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POWERING HEALTH
OPTIONS FOR IMPROVING ENERGY SERVICES AT HEALTH FACILITIES IN ZAMBIA

JULY 28, 2009

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CONTENTS

TABLES

ACKNOWLEDGEMENTS

The assessment team would like to express its appreciation to all individuals who contributed to the findings in this report. The insights and support of the Zambia PEPFAR team, including Rachanee Cheingsong, Alison Taylor, Herbert Hamachila, Clement Ndongmo and Mutale Dailes Nsofwa were invaluable. The time and support of the Zambia Ministry of Health and all individuals interviewed for this assessment were greatly appreciated.   The logistics for the assessment were seamless thanks to the hard work of Alison Taylor and the entire USG team.

EXECUTIVE SUMMARY

The acquisition of reliable and affordable power poses a challenge to many health facilities in developing countries. This is the case in Zambia where the PEPFAR (President's Emergency Plan for AIDS Relief) program requested USAID assistance in assessing options for improving energy services at health facilities.

With support from the USAID's Bureau for Economic Growth Agriculture and Trade, Office of Infrastructure and Engineering/Energy Team in Washington, DC, and CDC-Zambia, a team of energy specialists visited Zambia, interviewed stakeholders in the health and energy sectors, and visited a representative sample of seventeen health facilities to assess their energy supply conditions. This report presents the results of this assessment along with recommendations for improving energy service at these facilities. The Team investigated options for improving the energy reliability and quality at both on and off-grid-connected facilities. A technology neutral approach was taken for all analysis in the report, although special consideration is given to the applicability of renewable energy because of local stakeholder interest.

The quality of grid power in Zambia is currently quite reliable as compared to many developing countries. Most health facilities visited during the assessment that had access to grid power have only periodic power outages on a weekly basis, and occasional longer outages as a result of distribution equipment failure. Power anomalies, such as low voltage, were reported by some facilities. The assessment team did not have a chance to visit the Western Province where it was reported that the grid power was of poorer quality.

Access to the grid, however, remains limited in several rural areas of Zambia. Health facilities located in these areas must either do without electricity or rely on distributed generation systems (generators, solar panels, etc.) to produce power. In general, the success of these distributed energy systems at health facilities in Zambia was limited as a result of improper design, installation, operations, and maintenance.

Both the power quality and lack of access to electricity have a direct impact on PEPFAR programs. As PEPFAR Zambia continues to expand services to a wide network of heath centers across the country the lack of energy services at these facilities limits the types of services that can be provided. Lighting, minimal laboratory equipment, computers, communication devices, and cold storage are all essential tools for providing basic levels of medical care and all require power. In addition, availability of power was cited repeatedly in Zambia as being a key condition for attracting and retaining medical staff to rural health facilities. The quality of power at grid connected facilities limits laboratory operating hours and can damage expensive laboratory equipment or compromise test results. Prolonged outages complicate storage of cold chain dependent supplies and blood, although these seemed to be isolated incidents in the facilities visited during this assessment.

PEPFAR/Zambia and their implementing partners have taken steps to mitigate the effect of power shortages including the purchase of generators for health facilities, procurement of solar

PV systems for health facilities and staff housing, and initiating a pro-active assessment of the overall infrastructure needs (including energy) of an improved supply chain system. These efforts, combined with this energy assessment, are important first steps to minimize the impact of energy shortages on PEPFAR programming. Unlike some other PEPFAR focus countries where addressing energy issues is a pre-requisite to achieving PEPFAR objectives, in Zambia it is one of many challenges which should be considered, evaluated, and addressed as required. The following specific recommendations should be considered moving forward:

1) PEPFAR partners should make a review of supporting infrastructure (energy, water, physical facilities, etc) an explicit component of any project which involves adding new space or additional loads (e.g. laboratory equipment) to a health facility. Some partners have engineers on staff and appear to be effectively conducting such reviews, for others it was not clear that such a procedure was in place.

2) In general, PEPFAR partners are experts in Health related issues and they undertake infrastructure related projects out of necessity. PEPFAR/Zambia should consider if a contract to a firm that specializes in infrastructure issues is warranted to support and/or review all relevant PEPFAR funded infrastructure activities.

3) All energy systems (generators, solar systems, etc) should be provided to a health facility with a clear understanding of who will be responsible for the operations and maintenance of the equipment. If local hospital staff are not sufficiently skilled to operate the equipment than the proper training program should be supported. If the health facility does not have sufficient funds to operate and maintain the system than these funds must either be provided or the system should not be purchased. As a default, it can be assumed that rural health clinics require support to obtain the knowledge and funds required to keep energy systems operational.

4) PEPFAR could make a significant contribution to improving energy services at health facilities in the country without a huge funding commitment. Immediate targets of opportunity involve providing technical assistance to the Ministry of Health on energy issues (standards, staffing and training, donor coordination, etc) and improving energy services in rural health facilities through equipment refurbishing and staff training. Much of the required hardware required for rural health facility energy systems is already in place and could be brought back to life with a small investment in replacement parts and associated training of local technicians.

ABBREVIATIONS AND ACRONYMS

AVR: Automatic Voltage Regulator: Equipment placed between the power supply to the facility and the voltage-sensitive loads to provide conditioned electricity to the loads, at the appropriate voltage. An AVR can only operate successfully within a given range of input voltage from the utility.

ARV: Antiretroviral

COE: Cost of Energy: Usually presented as a Net Present Cost (NPC) of energy factored over 20 years. This includes all of the equipment and on-going maintenance for the system that will be expected in this time frame, and assumes a given cost of financing.

ZESCO: The national utility company in Zambia

kVA: Kilovolt-Amps: Equipment capacity ratings, (in power terms) are rated in kVA.

IPP: Independent Power Producers: Can be either quasi-grid entrepreneurs selling un-metered power, or – more generally – formal power producers under a written agreement with the utility company to provide electricity of a given quality and a specified price.

MOH: Ministry of Health

PEPFAR: United States Government President's Emergency Plan for AIDS Relief

UPS: Uninterruptible Power Supply: Equipment inserted between the normal power supply and the load that has sufficient battery capacity to allow the load to operate for a specified amount of time after the normal power supply disconnects. This time is used to either power up a generator, or to shut down equipment if no generator is available.

W: Watts: A unit of power – either consumed or produced

Wh: Watt-Hour: one watt being consumed (or produced) for one hour.

kWh: Kilowatt-Hour: 1000 Watt-hours

Wp: Watts-peak: The nominal size of a solar array based on the laboratory optimal rating of the panel. An array of 100 – 100 watt panels, would constitute a 10,000 watts-peak solar array.

