Renewable Energy Technology: Optimizing Energy Sources for the Development of Millennium Project Villages

Robert Freling, Executive Director
Jeff Lahl, Project Director
Solar Electric Light Fund (SELF)
July 8, 2005

Solar Electric Light Fund
1612 K. Street, Suite 402
Washington DC 20006

(202) 234-7265
www.self.org

TABLE OF CONTENTS

Abbreviations

AC	Alternating Current (Grid or "mains" power)
DC	Direct Current (Current coming from PV or batteries)
ESCO	Energy Service Company (or Co-op)
GPD	Gallons per day (pumping rate)
kWh	kilowatt hour (1,000 watts per hour)
MDG	Millennium development goals
mW	megawatt (1,000,000 watts)
O&M	Operation and maintenance
PV	Photovoltaic (solar-electric, direct conversion of sunlight to electricity)
RET	Renewable energy technology
SELF	Solar Electric Light Fund
SHS	Solar home system (photovoltaic power system)
Wp	Peak watts. (the name-plate rating on a PV module- its production under test conditions)

Introduction

Electrical energy is a great enabler of development across all sectors. The choice of how that energy is generated in communities is critical to the success of development efforts that depend on it. Establishing the most reliable and most cost-effective energy source will provide the necessary solid foundation for the many intervention strategies that benefit from electrical energy.

The choices involved with new energy generation, especially when developing a model for large-scale global dissemination, will have profound environmental effects on a world that already suffers from damaging and unsustainable patterns of energy usage.

Whether electrical energy is needed for school lighting, vaccine refrigerators, home-based business, well pumps or to support agriculture (irrigation pumping) and commerce (micro-enterprise centers) , it typically comes from one or more of the following sources:

1. National or regional electrical grids powered by fossil-fuel generators.
2. Community power supplies or local area grids powered by fossil-fuel generators.
3. Individual fossil-fuel generators used for specific applications (schools, pumps, etc.)
4. Central community power stations powered by renewable energy sources (hydro, solar, wind, biomass or some combination)
5. Decentralized renewable energy systems – stand alone, autonomous systems. (solar, wind, hydro, etc.)

In most developing countries, the expansion of national grids into rural areas is slow or non-existent due to the enormous costs involved and the many other development needs competing for very limited resources. In many countries, population growth has risen faster than the pace of rural electrification, resulting in a growing percentage of the rural population not served by electrical grids. In many cases the reliability and quality of grid supplied electricity fail to adequately supply even existing customers, let alone new ones.

For the foreseeable future, poor rural regions and communities will need to develop their own local electrical generation and distribution systems. A fundamental choice to be made is in considering the use of renewable energy sources such as solar-electric (photovoltaic, or PV) in place of fossil-fuel burning generators. This paper will state a case for the benefits of using PV systems to help meet Millennium Development Goals.

Fossil Fuel Burning Generators

Communities often turn to fossil-fuel generators (usually diesel) as the first choice considered when the grid is not available. Although offering the advantages of availability, portability and what might seem to be a reasonable upfront cost, generator-supplied power has many drawbacks and often does not represent the best sustainable energy source for small to medium communities nor even the lowest-cost option when considering life-cycle costs.

Problems often associated with fossil-fuel generators include:

- Constant critical maintenance requirements.
- A shortage of trained maintenance personnel in many rural areas.
- A shortage of spare parts for larger generator/motors.
- The constant requirement for expensive and/or scarce fossil fuels.
- The difficulty of transporting fuel to remote areas.
- Short lives for inexpensive generators.
- Low-reliability for critical needs such as communications, water supply and vaccine refrigeration.
- Severe global and local environmental liabilities if all un-electrified villages (1.7 billion people) choose fossil-fuel based generation.
- The ultimate unsustainability (unavailability) of fossil fuels. As world oil production goes on a predicted decline and fuels become scarcer and therefore more expensive while demand continues to rise, developing villages will be among the first to be priced out of competition for these resources. (Exxon/Mobil Corporation predicts that the world consumption of energy will increase 40% by 2020.)

SELF has observed while working in over 14 developing countries that the above factors, singly or in combination, have resulted in a large percentage of generators sitting idle or broken in disappointed communities. In one example in Nigeria, a state government supplied diesel generators to power community bore-hole pumps in 20-30 villages. During assessment surveys in many of these villages, SELF personnel did not find any of them working either because they had broken down and there was no mechanism in place to get them fixed or the villagers were not able to afford the fuel on a sustained basis. In many cases we've observed small, low-tech diesel motors (Lister-single cylinder type) in widespread use for agricultural purposes which can usually be kept running with local knowledge and spare parts. But again, fuel availability and affordability, size limitations, and environmental concerns do not make this class of motor appropriate for use as electrical generators in an African or global development model.

Solar-electric (Photovoltaic) Power Generation

Solar is just one type of renewable energy. In locations that have wind, micro-hydro, geothermal or other renewable resources, these technologies need to be considered as potentially being the best choice. However, in most developing areas of the world, the available solar radiation ranges from adequate to very good and it is the most constant widely available renewable energy resource. With no moving parts, photovoltaic (PV) systems also have the potential for the lowest maintenance and highest reliability. Solar-electric is a viable technology to consider for modeling global development solution.

Solar-electric competes very well with fueled generators in many categories as illustrated in the following table:

TABLE 1.0 SOLAR VS. GENERATOR COMPARISON

Generator Type	Advantages	Disadvantages
Solar Electric Generators	• Low maintenance • Low-tech standard maintenance • Long life of solar modules (20+ years) • No moving parts • No fuel needed • High reliability • Unattended operation • Easily installed • Environmentally clean • Highly flexible – systems modular and can be matched closely to load. • Moderate recurrent costs.	• Relatively high initial cost • Output is weather dependant • Highly dependant on batteries and battery maintenance.
Diesel or Gas Generators	• Moderate capital costs • Can be portable • Extensive experience usually available • Easily installed for point of use (non-grid) installations	• High maintenance and replacement costs • Frequent maintenance necessary • Shortage of qualified maintenance and repair personnel • Fuel expensive • Fuel often unavailable • Noise and air polluter • Potential of enviro. damage from fuel spills • Requires on-site operator. • Contributes to global warming.

Critics of photovoltaic technology often cite two factors which are believed to prevent widespread adoption of this technology for rural electrification: high upfront cost and the difficulty of sustaining these systems, which is usually perceived as high rates of failed systems.

