chief to maintain the station and oversee its activities. Some friction developed over who would control this resource, as a retired army officer contended with the hereditary chief for authority in the village. There was also some ill feeling by residents of villages near Tangaye, who were jealous of the benefits and attention Tangaye people were receiving.

Energy uses. - Originally, the project was to have two loads, the water pump and grain mill. When the PV array was expanded in 1982, lighting was brought to an outbuilding, and a PV refrigerator connected there as well. This PV lighting was used for literacy classes and health care activities. The grain mill was adapted (by altering the screen used to determine flour fineness) to allow the grinding of fermenting grain for brewing beer.

Spin-off activities. - Villagers' enthusiasm for the PV project spilled over to other grass roots development projects (e.g., profits from the mill were used to purchase saplings for a reforestation project), and informed their receptivity to development efforts by other outside agencies (e.g., a missionary health project).

Hammam Biadha, Tunisia (refs. 11 and 12)

People. - The Hammam Biadha project can be divided into two parts, the village power system and the agricultural applications. The first of these was better received than the second, as the central PV system provided power for the neighborhood of new scattered traditional houses (lending them an air of modernity and ease), the school and several stores, coffee house, dispensary, and mosque. The village is only 15 km from the main road and its access to grid electricity, and many residents of Hammam Biadha have lived where full use of an electrical grid has been possible. People were disappointed with the limitations of the PV system, especially regarding the number and sort of household appliances that they could and could not use (e.g., the proprietor of the coffeehouse purchased an expresso machine he could not plug in, another man wished to open a welding shop, householders wanted air-conditioning and other high-energy appliances). The PV and other renewable energy technology applications for farming failed altogether, due to a lack of or poor extension work to teach farmers the long-term advantages of the PV-powered drip irrigation, wind-driven pump, and passive solar green-houses (with berm walls) for growing seedlings and drying crops. The farmer given a wind-driven pump used it long enough to save sufficient capital to purchase a diesel pump; the PV-powered pumps for drip irrigation were converted to trench irrigation, or were abandoned altogether; greenhouses were not maintained. Extension work that should have accompanied the project was put in the hands of two Peace Corps volunteers who kept no records of their progress. The U.S. AID manager admitted that the definition and priority of the PV program had changed during the project period, and that ordinary oversight had been abandoned. The technology did not fail, although the human/social support system did.

Economy. - The program hypothesis was that the renewable energy agricultural projects would upgrade farmers' productivity and profits. To the extent that this happened, farmers used the profits to convert to fossil fuel energy sources, again, not because the renewable energy devices and power systems failed, but because the farmers were not effectively taught their long-term advantages.

Local government. - The NASA project was managed locally by the Tunisian electricity company, while components of the project targeted agriculturalists. As in any bureaucracy, it was difficult to establish links between the two ministries involved. In effect, agriculture ministry staff did not assume the project as their direct responsibility, and so there was no extension work that might have been accomplished under the rubric of existing agricultural programs. This sort of problem was encountered in other NASA demonstrations projects, including that in Gabon.

Gabon (ref. 4)

People. - The four villages receiving PV power community service systems were in different corners of a country inhabited by people of different ethnic groups and histories. Enthusiasm, participation, and social impact was different in each case. People in village A are of the majority ethnic group of Gabon and have been denied political power for some years. They feel neglected by the central government and saw the installation of the PV-powered systems as a means to modernize and gain recognition for their village and region. Their village is also in the home region of one of the key ministry officials organizing the Gabonese side of the PV program. People in village A were the most enthusiastic of any regarding data collection and forwarding, and positive exploitation of the PV system. Village B is a cluster of fishing hamlets on a rocky promontory jutting into the Ogoue estuary. At its center is a century-old mission and school where many old-guard Gabonese officials received their education. The school has fallen on hard times due to isolation and the difficulty of providing sufficient water for year round use. The PV systems were seen as a means to reestablish the school's importance, and to renew the vitality of the fishing community. Village C is on the edge of the Gabonese President's homeland. People were receptive, but not especially impressed by the PV system being given to them, as reflected in their lack of enthusiasm for reporting data, for performing on-going maintenance and using the system. Village D was the most problematic from the start. The dispensary nurse asked for special payment to use the system and report its data, and when he was exhorted to provide these services in the course of his ordinary duties for the betterment of the community he refused to do so. A school meant to receive one component of the project was never completed.