1 ASSESSMENT PURPOSE AND METHODOLOGY

This assessment was conducted at the request of the United States Government President's Emergency Plan for AIDS Relief (PEPFAR) program in Zambia and was supported by the USAID Office of Infrastructure and Engineering - Energy Team and CDC-Zambia. The purpose of the assessment was to investigate options to improve energy services to critical health facilities in Zambia. Specifically, the team was asked to investigate the following key issues:

- Characterize the direct impact that poor quality power and lack of access to power has on PEPFAR programming and other health sector programs;
- Review the efficacy of PEPFAR Zambia's Partners current approach to improve energy services at health facilities;
- Assess options for improving the facility wide power supply at several different types of health facilities

The report is technology neutral and focuses on cost effective and practical solutions to health facilities energy challenges.

The evaluation was conducted over a two-week period by a team comprised of Jeffrey Haeni, Rural and Renewable Energy Specialist, USAID Office of Infrastructure and Engineering/Energy Team, Walt Ratterman, Chief Project Officer and Director, SunEnergy Power and consultant to Institute of International Education, and Herbert Hamachila, dispatcher, CDC Zambia. Mr Tsibu Bbuku, a biomedical engineer with the Ministry of Health, and Fales Mwamba, laboratory specialist from the Ministry of Health, accompanied the team on the site visits in the Eastern and Copperbelt Provinces, respectively. Clement Ndongmo, Mutale Dailes Nsofwa, and Justine Chipalla, CDC-Haiti Laboratory infrastructure team, joined the assessment team for the field visits to the Eastern, Southern, and Copperbelt province, respectively. During the course of the assessment, the team visited over seventeen health facilities in three provinces as detailed in Appendix 1.

The site visits were strategically chosen to provide an illustrative cross section of health facilities in terms of their ownership (public vs. private), the level and nature of services provided, and in terms of their current energy supply. The full gamut of facilities was visited– from small rural clinics with no grid supplied electricity to large grid connected general hospitals.
The quality of grid power and specific energy challenges found at each facility varied greatly across the country. Even within the same city local variations in the quality of the energy distribution hardware often resulted in vastly different energy supplies at different facilities.

Thus, although some generalizations can be made concerning the problems and solutions for different types of health facilities, each facility must be analyzed individually by a trained technician before any site-specific solutions are implemented. Thus, this report is intended to provide a general guide to the types of interventions which could improve the energy services at a variety of health facilities in Zambia.

2 ZAMBIA PEPFAR PROGRAM OVERVIEW

The PEPFAR program in Zambia invested $269 million in FY 2008 in its efforts to address HIV/AIDS. The Zambia PEPFAR program has contributed to dramatic improvements to laboratory capacity, commodity and procurement systems, and health records management highlighting the program's commitment to health systems strengthening and linkages with development as an integral focus of it adequately respond to HIV.[1] Each of these efforts depends strongly on the quality of health facility infrastructure including access to energy, water, or modern structures. Although the PEPFAR/Zambia program does not have an explicit program to improve health facility infrastructure and energy systems, some of this work is being completed by implementing partners in their efforts to support individual health facilities.

2.1 IMPACT OF POOR ENERGY SERVICES ON PEPFAR PROGRAM

Poor quality and unreliable power affect many aspects of a health facilities operation. Poor quality power is defined by persistent power "spikes" and voltage anomalies that are damaging to a wide range of health facility equipment including air- conditioners, x-ray machines, lights, dental chairs and laboratory equipment. Power anomalies compromise the integrity of the results from some of the more complex electronic laboratory equipment. Low voltage power also increases the power consumption of some energy intensive devices such as refrigerators.[2] The lack of reliable power complicates nearly every aspect of hospital operations. Back-up diesel generators are an expensive way to generate electricity and fuel expenditures can cause stress on a hospital's operating budget. Power disruptions also complicate the cold storage of blood, rapid test kits, reagents, and vaccines and if no back-up power supply is available can halt the work of the hospitals laboratories, operating rooms, and other critical functions during power outages.

Each of these challenges is magnified even further for facilities with no connection to the national grid. Lack of access to power limits the reach of several PEPFAR initiatives (e.g. SMARTCARE program) and can serve as a primary barrier to attracting and retaining medical staff in rural areas of Zambia.

3 ENERGY SECTOR OVERVIEW

Solving the critical power problems of key health facilities in Zambia cannot be achieved in the absence of systematic improvements in the power sector. The quality of care that can be provided by the large grid-connected health facilities is directly related to the quality of power they receive from the grid. Thus, while power sector reform and investment lie beyond the manageable scope of the PEPFAR program, it is important to understand the fundamental problems facing the sector and the key players addressing the problems before deciding on site-specific investments.

3.1 ENERGY SECTOR CHALLENGES

The Energy Sector in Zambia is dominated by the vertically integrated state utility, ZESCO. ZESCO has a customer base of 300,000 and operates most generation, transmission, and distribution assets in the country. Copper belt Energy Corporation (CEC) is a privately owned company which supplies power to the copper mining companies. They purchase 55% of the power generated by ZESCO. ZESCOs primary source of generation capacity is three

[1] www.pepfar.gov

[2] In a study by Carmeis, a 9% decrease in voltage caused a 16% increase in refrigerator power consumption

hydropower plants, although they also have some smaller hydro facilities and ten isolated diesel systems.

In recent years, Zambia has been faced with power shortages as new generation capacity did not keep pace with demand growth. However, the recent economic downturn has curtailed mining operations with reports of a corresponding reduction in load shedding. The assessment team did not discuss these issues in detail with ZESCO, however, it is likely that power shortages could return once mining activity increase again.

One of the critical shortcomings of electricity system in Zambia is that about 80% of the population does not have access to grid power. Likewise, many of the countries health posts and rural health clinics do not have grid power although the exact number could not be verified. In order to address this challenge, the Rural Electrification Agency (REA) has been established with the overall objective of increasing the rural electrification rate. Such an effort will require significant investment and the REA is primarily dependent on donor support.

3.2 KEY PLAYERS

It is not uncommon to find a multitude of energy systems in developing country health facilities associated with different donor programs and initiatives. In Zambia, JICA appeared to provide the majority of support for the childhood immunization program and associated cold chain equipment, including solar panels in several cases. The World Bank was also supporting the Rural Electrification Agency (REA) through the Sustainable Solar Marketing Packages (SSMP) program, a rural electrification effort that will provide power to several rural communities including health centers. The REA has signed an MOU with the Ministries of Health and Education to take part in this program. In terms of government programs, the Ministry of Health claimed to have several initiatives underway including the procurement of over 25 generators for district hospitals throughout Zambia and the purchase of over 584 solar systems (supported by the World Bank). Despite repeated requests, the assessment team was unable to obtain detailed information on either of these procurements so it was difficult to determine if they were in-progress or awaiting the identification of donor funding.