In most cases within the context of village electrification, photovoltaic (PV) generators cost more than motor driven generators <u>only</u> when initial costs are the basis of comparison. In life-cycle cost analysis, PV is the least expensive option in most small to medium sized energy applications. The following are samples of studies that confirm the cost-effectiveness of PV generators for various applications:

General Applications

- A study published by Energy Economics (2002)[1] concluded that PV systems have lower life-cycle costs than diesel generators for daily loads of up to 16 kWh day in the worst PV case (low solar radiation) and up to loads of 66 kWh/day for the best PV case (high levels of solar radiation). This is approximately equal to PV array sizes of 4,000 Wp (the label output rating of the array) and 17,000 Wp respectively when allowing for typical system inefficiencies in regions having average solar radiation on the PV array of 5 kWh/day/square meter. The smaller load mentioned could power a school, clinic and small micro-enterprise center and the larger could power a village water pump plus school, clinic, micro-enterprise center and a number of homes.

- Studies of PV electrification programs in several Pacific Island nations (1994) concluded that PV systems have a lower life-cycle cost for home systems of at least up to 400Wp.(the largest size studied)[2]

- An International Energy Agency Study (1999)[3] found that PV can compete on a life-cycle basis with diesel for loads of up to 2.8kWh/day in the worst PV case up to 3.5 kWh/day in the best case. This range of power is equivalent to that needed to run a clinic and school and/or a battery charging station.

- A World Bank study (1996) of rural electrification of isolated villages in Indonesia showed that PV is the lowest-cost option when compared to an isolated diesel grid for population densities of up to 75 households per square kilometer and total populations of up to 500 households[4].

- A study from the University of Cape Town simulated various energy options for a variety of applications having different annual loads and found that schools and clinics having daily loads of 2 kWh/day and 1.4 kWh/day respectively are most economically served by PV systems in areas that have good solar radiation (4 kWh/day/square meter or better).[5]

- A National Renewable Energy Lab (NREL) study in 2000 showed that PV is competitive with diesel on a life-cycle basis for loads of 24 kWh/month and that a diesel-battery system is more cost-effective at loads of 200 kWh/month. However, there is a large spread between 24 and 200 kWh/month and the study does not show where the break-even load would be. The study is also set up to analyze a 10-year system life which does not give credit to the 20+ year proven life of PV modules. (Modules typically make up anywhere from 60% of the cost for small systems and 40% of the cost of large systems). The study also assumes a diesel fuel cost of $.18/litre which is extremely unrealistic, given current conditions (see below).[6]

Solar Water Pumping Cost Comparisons

- A Sandia National Lab study of 3 different sized solar pumping systems (106 Wp, 848 Wp, 1530 Wp) in Mexico showed that all had lower life-cycle costs than diesel-powered pumps. The PV systems vs. diesel had paybacks of 2, 2.5 and 15 years respectively when replacing fueled pumps (gas or diesel).[7]

- In a comparison of fueled pumps vs. PV, a German study showed PV-powered pumps to have the lowest life-cycle costs for PV array sizes of 1kWp and 2kWp and the same cost as fuel pumps for power ratings of 4kWp.[8] (The largest PV pump SELF has installed to date for village water supply is 1.9kWp)

- A study by GTZ (Posorski, Haars, 1995) in seven countries concluded that PV pumping systems for drinking water are economically competitive in the range of small diesel pumps (1-4 kWp solar systems).

New Economic Realities Favor PV

Since all of the studies cited above took place between 1994 and 2002, with the majority being in the 1990s, baseline pricing information for the both the cost of solar and the cost of diesel fuel have changed dramatically in favor of PV.

1. Fuel prices for generators

As examples, studies such as the World Bank[4] used a diesel fuel cost of $.19/litre and the Mexico pumping study[7] used a fuel cost of $.41/litre on the high side. Prices of diesel as of November2004 were as follows for several East African countries:[9]

1. Kenya: $.76/litre (up to $.81/litre 6/20/05 as per www.allafrica.com)
2. Ethiopia : $.42/litre (some countries have large fuel subsidies)
3. Tanzania: $.87/litre
4. Uganda: $.88/litre
5. Average of 47 African Countries: $.86/litre

> Recent G8 debt relief efforts could save sub-Saharan African Nations about $1 billion per year. However, International Energy Agency Chief Economist Fatih Birol states that the cost of increases in oil prices – about $10.5 billion per year, “is going to be greater than the debt relief given to sub-Saharan countries this year.” (from “Business Day” , Johannesburg, July 4, 2005)

2. PV module prices

PV modules prices have dropped dramatically over the last 12 years and should continue to do so. (Not withstanding the current price spike starting in October 2004 due to a world-wide surge in demand as well as competition with the micro-processor industry for pure silicon). The following table illustrates price reductions for 3 countries that are leaders in PV manufacturing:

TABLE 2.0 AVERAGE PV MODULE PRICE REDUCTIONS FROM 1992 - 2002[10]

Country	**Average Module Prices/W**	**Average PV System Prices**
Germany	-49% ($6.75 to $3.43)	-50%
Japan	-52% ($8.33 to $3.99)	Not available
United States	-24%* ($4.25 to $3.25)	-44%

* Note: Analysis starts with average module price of $4.25 Wp in 1992 which seems in error according to author's experience working in the U.S. PV industry during the 1990's. A more accurate number would be $6.00/Wp, which would put the percentage reduction more in line with those of Germany and Japan.

The lowest reported sale price in the U.S. during 2003 was $3/Wp. During 2002, SELF paid as little as $3.25/Wp for first-quality modules.

Cost reduction in PV modules is primarily due to huge increases in sales and production. From 1992 until 2003 worldwide annual production has risen from 50 mW to 670 mW.[10] Today, virtually all of the major PV manufacturers are building or have just finished new plants to try and meet demand while dozens of new manufacturers are entering the industry in India, China and even South Africa.

As supply again catches up with demand, and as total volume multiplies at a rapid rate and many more manufacturers compete in the market, especially new companies making lower-cost modules in China and India, PV module prices can again be expected to continue falling.

The other major components of PV systems, often referred to as "balance of system" or BOS (module mounts, batteries, fusing, charge controllers, etc.) have a more mixed pricing history, with some items that are PV-specific such as charge controllers and mounts, coming down in price over the last decade as scale increases and other items such as batteries and wire, belonging to much larger markets beyond PV, remaining stable.