Social patterns. - Our knowledge of the program's social impact is hampered by an unforeseen aspect of the research: it was recognized early in the NASA program that, while PV technology transfer to LDC's was a major purpose, that applied social science methods could be transferred to host country researchers, as an additional program benefit. Social impact studies were commissioned by Gabon with assistance and oversight provided by Dr. Roberts, then at the University of Michigan. In the first two cases, interesting and valuable data were obtained, even as host country researchers gained training and experience under the NASA program. This did not prove true in Gabon, as the social scientists saw the program as an opportunity to build a research capacity at the university, and demanded a 4-wheel drive vehicle, office equipment, and paid leave time. These were outside the purview of our program and the final arrangement made between the Gabonese government and the researchers was accompanied by such resentment that no report has yet been submitted to NASA, despite frequent urging. As a consequence, we do not know what final impact the program had on social patterns or other aspects of village life.

Local government. - When a Gabonese Ministry of Energy was established, it assumed responsibility for the NASA program from the Ministry of Mines through which the program had been initiated. The PV applications fell within the activity domains of the ministries of health, higher education, and rural development. As with the Tunisian demonstration, it proved very difficult to establish working relations among staff of these ministries, and this was exacerbated by the distance among the four villages that rendered regular supply, oversight, and other logistical problems extremely problematic (e.g., the PV-powered vaccine refrigerators were not regularly stocked with medicines requiring rigid temperature control and there were no video tapes sent to the schools equipped with VCR's).

Spin-off activities. - Gabon has close ties to France, its former colonial master. NASA engineers met with French counterparts in Gabon early in the program period, for what were expected to be frank exchanges of information ultimately useful to the Gabonese. The French seized the opportunity to maintain politico-economic advantage and quickly built a demonstration PV power system near the capital to the exact specifications of those planned for the NASA program before the NASA systems could be implemented. The thunder was stolen, diminishing somewhat the commercial and political benefits the American program might have had.

Utirik

People. - This project was unusual in that village residents themselves sought a PV power system to meet needs they themselves defined. They intended to pay for it with money that was theirs from congressional funding. NASA staff took care to design the system to provide power for community needs particular to local culture, such as night-lights in homes because of fear of ghosts. Villagers were enthusiastic about having and using the system. The greatest difficulties lay in the poor installation and training provided by the U.S. contractor. A local person was chosen to manage and troubleshoot the system. He is an able, clever, and well-meaning person, but his skills are limited to the tinkering of a "backyard Edison." His training was so shallow that it was not discovered until the completion of the training program that he cannot read and is thus unable to use the various manuals provided to care for the system. The isolation of Utirik within the Marshall Islands, and of the Marshall Islands within the rest of the world, contributed to the difficulties of effective oversight, as did the fact that the NASA program was in phase-out and the U.S. contractor had decided to abandon efforts to develop its capacities in PV system design and implementation. When the system had mechanical difficulties, the local manager made a sincere effort to rectify them. When fluorescent bulbs burned out, instead of requesting spares from any hardware store on Majuro, the capital of the Republic of the Marshall Islands, he replaced them with incandescent bulbs, although these use much more electricity and require rewiring. When batteries began to fail, he changed the loads and availability of power so that some portion of the system would still function. As laudable as his efforts were, he lacked sufficient training to make these changes correctly and as a consequence he damaged the system while trying to save it.

Social patterns. - A U.S. consulting firm was hired to perform an evaluation of the project and its social impact. This was not done as expected as the scientists hired disagreed with the contractor as to how their work was to be used and were summarily fired without pay by the contractor who then pieced together unedited information they had provided to file the report needed to receive his payment. As a consequence, the "evaluation" is so impressionistic and fraught with error that it could have been written without visiting Utirik at all and is, therefore, worthless. Again, it is not clear what impact the program has had on the community.

Local government. - While PV can be an ideal energy technology for remote areas like the Pacific because of its stand-alone low-maintenance characteristics, certain organization within the local government is required to provide effective oversight. Utirik is a tiny atoll many miles from Majuro, the equally tiny capital of the Republic of the Marshall Islands. The government of the Marshall Islands became relatively autonomous from the U.S. (through a "Compact") during the project period and necessary infrastructure to plan, implement, and oversee projects such as this one was virtually nonexistent and had to be created as the project evolved. The Marshallese officer in Majuro responsible for the project at the time had many other responsibilities during this hectic period in local history. His training in energy matters was nominal and his ability to reach Utirik on a regular or even emergency basis was problematic at best. The U.S. presence in Majuro was being redefined at the same time and there was no American representative on-site who could oversee the project and ease its organizational and logistical difficulties. Again, the technical potential of PV applications was not given a full test in this project because of socio-political factors on both the American and host-country sides.