If PEPFAR/Zambia implements a program to address the energy challenges at key health facilities, it will be critical to coordinate activities with the Ministry of Health, these other donors, and between different PEPFAR implementing partners and program areas. There is no reason to establish separate regional/national technical support staff to oversee health facility energy technology and cold chain storage equipment for the immunization program, blood banks, and ARV labs.

The assessment team did not have the time to evaluate donor efforts to improve the operation of the overall energy sector. However, given the long-term nature of this reform effort, and multitude of challenges that must be overcome, delaying on-site improvements in the power supply of grid-connected health facilities is not advisable.

3.3 RENEWABLE ENERGY OPPORTUNITIES

The vast expanses of Zambia that do not currently have access to grid power have generated a lot of interest among a variety of stakeholders into renewable energy options. Zambia has excellent solar resources and localized hydro and wind potential which can be used to generate on-site power that can augment, or replace, grid or diesel generator power.

4 FACILITIES ANALYSIS

The primary objective of this assessment was to develop site-specific solutions to the energy challenges at key health facilities. Site visits were made to over 17 sites strategically chosen to provide an illustrative cross section in terms of their support structures (public vs. private), the level and nature of services provided, and in terms of their current energy supply.

All district and provincial (level I and II) hospitals visited during the assessment had some form of grid power. Of the 72 district hospitals in Zambia, it was reported that only one or two of them located in the Western Province and in the North West are not on the grid.

This is not the case for health centers and rural health posts. A large number of these facilities have no access to grid power. Although aggregated data was not available, extrapolation of data collected during this assessment would indicate that between 50 – 66% of health centers and rural health posts do not have access to power.

The energy needs, challenges and solutions for each health facility visited during this assessment were often unique. However, regardless of the quality of grid power reaching a facility, one aspect was universal: a health facility's ability to deal with energy challenges was directly related to the quality of management of the facility. ***Without the correct people and support systems in place, no amount of investment in site-specific technologies will adequately address the health sector's energy challenges.*** With some notable exceptions, the majority of public health facilities visited in Zambia did not have the technical capacity, financial resources, and/or managerial discipline to successfully manage on-site energy systems. Therefore, a successful energy retrofit program will not only need to provide health facilities with the correct technology, but must also build the local capacity of staff and develop national/regional support networks to oversee the installation, operation, and maintenance of the energy systems.

Successfully mitigating the effect of no, or poor, grid power on health facility operations through the provision of on-site technologies requires *both*:

1) Proper system design and appropriate technology selection; and

2) Proper installation, operation, and maintenance through:

    a) Operation and maintenance funding

    b) Trained personnel and support/oversight systems

All too often, one of these criteria is absent leading to sub-optimal performance and/or rapid failure of on-site energy systems.

This section discusses two different types of facilities which were representative of the sites visited during the assessment: 1) Grid Connected District Hospitals and 2) Off-grid health centers and rural health posts.

Cost figures for different solutions are provided when possible but should only be considered rough estimates – primarily to illustrate the relative affordability of various solutions. Generally, they include primarily equipment capital costs and maintenance and operating expenses but do not include many of the other project related costs (e.g. overhead, training, etc) that are often part of these programs.

4.1 *LARGE GRID-CONNECTED FACILITIES*

4.1.1 CHARACERIZATION OF THE CHALLENGES

In general, the electrical supply situation at the grid-connected facilities visited in Zambia is currently quite reliable with limited load shedding. Observations by the assessment team and interviews with health facility staff indicated that power outages were viewed as more of an inconvenience than a direct barrier to delivering medical serves in these facilities.

However, each facility has its own set of circumstances. The assessment team visited 9 grid-connected, district hospitals and each had their own power challenges. These difficulties can be broadly categorized into (a) power availability and (b) power quality.

In general, there are two strategies that can be employed to address these two issues at grid connected facilities:

- Pursue solutions with ZESCO, such as dedicated feeder lines, that will improve the reliability and quality of power delivered to the facility. (For example, the main hospital in Ndomo is on a dedicated ZESCO feeder and has experienced very limited load shedding or power outages. This arrangement could be replicated on other facilities.)

- Invest in site-specific technologies designed to improve the quality of the power received from the grid and provide continuous power during grid power outages.

These two strategies are not mutually exclusive and even with significant improvement in the national grid quality and reliability, site-specific investments will need to be made to ensure continuous and high-quality electricity for the critical power needs of health facilities. This section focuses on site-specific technologies and solutions with the understanding that negotiations with ZESCO for better quality grid power should be a top priority for all facilities.

4.1.1.1 Power Availability:

Load shedding in developing countries is quite common as systems become overloaded and outdated equipment fails. As mentioned above, the hospital at Ndomo had negotiated for a dedicated power line to the hospital, and its experience was very reliable power supply with almost no load shedding and with power outages occurring only when there were storms or accidents.

Table 1 summarizes the experiences of other district level hospitals – *as reported by hospital staff*[1]:

Table 1: Summary of district hospital energy supply situation.

Facility	Power Availability	On Site Systems
Nyimba District Hospital	Power Outages last from several hours to several days, with the longer outages during storms.	Generator provides power to wards and operating theater. (not to lab or the balance of the hospital.)
Chadiza District Hospital	Currently Under construction.	Generator room is built. They believe they will have a generator to back up certain critical loads.
Chipata Provincial Hospital	Power Cuts are frequent.	A new 220KW generator provides power to the OR and to the Lab only at this time. It could be extended to other critical services.
St. Francis District Hospital	Power outages are not as frequent as they were before the mines shut down, but they occur about every week for a couple of hours. Longer power cuts occur during storms and line break-downs.	They have an old, 150 KVA, well-maintained generator that provides power to most of the loads. They need to disconnect high amperage loads before starting the generator. They have installed seven, inverter battery systems to provide continuous power for critical loads in the labs and the operating theater. Hospital has a very skilled team of technicians not found at most other facilities.
Mazabuka District Hospital	They have fairly regular power outages, but not as much as when the mines were operating. They are afraid the situation with more frequent power cuts will return when mining activity increases.	They have no generator, so when the power is down, the facility stops operating. They have some work-around solutions for the refrigerated items in the lab, but mostly they "hope and pray" that the

[1] These observations should be used as rough indications of hospital power situations. Hospital staff observations and recollections are not a substitute for on-site data collection.

		power comes back on before the supplies are damaged.
Gwembe District Hospital	They are experiencing worsening power outages in the past several weeks, with power outages lasting 5 or 6 hours.	They have no back-up generator. They would like to get one at least for an operating theater (that they hope to get when they are able to solve the power reliability issue.)
Monze District Hospital	Now, they see about one outage per day. Before the mines shut down, they experienced up to three outages / day.	They have a 120KW backup generator. Because the technician does not work on site, it generally takes about an hour for the generator to be started after the ZESCO power is lost.
Sinezongwe District Hospital	Many cuts due to rationing still, and many power interruptions due to storms. It is not unusual for the power loss to last all day.	There is no backup generator.