One likely source of BOS price reduction is the prospect of local manufacture and/or assembly of components such as compact fluorescent (CFL) and LED lamps, charge controllers, mounts and even deep-cycle batteries. As large, national or regional programs scale up, it becomes possible to establish new industries in-country to meet demand. Kenya, with a reported 80,000 solar home systems being sold (powering 1% of the rural population)[11] represents the size market where locally made or assembled BOS components can potentially drive down the cost of systems while creating jobs and industry. There are reports of this happening in Kenya and around the globe (such as a Women's Cooperative making PV electronics in Bangladesh) but we have not yet seen documentation of impacts on local system pricing.

Intensive research and development efforts continue to focus on ways to make PV more efficient and less costly. Many approaches to an amorphous technology that uses less expensive silicon are being tried as is research into making PV cells from nano-technology. Energy storage is another area where research may pay off with lowered costs for PV systems.

At the same time that pricing is dropping for PV, fuel prices for generators are likely to continue increasing over the long term, making it highly likely that PV, cost-effective now for many village energy needs, will continue to compete well with diesel for even larger loads and more applications.

Comments on:
<u>"Energy Services for the Poor " paper for the Millennium Project Task Force 1</u>

Given the findings of the studies cited above combined with our own experience, we cannot help but question some of the information presented in Table 5 of the "Energy Services for the Poor " study. First, for the consumption level of 100kWh/year, the total five-year cost of $1,450 seems much too high for a SHS. The total load of 100 kWh breaks down to 274 Wh/day. When allowing for system inefficiencies and a slight over-rating of panel output, the design load is approximately 340Wh/day. The size PV module needed to supply that load will vary according to the insolation available but will be in the range of 60Wp to 80Wp. SELF has supplied systems of this range in the field (including the CFL lamps and shipping costs) for between $440 and $770. At developing country wages of $15/day, the amount spent on paid-for maintenance would not exceed $50 over 5 years. Equipment replacement costs would be typically be limited to changing CFL bulbs for a maximum cost of $20 (5 bulbs x $4). In a well regulated and maintained system, the deep-cycle battery should last for 5 years. However, assuming it doesn't, the replacement cost would not exceed $80. Totaling up the initial cost (using the smaller 60 watt system) with the O&M costs, we get approximately a 5-year cost of $590 or without battery replacement, $510 – far below the figure used in Table 5.

A five-year analysis gives a distinct bias to a mini-grid as opposed to a SHS in that the PV module, the most expensive piece of equipment, has a useful life of well over 20 years while a fossil-fuel genset likely needs a major rebuilding every 5 years or so. Also, fuel costs are now higher than the study assumption and very likely to continue going higher. One way to think about PV is that you are buying 20+ years worth of energy up-front, at a known cost. This is not quite accurate for battery-based systems since the recurring battery costs are significant, but the battery costs are largely predictable and the principle remains the same that a longer life-cycle analysis typically favors PV, especially when the cost of fossil fuels could be enormously higher in 10-20 years.

In the case of the annual 10kWh load, the $94 five-year cost of a portable battery seems low (is this a lantern cost – with light, or just the battery?). A reasonable assumption might be that it costs at least $1 per month to charge the battery ($60 total) and that the small battery would need to be replaced at least 2 times during 5 years. We would have to question the quality of a lantern that together with 2 battery replacements (let alone bulb replacement) costs only $34. A high-quality solar lantern would probably give better service for only slightly more cost, would eliminate the need to transport batteries, and would not rely on fossil fuels. (The Sollatek Glowstar solar lantern is available in quantity for only $80 and a deluxe version with a larger PV module and a 12 volt power supply for radios or mobile phones is available for $115).

We acknowledge the note accompanying Table 5 that states the figures used are estimates and are not intended for use in recommending technology but we also note that the conclusions drawn from the table are used on the same page to make a case that " The costing exercise presented above demonstrates that as soon as consumption levels grow to 100 kWh/year and beyond, the cost of RETs such as solar PV could become prohibitive." On the same page, it is also stated that "sunk costs would be lost if indeed the consumption were to grow to 100 kWh/year, outstripping the capacity of a typical PV home system. " In fact, many of the systems we install are in that annual production range and they provide users with a great deal of power in the context of a rural village – often for several lights, radio and even TV. These systems will likely satisfy people for many years and if the systems are owned by ESCOs (typically our suggested method) they are not "sunk costs" but can be taken away and used elsewhere if grid electrification happens or alternatively, PV modules can simply be added to the systems to increase service. We are concerned that use of Table 5 and conclusions derived from it may take PV systems out of consideration before enough is known about cost comparisons for a particular project. SELF welcomes the opportunity to dialog on this issue.

Reliability of PV Systems

Failures of PV systems in the development context have primarily resulted from the lack of an adequate maintenance infra-structure.

The average solar system needs very little care. PV systems for development applications have moved out of the development and testing stage and are ready for widespread application. After many years of experience, the design of systems is well understood and most solar equipment is designed to work well for many years under rugged conditions. PV modules last for 20+ years without maintenance, charge controllers and lamp-holders: 5-10 years; wiring, mounts, etc. have a longer unspecified life. All that is normally needed for the above items is an occasional cleaning, the replacement of a light bulb every 2-3 years and a checking and tightening of wire connections every year or so.

The prime maintenance need and the most common source of early system failure is the storage battery. It needs to be checked, cleaned and filled every 4 to 8 weeks. Clean distilled water needs to be available for topping off the batteries to the correct level. A properly functioning charge controller needs to regulate the charging and discharging of the battery. System users need to be trained on proper use of the system. If properly cared for, a deep-cycle battery will give good service from 4 to 8 years. If not, the system fails early and the battery needs to be replaced by either an expensive deep-cycle battery or a relatively inexpensive car battery, which itself will only last a few months.

Hard to kill Even in poorly designed projects or in a private market scenario where no maintenance is being provided the home owner, people usually find a way to keep the systems running. In Kenya, where most systems have been sold by private enterprise of unknown qualifications with few maintenance programs in place, surveys indicate that over 60% of the systems are working well[11]. Of the others, they may not have all lights working or may be using a used motorcycle battery, they may be bypassing inoperable fuses or charge controllers or in some other way be abusing the system, but they are finding a way to get use out of their investment. From what we've observed in the field in the very worst case where PV systems were installed and left without any provision for care, a majority of systems will still be giving some degree of service 10 years later. If you don't break it and you point it at the sun, a PV module will provide energy with a robustness that survives the worst neglect in a way unmatched by any other generating source.