WHAT IS THE ROLE OF FOURTH WORLD 4TH LEVEL DEVELOPING COUNTRIES IN SPACE POWER RESEARCH AND DEVELOPMENT?

The so-called Fourth World (most of Africa, much of Latin America, and parts of tropical and central Asia) consists of the poorest of the poor countries. It is difficult enough for the governments of these countries to meet their peoples' most basic human service and educational needs, let alone participate in the space age. Fourth World countries lack sufficient resources or foreign currency credits to participate in a fossil-fuel or nuclear electrical future enjoyed or anticipated by the rest of the world. For now, these countries should continue to receive the benefits of PV technology and such space power derived technologies which are especially appropriate to their circumstances.

The presence and use of these technologies in the "Fourth World" will fire the imagination of children there no less then it fires the imagination of children in the U.S. Europe, Japan, and elsewhere. Some of these children will go on to become scientists and other technology specialists who will participate in national and international research and development activities in or about space.

Still, important questions remain. The gap grows geometrically, even astronomically, between the state and advances of technology (space-related or otherwise) in the First and Fourth World countries. A question such as "how can we increase Fourth World opportunities for participation in space-related research?" is sometimes supplanted by others such as "why should we increase such opportunities for participation when Fourth World countries have so little to give in return?" Is the commercialization of space to be a great poker game, to be played only by those who can "ante up?"

To return to a primary point of this paper, technology cannot exist in a social vacuum. There is an ethical side to technology development that cannot--or at least should not--be avoided. We must continue to take great steps in space for all of humanity and we must also find ways to bring the benefits to all of humanity.

Through this review of the NASA Lewis Research Center's terrestrial PV applications program, we have tried to show that there are appropriate uses for space technologies in rural development in LDC's. Implicit in our presentation of project benefits and shortcomings (as we see them in hindsight) is a recognition that technical engineering must be complemented by social engineering (in the best, participatory sense of that term), as rural people's own needs as they see them are identified, technical solutions to them are sought, and oversight infrastructure is reinforced or created. This has proven to be an exercise in and of great sensitivity on all sides and, in this regard, our failures have been as instructive as our successes. It remains for others to build on our experience and lessons learned.

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TABLE I. - NASA LEWIS REMOTE LOCATION PHOTOVOLTAIC SYSTEMS LOCATIONS AND TYPES

Country	Total watts	Village	Rural clinic	Vaccine refrig-eration	School lights/ TV/VCR	Water pumping	Outdoor lighting	Other
Haiti	284			1				
Dominican Republic	284			│				
St. Vincent	200			│				
Canouan	200			│				
Gautemala	248			│				
Honduras	200			│				
Guyana	1 854		1	│				
Columbia	284			│				
Ecuador	3 744		1	│				
Peru	284			│				
Morocco	355			│				
Jordan	160			↓				
Tunisia	34 647	1		2		2		Farm house
Gambia	640			2				
Mali	200			1				
Burkina Faso	3 800			1		(1	1	Grain mill)
Liberia	390			1				
Ivory Coast	990			3				
Gabon	12 080		4		5	4	4	
Zaire	355			1				
Kenya	3 140		2					
Zimbabwe	1 854		1	1				
India	355			│				
Maldive Islands	284			↓				
Thailand	200							
Indonesia	2 220			2				
Utirik Island	7 920	1						Earth station

TABLE II. - SUMMARY OF NASA LEWIS PHOTOVOLTAIC-POWERED REFRIGERATOR FIELD TESTS

[Systems tested at Lewis: Solar Power Corp./Adler-Barbour, 330 W peak/630 A-hr; Solavolt International/Polar Products, 400 W peak/315 A-hr; Marvel with Lewis photovoltaic array and array voltage regulator, 450 W peak/420 A-hr.]