It was reported that district hospitals in the Western Province and in the North-West had significantly worse power situations but these facilities were not visited during this assessment.

4.1.1.2 Power Quality

The issue of power quality mainly relates to the degree of voltage and frequency variations in the power being supplied by ZESCO. Poor quality power can damage sensitive equipment and compromise test results.

Low voltage was reported by lab staff as a problem at the following two facilities:

Monze District Hospital: They experience serious voltage fluctuations in the middle of the day. When this occurs, they are not able to use the FacsCount or Cobas machines. When the voltage drops, the tests that were in process are not usable.

Gwembe District Hospital: The voltage fluctuations are severe enough and regular enough that they shut down the laboratory every day between 11 a.m. and 2 p.m and during evening hours.

These are the only two sites visited where low voltage was a known issue to the lab staff. However, meetings with Becton Dickinson technicians revealed that they replace, on average, one or two power supplies per lab site per year for the FacsCount machine. The problems with the power supply failures are a direct result of poor power quality.

4.1.2 SITE SPECIFIC SOLUTIONS

In the absence of any near term solution to the grid power problems, investment in on-site solutions could make a substantial improvement in the power situation at hospitals in Zambia.

The complexity of the electrical system at large hospitals, coupled with the uncertainty in the future quality, reliability, and cost of the grid power supply, require that a detailed engineering and cost analysis be performed before any site-specific investments are made. This is a multi-day effort and such a study is beyond the scope of this survey report. Nonetheless, a general approach for improving the energy supply at these facilities is outlined below:

Optimize Grid Power – Since the grid power is present widely at the district hospitals, the first step is to assure that it is being utilized as well as it can be. Frequently, hospitals are designed and built with one set of electrical loads in mind, and then the facility grows – both in terms of physical size and quantity of electrical equipment. In Zambia, with the relatively low cost of grid electricity, there is a tendency to power many of the large electrical loads with electricity. (In countries with higher electricity costs, these large loads (laundry and kitchen) are often powered by thermal means.)

The result of the growing physical plant and the growth in electrical loads will result in a bottleneck of electricity supply where the ZESCO power lines connect to the hospital. A power supply that was originally correctly designed can now be too small to feed the facility. The solution to this situation would usually be a larger power supply and transformer for the hospital.

Re-wire Facility and Optimize existing systems – As the hospitals grow in size and electrical intensity, as described above, the wiring systems within the hospital also become outdated. Unless these systems are improved, to be able to carry the additional power to the new buildings and additional electrical equipment, this existing wiring will also result in throttling the power distribution. Addressing this challenge requires that the hospital power distribution systems (primarily between buildings) be improved.

Provide Appropriate Back-Up Systems – As the table above illustrates, there exists quite a variety of backup power systems existing throughout the district hospitals in Zambia. Some have generators that power most or all of the facility. Some have generators for only specific critical loads, and many have no generators at all. Only one facility we saw has employed inverter/battery systems as a solution for backup power. These solutions are discussed in more detail below.

Train Hospital Facilities Manager and Establish Support Structure – Significant improvements in the power situation at most health facilities in Zambia could be achieved with rigorous training for the facilities management staff. These on-site staff must also be supported by a trained electrician at the national level within the Ministry of Health or through a contract with a private sector firm.

4.1.3 DEALING WITH INTERMITTENT POWER: UPS SYSTEMS, GENERATORS AND BATTERY INVERTER SYSTEMS

When electricity supply is lost from the grid, the resulting problems vary based on (a) the type of load, and (b) the expected duration of the outage. For example a 20 minute power outage in an operating theater can have much different repercussions than a two hour disruption in the kitchen or laundry. On-site solutions to dealing with a loss of grid power of varying durations can be UPS Systems, Generators, Inverter Battery Systems, or a combination of two or three of these solutions.

4.1.3.1 UPS Systems:

Typically, a UPS system is dedicated to a given load and will only keep this load operating for a period of 5 to 10 minutes. The normal application allows the equipment user time to shut down a computer, or finish a test and turn off equipment. Since power outages are usually longer than this 10 minute time frame, these small UPS systems are not generally meant as complete power backup systems, but to allow the equipment to be turned off properly.

If the facility has a generator backing up the loads, and the generator can be started manually in 5 or 10 minutes, (or ideally has an Automatic Transfer Switch) then the UPS system will serve to keep the load powered continuously, between the time that the grid power is lost and the generator is started.

Therefore, the applications of the UPS systems need to be thought through, and coordinated with whether or not there is generator backup. However, as a first line of defense, it makes sense to assure that all of the equipment that should not have its power discontinued should be on a UPS system. This would include at least computers and specific lab equipment.

Currently, there is a widespread use of UPS systems at the district hospital laboratories. These systems do require maintenance like any other system. The UPS systems incorporate small batteries which keep the load powered for the short time that the power is disconnected. When the UPS system is utilized on a regular basis, the batteries wear out and provide power to the loads for a shorter and shorter time. These batteries can generally be replaced without replacing the entire UPS device.

4.1.3.2 Generator Backup Systems

All district and provincial level hospitals should have reliable generator backup systems. However, three of the eight facilities listed above (37.5%) did not have a generator. Many of the functions in these health care facilities depend on a supply of electricity for critical care situations, and the loss of power at the wrong time can easily contribute to loss of life.

The decision to incorporate a generator into a power scheme to provide continuous power requires that several questions be reviewed and decided, in order to make an effective back-up power system. These decisions include:

- Will the generator provide backup power to the entire facility, or to certain loads deemed critical? (Generator Sizing)
- Will the system include an automatic transfer switch? (ATS)
- Is there a budget to pay for the ongoing fuel and maintenance costs associated with the generator? (Funding)
- Who will be responsible for the daily maintenance of the generator? (Operation)

A review of some of the generators provided to date by the PEPFAR/Zambia program indicated than many of these issues had not been properly thought through and resolved with the local health facility management team.