PV water pumping systems are typically most efficient without batteries and are therefore the most reliable, cost effective and maintenance-free application. A good solar pump will run for 10 years or more with no maintenance whatsoever other than the occasionally cleaning of dirt off the modules. In the Nigerian State mentioned above that is littered with dead diesel pumps, a couple of the villages had been given solar pumps that were reported to be working very well for years with no problems. When visiting one of these villages, we asked the village elders when the pumping system was last serviced or repaired. After looking at each other for several moments, they admitted to having no memory of anyone working on the system after it was installed 6 or 7 years previously. This was probably accurate as the state water officials who installed the pump admitted to us that they had no budget to make any repairs in rural villages.

Proper PV system and battery maintenance is not difficult if the necessary financial, technical, and organizational systems are in place. In all SELF-designed projects the following sustainability measures are implemented:

1. **Organizational systems**
    - A responsible local partner is identified to be in charge of maintenance and re-supply. The partner may be a village co-op, a lighting committee, a women's group, an NGO, a utility or a private enterprise. (This is almost always a "full partner"- involved with the design and all other aspects of implementing the project)

    - The local partner must be experienced or trained in basic business management (bookkeeping, inventory control, etc.)

2. **Financial systems**
    - O&M fees are established and collected. An accurate calculation must be made of what it costs to materially sustain the systems (replacement bulbs, batteries, etc), the local partner's labor, administrative and overhead costs (and profit, if applicable), and a system must be devised to collect and manage the fees.

3. **Technical systems**
    - Local PV system installers are trained as part of the initial project installation. During the training and installation they learn about system components and how to put them together safely and properly.

    - Of the installers, some men and women from each village are trained to be "first-level" maintenance technicians to take care of basic system needs such as battery care, system cleaning, bulb and fuse changing and the collection of distilled water from solar stills. They live in the villages and are always available to service systems. Another important role of these technicians to help educate users on the proper operation of their systems.

- Another smaller group, usually with more technical education or electrical background, are trained to be higher-level technicians who can trouble-shoot and fix the occasional non-working system. This group also does periodic inspections of systems and supervises and re-trains the first-level technicians. They may or may not live in the project villages. They may be part of a regional organization that helps sustain PV systems in many villages.

- The local partner maintains an inventory of spare parts such as bulbs, fuses, controllers, etc. For the first 1-2 years, the spare parts are usually furnished from the original project budget until the fee collection system becomes fully functional, builds revenue, and is able to purchase spares from user fees. SELF assists the local partner in establishing buying relationships with suppliers of good equipment at the lowest possible prices.

SELF has found that follow-up is often needed to make sure these sustainability measures get "institutionalized" to the extent that they are working consistently and well. Often the local partner has no prior experience in some aspect of sustaining the project and multiple follow-up steps (evaluation, training, capacity building,) are necessary for 1-2 years after the completion of the installation. Ideally, solar electrification projects are large enough so that one highly developed and experienced local partner can in turn train other partners or branch offices within a large district, region or state.

With a good local partner, the above measures can be accomplished. They represent the same measures needed to sustain any village-based electrical generation scheme (diesel, or otherwise) where the community is responsible for maintaining their own systems.

Additional Advantages of PV Systems

In addition to cost and reliability advantages, PV has the advantages of being modular and of being able to be tightly focused on specific loads for maximum effect.

In our experience, PV (or any remote generating source) is most reliable when used in a distributed generation format as opposed to a central generating station. If a central station fails, be it PV or diesel, or if the town can't afford the diesel fuel, all applications are without electricity. If a distributed system such as a school or home fails, then only that specific system is without power. The added benefit of distributed generation is the cost savings of not having to string wires throughout the town – a practice which also adds insecurity to the system in terms of reliability (line problems and many more electrical connections exposed to the elements and subject to failure) and safety for villagers from fallen poles or wires.

The issue of empowerment needs to be considered as well. Village electrification is above all about empowering individuals to better their lives. It is more empowering to a school principal or a health clinic officer or a farmer or a woman working on crafts to have control over his or her own power supply than it is to be dependent on a central electrical supply authority. Many people in developing countries have seen their governments at all levels struggle and often fail to deliver basic services to poor communities. Rather than be dependent on Government or some central authority running a mini-grid, SELF has found that most people would rather take control over critical areas of their own lives. With PV systems, it is possible to have a great deal of individual and local control. It is also possible to have a great deal of local control over a community-based diesel mini-grid but there will always be a total dependence on the lifeblood of the system: the diesel fuel, which is subject to control by a great many forces outside of the community.

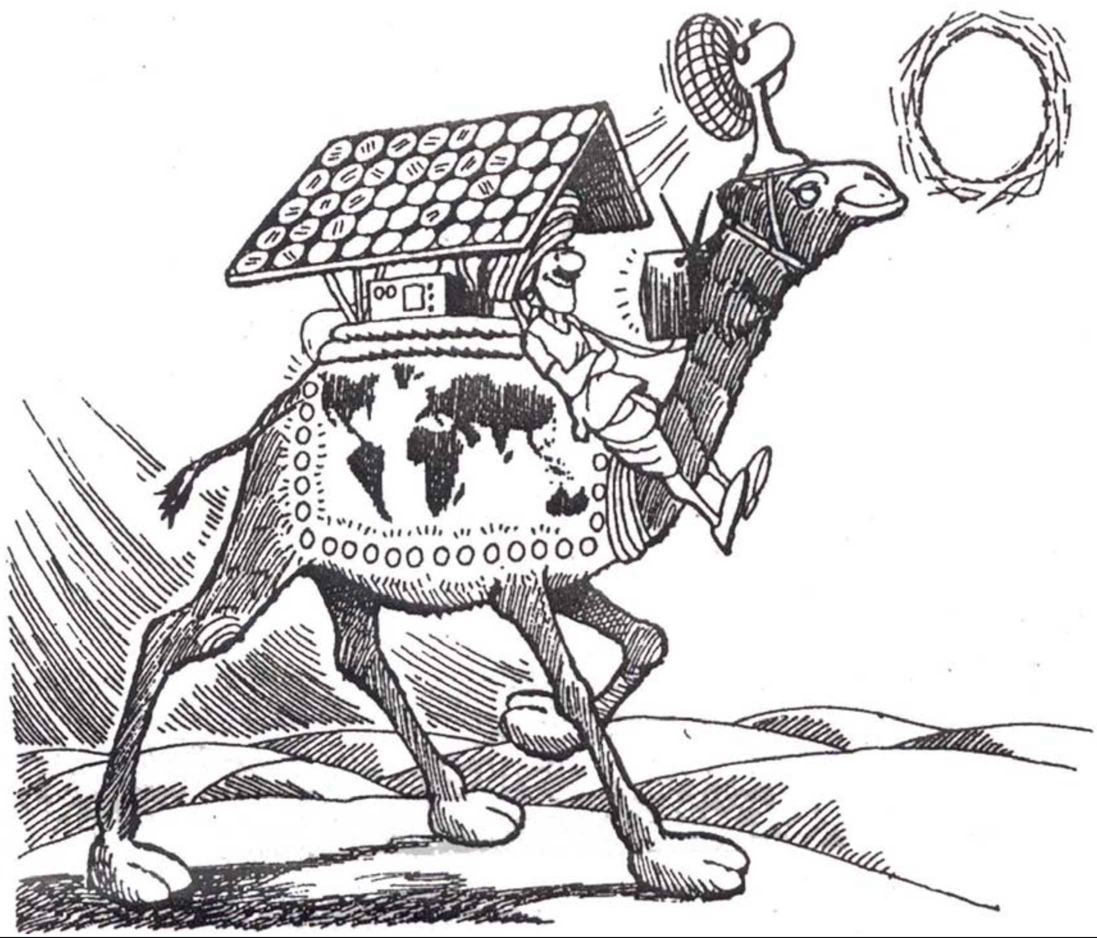
During the assessment and design phase of SELF's Nigeria project, we sat down many times with villagers and talk to them about their needs and get their ideas on how the electrification program might best be structured. When we broached the subject of sustainability, we talked about what it takes to maintain PV systems and explained that funds must come from somewhere to pay for the maintenance and resupply efforts for the community service systems such as water pumping, streetlights, school and clinic. We then asked if the people thought it would be better if the funds came from the Local Government (equivalent to a County government) or if the people should organize and pay for the O&M costs themselves? We were drowned out by the chorus of people shouting that they want to manage and pay for the systems themselves. Here and elsewhere, we have found that people want to be empowered to better their own lives and don't want to be dependent on others.