(a) Latin America/Caribbean

Site affiliation	Location	Date	System manufacturer	Refrigerator supplier	Array peak power, W	Battery current, A-hr
Center for Disease Control	Bocas Del Palo, Columbia	11 Sept. 1982	Solar Power Corp.	Adler-Barbour	284	630
	Pucara, Peru	14 Oct. 1982			248	[a]525
Agency for International Development	Las Tablas Dominican Republic	28 Aug. 1982			284	[a]525
	Anse-a-Veau, Haiti	2 Sept. 1982				630
	Comuna Cobos, Ecuador	23 Sept. 1982				
	Schepmoed, Guyana	30 Sept. 1982			↓	
	Tierra Blanca, Guatemala	7 Oct. 1982	↓		248	
	Waramuri, Guyana[b]	1 Feb. 1983	Solarex		---	
	Pedro Vicente Maldonado, Ecuador[b]	31 Mar. 1983	Solarex	↓	---	↓
	Guiamaca, Honduras	12 Jan. 1984	Solavolt International	Marvel	200	420
	New Sandy Bay, St. Vincent	18 Jan. 1984	Solavolt International	Marvel	200	420
	Canouan, Grenadines	25 Jan. 1984	Solavolt International	Polar Products	160	315

(b) Africa

Site affiliation	Location	Date	System manufacturer	Refrigerator supplier	Array peak power, W	Battery current, A-hr
Center for Disease Control	Kaur, Gambia	27 Jan. 1983	Solar Power Corp.	Adler-Barbour	320	630
	Gunjur, Gambia	27 Jan. 1983			320	
	Niofouin, Ivory Coast	5 Feb. 1983			355	
	Zaranow, Ivory Coast	5 Feb. 1983			355	↓
Agency for International Development	Kionzo, Zaire	11 Feb. 1983	↓		355	[c]525
	Chiota, Zimbabwe	15 Feb. 1983			284	630
	Kibwezi, Kenya[b]	10 May 1983	Solarex		---	
	Ikutha, Kenya[b]	10 May 1983	Solarex		---	
	Chikwakwa, Zimbabwe[b]	31 May 1983	Solarex	↓	---	↓
	Ouelessebougou, Mali	14 Feb. 1984	Solavolt International	Polar Products	200	315
	Menee, Ivory Coast	25 Feb. 1984	Solavolt International	Polar Products	280	315
	Orodora, Burkina Faso	21 Feb. 1984	Solavolt International	Polar Products	200	315
	Iuehu, Liberia	12 Oct. 1984	Solar Power Corp.	Adler-Barbour	390	630

Table II. - Concluded.

(c) Near East

Agency for International Development	Hammam Biadha, Tunisia	Jan. 1983	Solar Power Corp.	Adler-Barbour	---	630
	Bouaboute, Morocco	28 Oct. 1983	Solar Power Corp.	Adler-Barbour	355	[a]525
	Es-Smirat (Siliana), Tunisia	3 Feb. 1984	Solavolt International	Polar Products	240	315
	Bir Amama, Tunisia	6 Feb. 1984	Solavolt International	Marvel	240	420
	Mowaqar, Jordan	28 June 1984	Solavolt International	Marvel	160	420

(d) Asia

Center for Disease Control	Bhoorbaral, India	19 Oct. 1981	Solar Power Corp.	Adler-Barbour	355	630
Agency for International Development	Cibung Bulang Indonesia	16 Apr. 1982	↓	↓	320	↓
	Batujaya Indonesia	16 Apr. 1982	↓	↓	320	↓
	Kuluduffushi	6 May 1982	↓	↓	284	↓
	Tambon Tha Thong, Thailand	2 Nov. 1983	Solavolt International	Marvel	200	420

[a] One battery damaged or lost in transit.

[b] Refrigeration is part of a larger clinic system.

TABLE III. - PHOTOVOLTAIC SYSTEMS PROJECTS PRIMARY OBJECTIVES

Project	Objective
Tangaye	U.S. AID project objective to determine the effect of energy on womens' use of time when relieved of lifting water and milling grain for flour by hand.
Tunisia Village system and farmhouse system	U.S. AID/Government of Tunisia (GOT) project objective to minimize rural-urban migration through rural village electrification by a PV-powered electric utility grid (with exceptions of pumping water due to in-place in-place pumping system and electricity substitute for private diesel driven milling operation) and a PV power system for a typical farmhouse.
Irrigation	U.S. AID/GOT project objective to demonstrate to local horticulturists improved agricultural output through use of a drip irrigation system using a PV-powered pump.
Vaccine refrigerators	U.S. Centers for Disease Control/World Health Organization objectives to demonstrate and simultaneously conduct field trials of three types of PV-powered vaccine refrigerator systems.
Gabon	Government of Gabon objective to demonstrate and gather data on applicability of PV power systems for community services (water pumping, village street lighting, dispensary (lights, ventilation and vaccine refrigerator), school lighting and TV/VCR for educational programs).
Utirik	Island residents desire to use their own money to obtain PV system for electricity for limited residential lighting and some community services (refrigerators for school, dispensary and queen's home, street lighting at three strategic locations, and ventilation in community buildings).
Earth station	U.S. AID project objective to demonstrate applicability of PV system to support a rural education project which used a satellite earth station for video and audio teleconferencing, graphics/fax capability, classroom lighting, and telephone to a nearby village for university classrooms in a remote location in Indonesia.
Medical clinics	U.S. AID project objective to increase health services in rural areas by demonstrating applicability of PV power systems for rural clinics by providing electricity for vaccine storage, lighting and other discretionary uses; e.g., dental equipment, communications, staff residential lighting and water pumping.