4.1.3.2.1 Generator Sizing:

Ideally, a generator should be sized to handle the necessary loads with a 20% margin of safety. In other words, the total loads to be powered should equal about 80% of the production capacity of the generator. If a generator is too small, this will mean that the operator must first go through the facility and turn off loads that cannot be powered by the generator. If the generator is too large, more fuel will be burned than is necessary. If the generator is loaded at less than 25% capacity, then it becomes extremely inefficient, and the life of the generator will be shortened because it is being operated sub-optimally.

Examples of all of these conditions were observed in the district hospitals visited in Zambia. Three of the district hospitals have no generator. At Nyimba District Hospital, the generator provides power only to the wards and operating theater. At Chipata Provincial Hospital, the new 220KW generator is only being loaded to about 25% of its capacity. At St. Francis District Hospital, the generator can only be started after the operator assures that the high current loads are disconnected.

4.1.3.2.2 Automatic Transfer Switches (ATS)

An ATS is an electrical device located between the generator supply and the main power system that detects when the grid power is lost. When the grid power is no longer present at the ATS, it immediately and automatically starts the generator and switches the power supply over to the generator. The use of an ATS is generally considered to be a standard piece of equipment when supplying generator systems to a health facility.

With the use of an ATS, the switchover from grid power to generator power is normally completed in 10 to 15 seconds. When there is no ATS the switchover time is dependent on the notification and the response of the operator. In the few facilities visited where the operator is a full time employee, we learned that this switchover can generally be accomplished in 10 or 20 minutes. In the locations where the technician capable of starting the generator works in town, it is often an hour (or more) before the backup power can be put into operation. For obvious reasons, a backup power system that takes an hour to come on in a hospital setting is not an ideal critical backup power system.

In the limited set of district hospitals visited, we only saw one ATS, at Chipata Provincial Hospital. (It was not operational at the time, but there are steps being taken to repair it.)

4.1.3.2.3 Funding for Operation and Maintenance

When the generators are supplied, there needs to be sufficient planning to provide the budget for the daily operation, the routine maintenance, and the regular servicing of the equipment.

Fuel is expensive. Without it, there is no backup system.

Similarly, maintenance has a cost associated with it, and is critical to the continued operation of the system. The maintenance consists of daily activities as well as routine services for the equipment. The daily maintenance work requires the services of a full time plant electrician – especially for the larger facilities. The regular services for the larger generators are often better performed by a third party company specializing in doing these services.

This ongoing operation and maintenance requires management dedication to the training that is needed for the personnel, the hiring of permanent staff, and the allocation of appropriate funding to keep the machinery running.

All too often, the generator is purchased and installed on site, without any of these other, critical functions being considered. If regular maintenance is not performed on generators they will be permanently damaged and their lifespan will be reduced.

4.1.3.3 Inverter / Battery Systems: (IBS)

An inverter battery system is similar to a UPS system, except it is designed to provide backup power for a given set of equipment, and for a longer time.

For example, an IBS could be installed for a laboratory that would provide backup power to the refrigerator and all of the critical pieces of lab equipment. This might be designed to provide power for the normally expected power outage – such as 4 hours.

The IBS system depends on the grid (or generator) to charge the batteries, and then keeps the batteries full, and on standby for when the grid power is lost. The switchover from grid power to battery power is nearly instantaneous. (Generally in the area of 16 to 20 milliseconds). This speed of transfer is such that most equipment will not recognize that power was lost and reconnected.

In some instances, the inverter battery systems can be used to alleviate the need to turn on the emergency generator. For example, at St. Francis District Hospital, they have installed seven Inverter Battery Systems, where they feel continuous electrical power is most necessary. (These are in the wards to power lights and the suction machines, and in the operating theater.) If the experienced power outage occurs at night and is of a moderate duration, they do not need to start the generator and can cope with a loss of grid power of several hours, utilizing only the inverter battery system.

As in the other system solutions, the inverter battery systems requires attention to proper design, proper installation, trained operation, and well-funded maintenance.

4.1.3.4 Summary – Dealing with Intermittent Power Problems

The above systems (small UPS systems, generator backup systems, and inverter battery systems), are all viable solutions to the problem of intermittent power in health facilities that are connected to a grid supply. If critical services are performed at the facility, then a backup generator is always recommended.

If the power supply is good and outages are few and of short duration, the next level might be simply to place small, inexpensive point of use UPS systems on specific pieces of equipment to continue their power supply during a short outage or time between loss of grid power and commissioning of the generator.

In areas where power losses are more frequent and there is a desire to run the generator fewer hours, inverter battery systems can be a good solution. Some sites will incorporate all three systems to comprise a reliable power system for critical equipment.

Training of district and regional personnel in Zambia is required to be able to have people who are able to compare the different solutions and arrive at the appropriate answer for the given health center.

None of these systems will work without the management commitment to recruit appropriate maintenance and operational personnel and to be able to fund the ongoing costs that these systems require. Maintenance contracts with private sector firms are also an option, but often can be prohibitively expensive for public health facilities.

4.1.4 DEALING WITH POWER QUALITY PROBLEMS

The sensitive electronic equipment being provided to the ARV labs requires that the power supply is not only continuous, but of high quality as well. Power anomalies can damage equipment and jeopardize test results. Options that exist to improve the power quality to equipment include:

- Point of use power conditioners
- Facility wide power conditioners
- Double Conversion UPS Technology
- Inverter / Battery Systems with No-Contact Inverters

The Point of Use power conditioners are similar to the Point of Use UPS systems, in that they exist for the single piece of equipment with which they are associated. Where voltage variations are a problem, an Automatic Voltage Regulator, (AVR) placed with the equipment is often the most economical choice.

If voltages are constantly an issue, and if there are many pieces of equipment throughout the facility that are affected by voltage variations, it could be necessary to install a facility AVR. This is generally not required unless there is a large quantity of motors in a facility such as air conditioners. The only sites that we visited that might warrant these larger AVR's would be the two sites where the operators said that they had to completely shut down due to low voltage. This was at Monze and Gwembe District Hospitals. In these locations, other design solutions should be checked first to assure that the voltage problems are not created on-site by improper wiring, or distribution equipment sizing.

Double Conversion UPS technology refers to a level of UPS system that completely isolates the equipment from the voltage supply from the grid (or generator). Most standard and point of use UPS systems provide little in the form of power quality correction. But with the double conversion technology, the grid power is used to charge batteries and then an inverter is used to create clean, AC power from these batteries. However, being a UPS system, this equipment is normally designed to last a short amount of time – designed to carry the system through a short power outage, or for the time it takes to start up a backup generator.