The modularity and small size of individual generating units (usually modules of 10Wp to 150Wp) allow a very tight and efficient focus of energy resources to specific tasks.

In the typical development scenario where there are many needs and few resources, energy resources need to be targeted to address the most critical needs of the community at its current state of development instead of trying to reach every home and business with the relatively unlimited but extremely expensive energy potential of the grid. Over-electrifying at an early state wastes precious resources that are more appropriately used for more critical needs.

Small, affordable PV systems can be spread around the community to reliably address targeted needs in health, water supply, education, income development, and security as well as the commercial and educational needs of households. As end-users fully utilize their systems' energy potential and come up with new energy needs, they can incrementally add new generating capacity to their systems simply by adding PV modules. For example, a health clinic that adds electrical lab equipment can add 2 more modules to their existing system in a much more efficient and economical way than replacing a smaller generator with a bigger one or by initially over-sizing a generator and running it at great inefficiency until load catches up with generation.

Incremental electrification using PV allows electrification to expand to meet demand and affordability rather than demand and affordability lagging behind the large investment made in a central electrical supply system.



(This amusing cartoon illustrates the flexibility of PV technology, but PV-powered vaccine refrigerators have actually been mounted on camels to deliver vaccines to remote areas in the Sahara).

<u>Real PV Costs from the Field: SELF's Experience</u>

The following chart illustrates some typical total equipment costs of recently installed systems on SELF projects in Asia and Africa. The PV module-only price for the Nigeria project was $3.26 Wp. The compact fluorescent lamps (CFL) used in all but the pumping systems are included in the prices below.

NIGERIA 3-VILLAGE PV ELECTRIFICATION PROJECT (2003-2004)

Total Installed PV: 18kWp

System Type	Service Provided	PV Wp	System Cost*	$/Wp	Notes
Streetlight	13w CFL lamp for 12 hours/nigh	50	$550	$11.00	
Clinic	(3) 11w CFL, fan, vaccine refridg	160	$1,368	$8.55	w/o refridge
School	(22) 11w CFL lamps, computers	320	$4,150	$12.97	(1)
Home system 1	(3) 9w CFL lamps	50	$590	$11.80	
Home system 2	(5) 9w CFL lamps	80	$773	$9.66	
Irrigation pump	3,200 gallons/day	256	$1,651	$6.45	w/o pump
Bore hole pump	3,400 gallons/day	1920	$9,400	$4.90	w/o pump(2)
Micro-ent. Cntr	Provides 6kWh/day	1600	$14,465	$9.04	(3)

BHUTAN SOLAR HOME PROJECT (2004)

System Type	Service Provided	PV Wp	System Cost*	$/Wp	Notes
Home system 1	(4) 7w CFL lamps	37	$247	$6.68	
Home system 2	(6) 7w CFL lamps	60	$440	$7.33	

* System costs include imported equipment, shipping and local materials

Notes:

1. Two classrooms were illuminated in addition to 2 administration rooms and inverters and AC powerpoints were provided for compters, TV/VCR, etc. Actually consists of 2 sub-systems in case classrooms in different parts of the school, causing high BOS and system costs.
2. Does not include cost of drilling and installing bore hole.
3. Provides space and power for 6 small businesses: tailors, barbers, radio repair, etc.

The SELF Model for Village Electrification

Over the last 15 years, SELF's mission has evolved from almost exclusively promoting solar home systems (SHS) to predominately focusing on productive end-uses such as micro-enterprise and agriculture as well as satisfying critical community needs for energy in the sectors of health, education and water supply. Through its own experience and that of others, SELF has developed an integrated PV-based energy development model for villages that applies focused amounts of energy where it will catalyze the most effective development in the quickest and most sustainable way. It is a multi-sectored approach that recognizes the synergies of simultaneous improvements in health, education, water supply, communications and commerce. In order to ensure that the delivered power is put to the most immediate and effective use, targeted applications hardware such as vaccine refrigerators, computers, lights, water pumps and small appliances for micro-enterprise are often included as part of the project. Full sustainability measures are designed with the community to make sure the PV systems have a long and productive life.

The concept has first been used in 3 villages with a total population of 9,000 in Jigawa State, Northern Nigeria. While hard evaluation data is not yet available, the project is considered successful enough and has been so well received that the government of Jigawa State is planning for 30 more villages. SELF is also planning similar projects in Senegal, in the Delta Region of Nigeria and for a District-wide project in Benin.

Villages have different needs that must be determined by a participatory process. There is no "one-size-fits-all" solution. However, there seems to be a pattern of energy needs in underdeveloped villages around the globe that can often be met by the following system types.