TABLE IV. - NASA LEWIS PHOTOVOLTAIC SYSTEMS PROJECTS ANTHROPOLOGICAL BACKGROUND AND ENERGY RESOURCES BASELINE DATA

Project	Anthropological background	Energy resources
Tangaye	Villagers are small-scale farmers living in decentralized hamlets; hereditary chief related by kinship and clan to many villagers; feeling of isolation and neglect by central government; immediate enthusiasm for project; semi-skilled workers available to run mill (no prior training, little formal education).	Water: 10m well, lifted by hand Winnowing and milling: hand operation (mortar and pestal)
Hammam Biadha Village system	Village of about 150 people with neighborhood of "modern" masonry houses, traditional houses, schools, stores, mosque, coffee house and other centralized facilities; many residents have lived in urban areas and have relatives who still do; experience with grid electricity in cities; possess electrical appliances they would like to run on project power.	Water: diesel driven village pump Graining milling: private diesel-powered mill Electricity: none
Farm house system	Farmsteads sprinkled across wide valley; farmers engaged in multi-crop agriculture, mid-level technology (some mechanical means); orchards desired, as promulgated for area by government extension programs.	Electricity: none
Drip irrigation	Farmers familiar with diesel pumps for trench irrigation; have open wells for irrigation, understand irrigation by <u>seeing</u> water brought in quantity to seedlings.	Water: diesel driven pump with conventional trench irrigation
Gabon villiage community services systems	Four villages in four corners of the country were selected by the central government as resentative situations and to spread development benefit; each village to receive four PV-powered community service systems; accessibility of each village difficult, especially during rainy season; each village a different ethnic group with different history of development--each to be considered on case-by-case basis; in first, people feel neglected by government and are anxious to become "modern;" in second, major impact of system is abundant water and power to mission school; in third, village near president's homeland; in fourth, isolation, apathy and disaffectation. Social-impact research conducted by local anthropologist.	No pumped water or electricity, no on-site vaccine storage

TABLE IV. - Concluded.

Project	Anthropological background	Energy resources
Vaccine refrigerators	Each location chosen by host country, many very remote; little chance of regular or direct oversight.	No vaccine refrigerator or kerosene fueled refrigerator/freezer
Utirik	Atoll very remote, fishing and coconut farming main pursuits; residents directly affected by fallout from 1954 hydrogen bomb blast, much direct and later-generation radiation sickness; U.S. Government provides welfare support and money compensation for radiation accident; villagers used $100K in compensation funds toward purchase of PV system; most have lived in Majuro or Kwajalein where grid electricity available; people familiar with VCR's and other electrical appliances; semi-skilled labor available for PV system maintenance.	No pumped water or electricity for community (some individuals had engine-generator sets)
Earth station	No anthropological data available.	No electricity or communications
Medical clinics (5 each)	PV-powered electricity provided to rural clinics in Guyana, Ecuador, Zimbabwe, and Kenya (two systems), all in remote settings; difficult logistics, little possibility of training for nurse or for regular provision of cold-chain vaccines needing refrigeration; occasional visits by MD; social impact research conducted in Guyana and Zimbabwe by local anthropologists.	Variable ranging from diesel-powered generator for lights to no electricity

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16. Abstract

Between 1978 and 1984, the NASA Lewis Research Center was responsible for the design, fabrication, installation and operational support of 57 photovoltaic power systems in 27 countries. These systems were installed in locations not served by a central power system and ranged in size from 40 W for powering street lights to 29 kW for providing power to a complete village. Several of the systems projects had social/economic studies components that provided for an assessment of how the introduction of both electricity and a novel high-technology power system affected the users and their society.

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