Inverter Battery System with No-Contact Inverters: In the Inverter Battery systems discussed earlier to provide continuous power, the power that is available from either the grid or a generator is used to (a) power the equipment, and (b) charge a bank of batteries. This system is typically used for a large set of loads, such as entire laboratory, ward, or operating theater.

In the normal configuration, this IBS system does not provide protection from poor quality power except to the extent that you can program it to disconnect under certain circumstances of bad power, but then you also limit the amount of charging power that is available to power the batteries, and the system does not work optimally.

A solution that provides both backup power, as well as power conditioning for specific, sensitive loads is to have certain inverters in the system wired as "no contact" inverters. This means that there is no grid or generator power taken into these dedicated "no contact" inverters, and they exist solely to take power from the batteries, convert it to high quality AC power, and provide energy to the loads.

This "no contact" IBS differs from the standard IBS in that it requires more inverter and charger capacity, and generally will require a somewhat larger battery bank. But the result will be clean power to specific loads that may need it. This system has been used in Haiti on the ARV laboratories where the grid power was so unreliable and of poor quality that CD4 machines and hematology analyzers were being damaged on a regular basis.

4.1.5 ENERGY EFFICIENCY CONSIDERATIONS

The energy challenges in Zambia should be an important consideration in the construction of all new health care facilities. Incorporating energy efficiency measures, such as natural lighting and cooling and energy efficient equipment, into the hospital design will help to reduce future challenges associated with the unreliable grid power. Health facility design issues are complex – and a multitude of stakeholders need to be consulted in order to strike the correct balance between facilities that are modern, efficient, and functional. The use of air-conditioning, for instance, is an issue that deserves close examination. Air-conditioning units are notoriously sensitive to power anomalies and are difficult to keep operational in developing countries. They also draw a significant amount of power. On the other hand, climate controlled rooms can be essential for sensitive laboratory equipment, special drug and reagent storage, and for sanitary purposes. Only an informed discussion between health professionals and facility engineers with a collective knowledge of the facility-specific function, power issues and climate can appropriately address this issue. The donor community should take a proactive approach to ensure that these critical discussions occur. Facilities that are built to Western standards without the corresponding reliability and quality of Western energy services can be problematic.

In addition to architectural designs, the type of equipment purchased is critical for reducing power consumption at health facilities. All lighting loads connected to battery back-up should use energy efficient CF lamps. The PEPFAR program in Zambia is distributing standard desktop computer which are power intensive compared to laptops or solid-state desktop options.[1] Energy efficient and properly sized refrigerators and should be used when possible. If air-conditioning must be used, units with a high EER rating (ratio of BTU/watts) should be purchased. Where air conditioning is deemed necessary, further study should take place to be sure the smallest practical spaces are being cooled.

Hospital energy-efficiency retrofits are a well proven technique to reduce health facility energy bills and reduce the overall energy consumption of the sector. The assessment team did not observe any coordinated energy efficiency efforts at the facilities visited during the assessment. The payback period for energy efficiency retrofits will be longer because of the low cost of electricity in Zambia but such efforts will likely still be cost effective.

4.2 RURAL HEALTH CENTERS

Although the majority of the district hospitals are on the national grid, this is not the case for the far more numerous health centers. The health centers that are not on the grid can be classified into two categories: (a) those that have solar power for very limited loads, with varying degrees of functionality, and (b) those that have no electricity at all. A third category is also possible– health centers with diesel generators - but no generators were observed or reported at health clinics or rural health posts in Zambia.

This section reviews the energy situation at health centers and rural health posts including:

- The current power situation.
- Efforts that have taken place to date.
- Critical challenges
- Strategies for Improving Solar System Sustainability

4.2.1 THE CURRENT POWER SITUATION AT HEALTH CENTERS AND RURAL HEALTH POSTS

There are 72 districts in Zambia. Each district typically has a district hospital, health centers, and rural health posts (RHP). The smallest district visited during the assessment had 10 health centers and RHP, and the largest had 45. Most had between 25 and 30 health centers and RHP. This would lead to an approximate number of health centers and RHP of about 2,000 throughout Zambia. A sampling of the power situation in a limited number of districts is detailed in Table 2:

Table 2: Representative energy supply for health centers and RHP in Zambia.

District	No. of HC's and RHP	No. on Grid	No. on Solar Working	No. on Solar Not working	No. with No Power
Chongwa	30	12	3	3	11

[1] See, for instance: http://www.inveneo.org/

Katete	26	7	10	4	5
Mazabuka	45	10	0	0	35
Gwembe	9	4	4	5	
Sinezongwe	14	5	3	3	3
Total	**124**	**38**	**20**	**15**	**54**
Percentage		**31%**	**16%**	**12%**	**44%**

The above figures are based on discussions with various health care professionals and should be taken as approximations. It is quite common to find solar systems which are reported as "working" to be non-functional upon actual examination.

The number of health centers that "have solar power" must be understood in context. Solar power systems have been provided for a variety of applications.

- Solar Vaccine Refrigeration
- HF Radio Communication
- Facility Lighting
- Staff Housing Lighting

Therefore, even if a health facility has a solar system it does not mean there is energy available for any loads other than the load that the system was designed for. In other words, a site reported to have a "working solar system" often will not have power available for any basic lab equipment, or a computer for the Smart Care system.

Additionally, several sites that were reported as having functional solar systems were found to have systems that were not functioning. (see Appendix 6: Mtherese Health Center case study)

In fact, the only operational solar systems observed were the systems that had been specifically designed and installed for either the communications radios or for the vaccine refrigerator program.

Therefore, a broad overview would imply that about 2/3 of the health centers do not have acceptable power sources that can be utilized to meet additional electricity needs, such as lab equipment and smart care systems. It is likely that very few of this group have functioning lighting systems for either the patient care areas or the staff housing, both of which were mentioned repeatedly in Zambia as high priority items.

The off-grid energy systems that do exist and are working are primarily dedicated for the HF Radio system or a vaccine refrigerator, and cannot be extended for other uses.

4.2.2 ENERGY EFFORTS TO DATE AT HEALTH CENTERS

There appear to be many efforts under way to provide energy to health centers in Zambia. Some of these are related to providing grid electricity to the health center, which if cost effective, provides the greatest amount and least cost electricity. Other efforts include various programs to address the need for solar electricity in health centers.

There is a need to coordinate the efforts of these various entities to assure that there is a consistency in approach, and a higher level of design and installation standards than are currently being used for many of the systems at Zambia health facilities.