1. **Village Water Pumps** Adequate supply of clean water is usually among the most critical needs of a community. PV systems can supply water from either a submersible pump in a bore hole or from surface water at the following typical rates:

   - Submersible pump: 9,000 – 10,000 gpd $14,000*
   - Submersible pump: 4,800 gallons/day $ 7,000*
   - Surface pump: 3,200 gallons/day $ 3,385

   * Additional cost of drilling and installing well: $4,000-$10,000
   Smaller pumps are available. Total lift in well example: 124'

Manual pumps can work well and are a good option for water depths of 50m or less. Solar pumps typically have a greater flow rate and can serve deeper wells. With more capacity, solar pumps can serve more than one tap and therefore reduce the amount of time spent getting water.

2. **Village Clinics** Typically the needs here are lights and possibly a vaccine refrigerator. Fans are sometimes required as is power for other medical and/or communications equipment in larger health centers. Power for a TV/VCR for AIDS, malaria and other health education programs can be added for little additional cost. A small PV system and a WHO-approved super efficient refrigerator-freezer with lighting package is an economical and reliable high-impact application.

   - 3 lights, vaccine refrigerator, fan. $3,072*
   - Above package with power for TV/VCR $3,700**

   * Includes Sunfrost refrigerator
   ** Cost of TV/VCR not included

3. **Village Schools** School needs can vary tremendously according to enrollment, ages served, capacity of the teachers, etc. In general, lighting 2 or more classrooms can serve the community for adult education, night-time education for children where there are not enough teachers during the day, community meetings, and as places for students to work on their lessons at night. Providing alternating current (AC) for plugging in standard appliances allows the use of audio-visual equipment and the use of computers – an important step in bridging the digital divide. A basic school system that provides lights to 2 classrooms as well as to 2 offices along with AC

power energizes a multi-functional facility that can benefit dozens of adults and children at a reasonable cost.

- 21 lights, 450 Wh/day AC load, 320Wp PV $3,653

4. **Streetlights** At first glance, street lighting might seem to be a low-priority need and in some places it undoubtedly is. However, our experience in Northern Nigeria showed that after water pumping, streetlights were among the most valued PV applications developed in the villages. In some places security is a major concern and in many hot climates people come out in the cool of the night to socialize and to do business. We have observed new businesses being created under the bright and cheerful solar street lights and have ourselves participated in many meetings that took place at what have become natural gathering places under the lights. We believe the streetlights were highly valued because like water pumps, nearly everyone benefited from them. A few strategically placed lights can light up village water taps, meeting places and markets as well as major street intersections and specific areas that need security lighting.

   - 13 Watt CFL light, 100Ah battery, 50Wp PV for 12-hours per night. $550

5. **Micro-enterprise Centers** The PV-powered micro-enterprise center (or multi-function platform) is a central PV system of 1-5 kWp that serves several small businesses grouped together in one general location that may be a single building or a cluster of small shops. Because not all businesses need full power at the same time, a smaller, more affordable PV system is shared than what would have been needed for individual systems for each business. There is also an economy achieved by a larger system over individual systems. In our experience, a PV micro-enterprise center allows existing businesses such as tailors, radio repairers and barbers to increase production by upgrading from manual to electric appliances. But perhaps most exciting is the ability to create new enterprise that was not possible before electrification. We have seen video theaters, cell-phone businesses and internet cafes sprout up as the result of PV micro-enterprise centers being established. A women's group in Nigeria is experimenting with an electric oil press to replace the arduous and time-consuming method of making ground nut oil by hand.

   Until recently, we have had difficulty providing economical PV systems for applications calling for motors of 1 hp or larger. However, we are learning of the development of extremely efficient machinery such as grain mills and drill presses should make PV micro-enterprise centers even more versatile and valuable for increasing community income. Development continues on creating a PV equivalent of the Diesel-powered Multi-functional platforms as used in Mali. Unfortunately, we are getting reports that many of the Mali systems are becoming inoperable due to breakdowns of the diesel engines and prohibitively expensive fuel.[12] PV power systems have the potential to make this type of system more sustainable.

Previously, we've talked about the greater overall reliability of distributed systems versus central systems. To design maximum reliability into a micro-enterprise center - a central system of sorts, we design redundancy into the critical electronics such as charge controllers and inverters by using two or three smaller units where we could have gotten by with one larger unit. The result, achieved with less than a 2% cost increase, is that the failure of any single piece (or even multiple pieces)of equipment will not shut down the center. And as the failure of an entire PV array or the complete failure of a battery bank in a large PV system is virtually impossible due to their modular nature (having many individual modules and batteries), the PV system has an extremely high level of reliability – especially when compared to motor-driven generators.

An initial PV micro-enterprise center might serve 6-10 small businesses and have the following specifications and cost. Due to the modularity of PV, the center can be easily expanded to meet demand.

- Load: 6 kWh/day, PV: 1.6k/wp $14,465

6. **<u>Home Lighting Systems</u>** In terms of productive end-use, electrifying individual homes is desirable for at least two applications: to aid education for both children and adults and to support home-based economic activity. Including a voltage adapter and/or dry-cell battery charger can also save families the considerable cost of expensive throw-away dry-cells used for radios and torches.

There are many strategies for electrifying homes, each with advantages and disadvantages and again, there is no best solution for all. Some options to consider beyond mini-grids include:

- Car batteries charged at central charging station. Advantage is moderate first cost as the PV system cost is usually shared by more households. Disadvantages include limited power available, high risk of battery damage during transport, short battery life, danger in transport from acid spills and from accidental short-circuiting of the battery.

- Modified battery charging stations. We note the proposed battery charging scheme for Sauri, Kenya. Without knowing more details, our questions are 1) What is the charging source? 2). What are the costs for the lamps and for charging? 3). What is the life (number of charge/discharge cycles for the battery? 4). What is the quality of the light? (lumens, lamp type, wattage) 5). How many lamps per household? The overall concern here is that this solution might offer very limited service and uses small sealed batteries that typically do not last very long with constant use. This scheme may be similar to a solar-lantern program where the batteries are charged at home with small PV panels designed to recharge the lanterns. The costs and benefits of these 2 schemes need to be examined for over-all service and cost-effectiveness.