4.2.2.1 Grid Extensions to Health Centers

Zambia has placed an important emphasis on rural electrification and has established the Rural Electrification Authority (REA) to oversee and coordinate this effort. Zambia's master plan includes connecting all rural areas to the national grid by the year 2030. The grid extensions are planned in a linear fashion, with roughly the same number of communities being connected each year. REA was careful to point out that this plan was depending on funding (at a requirement of about $50 Million USD per year) that is not currently in place.

Grid extensions are easier in the eastern and north eastern part of the country, where most rural areas are within 60 km of the national grid. In the western and northwestern areas, grid extension will be much more time consuming and costly as the national grid is not as prevalent in these areas.

As a summary, although it would be good to check with REA to determine their exact plans for electrifying certain communities in the near term, it would appear that grid extension is not going to provide power to a meaningful number of health centers in the next 5 to 10 years. Meeting the 2030 target will also be very difficult.

4.2.2.2 Solar Systems for Vaccine Refrigeration

There have been several programs to provide solar power for vaccine refrigeration. One of these programs has been successful, and is operated through the Childhood Immunization Program of the Ministry of Health. There are other programs that have attempted to provide solar power to vaccine refrigerators, but have not been as successful.

In co-operation with JICA, the MOH Cold Chain department implemented a vaccine refrigerator training program in 2007 and trained technicians from all 72 districts. The training program included the solar power systems needed to power the solar refrigerators (kerosene refrigerators were also used in some cases). Many of the technicians hired for this program are from the cold chain training program at the vocational/technical training school. There are a total of 405 solar powered refrigerators under the responsibility of this department, of which 181 are from the JICA supported program which utilized good quality design and installation practices.

These vaccine refrigerator systems are a very good example of what can be done when the all of the proper design, installation, operations, and maintenance steps required for energy systems are followed. However, the presence of these vaccine refrigerator systems on a site does not mean there is power for anything else. In fact, part of the success of this system is that it specifically does not allow connection for any other loads.

This program is no longer funded and no future trainings are planned. There are now 26 districts whose trained technicians have left. The group still does repairs on the refrigerators and tries to do repairs on the solar systems. If PEPFAR decides to support an effort to improve the energy systems at health centers and rural health posts this model and the existing technician staff network should be replicated and strengthened.

4.2.2.3 Solar Systems for HF Radios

The HF Radio system is installed and maintained by Flying Doctors. Flying Doctors started as an NGO from Australia and is now an employment division of the Ministry of Health.

Flying Doctors maintains about 3,000 HF Radio systems in Zambia. This includes health centers and educational facilities. They have a staff of three. In general, these systems consist of a specifically dedicated solar panel and battery, sized to power only the radio. The head technician from Flying Doctors informed the assessment team that the majority of the systems were working, again a result of a well thought out design for a restricted load and established maintenance procedures.

Again – the presence of the solar systems for the radios does not imply that there is any power for other loads.

4.2.2.4 SSMP Program

Within the REA, there is a group working on Sustainable Solar Marketing Packages (SSMP). The thrust of this program is to kick start the solar home system business in various communities. In each community that they target for this program, the successful bidder will also install solar systems at the health centers and various educational facilities, and maintain these systems for a minimum of 5 years. There is a memorandum of understanding in place between the ministries of education and health to support this effort.

This program has not yet started, but has targeted one area in each of the Eastern, Southern, and Western provinces for its inaugural round of bidding. The actual start time frame of this project is not clear, but is presumed to be imminent.

4.2.2.5 Effort by the Ministry of Health

MOH officials reported that there is a tender on the street to provide solar systems for 584 health centers. The assessment team has asked for the relevant documents related to this tender but has been unable to get them. At the time of the assessment, the prominent solar system supplier in Zambia (SunTech) was not aware of such a tender.

If this tender does move forward, a significant effort will need to be launched to a) review of the technical specifications b) ensure that the systems are installed properly and c) establish operational and maintenance staff and funding.

4.2.2.6 Efforts by PEPFAR Partners

ZPCT has recently awarded a contract to purchase and install solar lighting systems at 39 health facilities. These are directed towards staff housing lighting only and will not provide any additional electricity for the health centers themselves. It was not clear if a plan had been developed to ensure the long term sustainability of these systems after the initial warranty (1 year) with the equipment provider had expired. The assessment team was unable to get information on any similar programs with other PEPFAR partners.

4.2.3 STRATEGIES FOR IMPROVING SOLAR SYSTEM OPERATION AND SUSTAINABILITY

The high percentage of failed solar systems in Zambia (and most other developing country) health facilities indicates that the status quo is not an effective approach to provide power to off-grid health facilities. Lessons learned in Zambia and other countries have demonstrated that sustainable off-grid energy systems require attention to four key areas: Design, installation, operation, and maintenance. Failure to properly address any of these issues can quickly lead to energy system failure.

4.2.3.1 SYSTEM DESIGN

4.2.3.1.1 Load Analysis:

All battery based power systems must be carefully designed and managed to ensure that the batteries are not overdrawn and are fully recharged. Many of the battery bank/inverter systems reviewed in Zambia had failed because the system had not been correctly sized to power the connected loads for the desired time. Before a system is provided to a health facility, a load analysis must be conducted to determine the correct number of batteries for the desired time of operation. The load analysis determines the proper size of system that is needed for the identified loads. A proper load analysis can help maximize the utility of the energy system and minimize battery failure resulting from excessive discharge. A load analysis is not complicated and with the correct training, could be completed by PEPFAR implementing partner personnel or by a nationally based electrical engineer.

Table 3 shows a load summary for a standard rural health center in Zambia.

Table 3: Summary of rural health center loads

Qty	Load	Watts	Hours/Day	Energy/Whrs/Day
Option 1:				
1	CB Radio-Transmitter	20	1	20
1	CB Radio-Receiver	10	6	60
1	CF Light	20	6	120
1	Security Light	20	6	120
1	LED Light	1	10	10
	Total			**330**
Option 2: all items above plus:				
1	Vaccine refrigerator			650
	Total			**980**

4.2.3.1.2 Design:

In addition to the load summary, an appropriate design must consider whether the power system is providing electricity for "the health center" or providing electricity for dedicated loads at the health center.

For example, as discussed above, there are many successful systems in Zambia that provide energy for only the vaccine refrigerator or the HF Communication Radio.

A system that is designed for "a health center" will need to include all loads at the health center, plus a provision for future loads.

Given the success of the systems designed for specific loads, multiple systems powering different loads in a given facility may be a prudent approach. Although the initial capital cost will be higher for such a design, the lifetime of such systems will likely be much longer.