- Solar Home Systems. Individual solar home systems are an option delivering the most service with the greatest sustainability. However SELF acknowledges that there is a significant first-cost barrier that prevents many families from being able to out-right purchase these systems (most systems sold privately in Kenya are quite small and are therefore limited in service, and sometimes in quality). To over come the first cost barrier, there are some models that are worth considering:

  A. **Energy Service Company** (ESCO). In an ESCO format, the company (or Co-op) provides PV systems to interested families, maintains ownership of systems, and charges a monthly fee for the service – which is usually about the same that families would pay for kerosene. The monthly fee covers O&M costs (included in the service), ESCO operating costs and a small profit. The advantages are affordability to households, and the ability of ESCO to repossess the system as leverage for ensuring monthly payments. The challenge is that someone still has to pay for the initial capital cost of the PV systems. If the money to do so comes from aid and/or government, then it has to be asked if buying home systems are the highest priority for an electrification program with limited resources or if it should be done on full or partial cost-recovery basis.

  B. **Revolving capital funds** One way to enable wide-spread electrification using solar home systems without buying a system for everyone is to set up an ESCO with enough seed capital to purchase and distribute a viable amount of systems. As the monthly payments accumulate, a portion is used to buy and install more systems. Meanwhile, the ESCO is selling PV systems outright to those who can afford them. Eventually, through these two mechanisms and through micro-financing, many homes are able to be electrified, largely through private enterprise mechanisms.

  C. **Microfinance** A micro-finance scheme with low down payments and monthly payments similar to the cost of kerosene is another way to make more systems available to families. With the long life of PV modules, it is possible to finance a system over many years, allowing reasonable payments. The ideal would be to expand existing micro-finance networks to include PV systems in their portfolios.

  D. **Emerging Technology** SELF recently completed a project in Tanzania that utilizes light-emitting diode (LED) lamps that are extremely efficient and long-lasting and that allow for smaller, cheaper PV arrays and batteries that require little or no maintenance. To date, the cost of LED lamps themselves is preventing a drastic cost reduction in total system price but there is great promise for these systems if the lamps could achieve cost reduction through local manufacture. However, in some cases now, especially where adequate maintenance might be a problem, LED systems should be considered. A 2-lamp LED system offering 5 hours of service per night per lamp would cost about $330 compared to a 4-light, 9-watt CFL system costing about $250. However, the O&M costs and battery replacement costs would be much lower for the LED system in a life-cycle comparison.

A major lesson concerning SHS that SELF has learned while working globally over 15 years is that more people are willing and able to pay for these systems than statistics might indicate. Time and again, we've been told that families can't afford these systems and have then gone into villages to find a tremendous willingness to pay for them. In one Nigerian village considered to be extremely poor, we had only 20 SHS systems to distribute by lottery for demonstration purposes. The financial requirement made of applicants was a willingness and ability to pay the equivalent of $5 /month for O&M/replacement costs. We had dozens of applications and our Nigerian partners were deluged with people knocking on our doors at night with sacks full of money, offering to pay their fees a year in advance if only they could be considered for a system.

It is often assumed that people will at least be willing and able to pay the equivalent of what they are spending on kerosene for lighting. In our experience, many are actually willing to pay more because they recognize the value of better lighting without the fumes and they quickly perceive the potential of better light for increased home-based income generation, school work, and an overall benefit to their quality of life.

A combination of cash purchase, micro-financing and fee-for-service options can be used to reach the full strata of the community ranging from the very poor to the wealthy. The wealthy would be able to simply purchase a system. Families with fewer resources can purchase through micro-finance and poorer families can eventually get use of a system through the revolving fund at a lower fee-for-service rate.

SELF recommends a solar home electrification program that combines the benefits of micro-financing, revolving capital fund and an Energy Service Company/Co-Op organizational format as a way to begin a financially sustainable method of serving village families with the benefits of electricity.

7. **PV systems to support Agriculture** PV systems can help increase food production through irrigation pumping and by powering food production processes (grinding, milling, etc.).

   SELF is particularly interested in combining solar water pumping with drip and other micro-irrigation technologies to grow foods during normally dry seasons and is currently working with irrigation experts to develop a pilot project based on these technologies in Benin. A large variety of solar pumping configurations are possible to meet the specific needs of a community, ranging from surface to submersible pumping with flow rates of a few hundred to thousands of gallons per day and at costs of less than $2,000 to over $10,000.

As previously mentioned, new efficient DC motors and appliances are making more food processing applications cost effective for using PV systems.

8. <u>Other Applications</u> The above list is certainly not exhaustive. Depending on the individual needs of communities, other applications such as communications and water purification may need economical and reliable power sources. Essentially any application that does not involve large motors or large amounts of heating or cooling is feasible with PV technology.

A Typical Village PV Energy System Package

The following chart shows a possible energy package designed to meet the critical energy needs of a community. (Costs given are for PV generating systems and CFL lamps only – no pumps, refrigerators, TVs, etc included)

1. Water pumping – bore hole. 9,000gpd. For drinking or agriculture:	$9,400
2. Water pumping – surface pump. 3,200gpd. For drinking or agriculture	$1,651
3. School lighting and AC system.(21 lights as described above)	$3,652
4. Clinic. Power for lights, fans, vaccine refrigerator and TV/VCR	$1,968
5. Micro-enterprise Center. 6-8 businesses, PV: 1600Wp,	$14,465
6. Streetlights – 10 lights.	$5,500
Total:	**$36,636**

Total installed PV watts: 4,116

Cost per watt, average for all systems: $8.90

Cost per person if 5,000 population: $7.32

The above list is representative and will not meet the requirements of all villages; some systems will need to be deleted, some added, some expanded in size or in other ways modified. The costs given are system costs and not project costs. Factors determining costs will vary according to location. The list does however give a baseline look at the enormous potential that PV systems have to target very specific critical energy needs.

Conclusion

The commissioned paper for the Millennium Project Task Force, "Energy Services for the Poor" eloquently lays out the compelling case that modern energy services are an essential prerequisite for enabling countries to meet Millennium Development Goals of reducing poverty, illiteracy, hunger, disease, environmental degradation and gender discrimination. Baseline community energy needs for clinics, schools, water supply, agriculture, private enterprise and security need to be met by basic, sustainable, effective energy sources that are high impact, affordable, flexible and scalable.

While there is no perfect energy source for all applications in all locations, photovoltaic-based systems meet the energy source requirements listed above and can play a significant role in Millennium Project villages.

1. **PV is cost-effective**

   PV systems are cost-competitive on a life-cycle basis against fossil fuel generators (gas or diesel) used in either a stand-alone or a mini-grid modality for small and moderate loads. Long term decreases in PV system costs together with increased costs for fossil fuels indicate that PV will continue to become more competitive for more applications and larger loads. The energy costs for a PV system going forward are essentially known at the time of purchase, whereas the future energy costs of a generator-based system are unknown, at the mercy of global forces and instability and are most likely to rise substantially. The cost of using fossil-fuel generators also needs to include an environmental cost (see below).

2. **PV is reliable**

   Both generator-based and PV systems require maintenance to stay fully operational. However, there are significant differences in the overall robustness, or "survival potential" of the two technologies. In an ideal world where there is an adequate maintenance program, enough trained personnel and spare parts, and an organization with the finances, capacity and staying power to keep them all going, both technologies could be equally reliable (providing the generators can get the fuel). While we all do everything we can to incorporate successful maintenance programs into a project, we also know that in remote, impoverished areas literally at the end of the line for transportation, communications, and resources, that it is extremely challenging to maintain all of these elements, all of the time, for a long time. The energy source used in these locations therefore needs to be as inherently reliable and autonomous as possible. In this respect, PV has some distinct advantages:

   - **Low-tech maintenance** In general, PV systems are maintained simply and inexpensively. It is easier, cheaper and quicker to train a village solar technician (and to keep several of them around) than it is to train and employ diesel mechanics and electricians to maintain a diesel mini-grid. If all spare parts are in stock (much easier for PV), the down-time for a worst-case PV repair (changing out a piece of equipment) might be an hour. The worst case down time for a diesel might be several days or longer for a rebuild.

   - **PV is better suited for distributed generation** To save the significant cost of distribution and to avert the possibility of a central plant failure shutting down all applications, distributed generation using PV is a recommended solution. Diesel or gas generators for small distributed applications are neither economical nor practical.

- **PV has a better survival potentia**l In the case of inadequate maintenance or resupply, PV systems have a greater potential of surviving than do diesel generators. As mentioned previously, PV systems that have gotten little or no care still work for many years. The most vulnerable part of a PV system- the battery- can usually be replaced locally, if needed.

- **PV systems are not dependent on outside fuel sources** Fuel for generators is now and may be increasingly difficult to get – especially at the ends of the supply chain. (We note that in Nigeria, the most populous nation in Africa and one of the world's top 10 oil producing nations, fuel is expensive and often hard to get and there is frequent civil unrest to protest these conditions).

  When comparing system costs, the reliability of the systems needs to be considered. There is a significant productive loss when applications that are dependant on electricity (vaccine refrigerators, crop irrigation, businesses, etc.) can't get it due to the generating source not working. An energy option that may have a lower initial cost might not only be more costly in the long run but can also be very damaging to the community if doesn't continue to run.

3. **PV is flexible and scalable** Due to its modularity, PV is flexible and easily scaled to focus precise amounts of energy at very specific tasks for maximum efficiency. PV modules and batteries are effectively "building blocks"" that can be assembled and reassembled in varying combinations to meet changing needs –especially when they are under the ownership and control of an ESCO-type organization.

4. **PV is a clean, non-polluting technology** When developing models to lift the worlds most disenfranchised out of poverty, it will be counterproductive to make progress on these goals while at the same time damaging an already stressed environment. The electrification of 1.7 billion people cannot happen with diesel generators or even with many of the cleaner fossil fuel technologies without disastrous consequences nor can it be sustained for more than a few decades. Environmental damage caused by the unnecessary large scale electrification with fossil fuels would be a deferred but real cost in the form of health problems, dislocation, loss of arable land, flooding and the many other maladies caused by climate change, and polluted air, land and water.

With the concept of using diesel powered mini-grids as a transitional strategy while waiting for cleaner or better solutions, comes the danger that once established and entrenched, this technology will be difficult to replace. In that case, developing countries will be in the same situation we in the most developed countries find ourselves in: burdening the earth's environment by using enormous amounts of fossil fuels because it was the easiest and cheapest solution in the short-term. In the meantime, it may be decades before many countries can afford large-scale grid expansions and cleaner fossil fuel-based technologies may also be more expensive and complex or in other ways inappropriate for use in undeveloped rural areas of the globe. We now have an opportunity to encourage a more far-sighted approach by using renewables that provide the service without the environmental liabilities we can ill afford.

When considering all the issues, cost remains important, but it is only one factor along with reliability, sustainability, effectiveness and environmental concerns. PV compares well against all other options in all of these areas.

SELF understands and is very experienced with PV technology, sustainability design and project management and welcomes the opportunity for dialog with the Earth Institute to explore how PV technology can help the Millennium Project Group meet its energy goals of empowering people to improve their lives in a clean, sustainable manner.

Footnotes

[1] Kolhe M., Kolhe S., Joshi J.C. “Economic viability of stand-alone photovoltaic systems in comparison with diesel-powered systems for India.” *Energy Economics*, 24:155-165.

[2] Liebenthal A., Mathur S., Wade H., “Solar Energy: Lessons Learned from the Pacific Island Experience” The World Bank, Technical paper number244, May 1994, Washington D.C. USA

[3] Hemet B., van and Loois G. (editors) IEA “Lessons Learned Book”, 1999

[4] “Best Practices for Photovoltaic Household Electrification Programs: Lessons Learned from Selected Countries.” World Bank technical paper number 324. 1996

[5] Kailasanathan A., and Seeling-Hochmuth G., University of Cape Town “Results of Performance and Financial Simulations on Hybrid Power Systems Around South Africa”.

[6] Allderdice A., and Rogers J.H., “Renewable Energy for Micro-Enterprise,” NREL, 2002

[7] Foster R., Cisneros G., New Mexico State University and Hanley C., Sandia National Laboratory, “Life Cycle Cost Analysis for Photovoltaic Water Pumping Systems in Mexico,” as presented at the 2nd World Conference on Photovoltaic Solar Energy Conversion, 6-10 July, 1998, Vienna, Austria.

[8] Bucher W., “Renewable Energies in Rural Areas.” German Aerospace Research Establishment.

[9] “International Fuel Prices 2005 – 4th Addition Data Preview.” Provided by GTZ (German Technical Cooperation) at website: www.zietlow.com.

[10] International Energy Agency “Trends in Photovoltaic Applications. Survey Report of Selected IEA Countries Between 1992 and 2003.” Report IEA-PVPS T1-13:2004

[11] Kammen, Daniel M., University of California, Berkeley. “ Chapter 16, Case Study 5. Methodological and Technological issues in Technology Transfer.” Report for the Intergovernmental Panel on Climate Change. (UNDP, WMO)

[12] Personal conversations with the Honorable Konimba Dembele, Member of Parliament, Mali, and CEO of Emicon.