In summary, a good design is going to be one that:

- Fairly addresses the loads for a given number of hours' use per day.
- Provides for the appropriate battery system to store this energy,
- Provides adequate charging means (solar panels, generators, and controllers) to put this energy into the battery, and
- Includes provisions to protect the system from additional loads or abuse to the batteries.

Experience in several countries has indicated that diesel/PV hybrid systems are excellent options for all but the smallest of health facilities. The additional of a diesel genset allows battery charging during extended periods of inclement weather and when the load temporarily exceeds original design specifications.

4.2.3.2 INSTALLATION

Correct installation and wiring of the solar systems is critical to ensure proper operation. Even if a proper design is conducted, if a solar system is installed improperly, it will fail on short order.

Elements to consider in good solar system installation include:

- Panels installed on roof or on poles securely, with prevention of theft in mind.
- Wiring from the panels to the control equipment that considers:
  - Appropriate Series / Parallel wiring and Circuit Protection
  - Adequate (large enough) cabling to prevent voltage drop.
- Appropriate Charge Controller
- Secure Installation for Charge Controller to prevent attachment of added loads
- Cable Installations secured strongly with strain relief connectors
- Battery mounting system that prevents battery abuse (and theft)
- Strong cabling to load equipment.
- Appropriate informational placards

The systems that were installed as part of the JICA vaccine refrigerator system incorporated the majority of the above items and are still working. Most of the other solar systems installed at health facilities in Zambia that were reviewed incorporated very few of these installation elements, and are not working.

4.2.3.3 OPERATION

Proper system operation refers to the day-to-day use of the system in a way that allows the system to work as designed and installed. A properly designed and installed system can still be rendered useless by improper operation.

Since solar systems are designed for specific loads, it is the responsibility of the operator and all the health facility staff to manage these loads. The operator must in some ways become an "energy policeman", ensuring that additional loads are not connected to the system and that the loads which are approved are not used for more time than the system was designed.

If the system was designed to power 2 computers for 4 hours each, the operator must be sure that this is criteria is being adhered to.

The system operator must also see to it that other activities (that are fairly common) that shorten the life of a system are not allowed. For example, it is common that the batteries are removed from a system in the evening and taken to a home to provide energy for lighting there. The battery is returned in the morning to be part of the health center solar system. This practice increases the designed load that both the battery storage system and the solar panel charging system were designed for and will assure an early demise of the system.

4.2.3.4 MAINTENANCE:

There are maintenance functions that must be performed on a regular basis to keep systems that are properly designed, properly installed, and properly managed, working. On smaller systems, these tasks are fairly basic, such as keeping all of the equipment clean, assuring that the solar panels do not have dirt building up on them, and checking the batteries for proper water level on a regular basis. Maintenance staff also need to be able to know when supplemental battery charging is required, or when even the designed loads need to be reduced as a result of a lack of sunshine. More complex maintenance issues, such as trouble shooting the system when it is not operating properly or replacing individual components that periodically fail, require both trained staff and funds as discussed below.

Without this maintenance function in place, the systems will quickly fail.

4.2.3.5 TRAINED SUPPORT NETWORK

The successful implementation and operation of solar systems will likely involve a multi-tiered support structure and training will be required at each level.

At the facility level, health care professionals or facility managers must be trained on basic system operation and maintenance. Experience has demonstrated that with minimal training local users are capable of performing the required routine maintenance checks, such as adding water and cleaning terminals, required for battery-based systems to operate successfully.

Ideally, this local user training should be a required component of system installation protocols. The distribution of "user guides" is also recommended covering proper system operation and maintenance protocols.

When the local user encounters a problem that they are unable to solve, they must have a pre-determined contact at the district, regional or national level that is trained to diagnose and correct all potential system problems. At the national level this individual should be an energy professional with extensive training in the proper installation and operation of energy systems. This technician should be responsible for overseeing all of the system designs and installations and provide training to the local users at the time of installation. The number of installations, size of a country, and accessibility of the facilities in a given country will determine if this support must also be provided on the regional level. In Zambia, the district cold chain technician may be able to offer a first line of defense given the correct training.

4.3 MAINTENANCE/REPLACEMENT FUNDS

Significant effort has been expended in the past to design effective financing models to cover the high initial capital costs of distributed energy systems in developing countries.[1] Given the grant funding available within the PEPFAR program, the initial capital cost of the various types of energy systems is not the primary barrier to the utilization of this technology for any of the recommended applications in this report. Rather, ensuring sufficient funds to cover the lifetime maintenance and replacement costs - which may be required after the donor community has left - present the most significant challenge.

Batteries and inverters (two critical components of solar systems) are designed to last approximately 3 – 10 years, making periodic component replacement a necessity. Solar panels, if treated properly, can last up to 20 years. Regardless of the level of training of local users and technicians, these systems will not be sustainable in the long term if funds are not available to purchase replacement parts. This issue is of particular importance to health facilities in Zambia, because they claimed to have little or no revenue stream that can be utilized to cover system maintenance.

A prudent approach to pursue in Zambia may be to set aside replacement funds in an account at the time of system installation. The optimal administration and structure of such a fund needs to be further studied, but it must be designed in a manner that prevents the money from being utilized to cover other hospital operating or maintenance costs. Co-mingling of energy system maintenance funds with overall facility operational budgets has not been successful for two reasons: 1) system failure can not be predicted and is therefore often not included in the facility's yearly operating budget request, 2) even if money is provided for this purpose, it is often used for other perceived priorities if the system is operational at the time the funds are received.

[1] See, for instance, Cabraal, Cosgrove-Davies, and Schaeffer, "Best Practices for Photovoltaic Household Electrification Programs", World Bank Technical Paper #324.

Upfront payment for maintenance contracts is another option that has been used with mixed results. To be effective, both the structure and duration of the contract needs to be carefully considered. Typically, maintenance contracts are purchased from the installation company for an initial period of 1– 5 years. Trouble free performance of the systems during this "honeymoon" period can be an incentive to not renew the contracts with system failure following in short order. If maintenance contracts are used they also need to be structured in a way that provides a strong incentive for the contractor to optimize the performance and lifetime of the system – not just replace parts when they break. Maintenance contracts are also expensive and several of the health facilities in Zambia did not seem willing/able to pay for such contracts for existing energy infrastructure.

The MOH may want to consider establishing an internal inventory of replacement components for off-grid energy systems under its jurisdiction. Such an approach could benefit from bulk procurement discounts, would alleviate the financial burden from the budgets of the individual health clinics, and would allow technicians to quickly respond to the maintenance needs of any faulty systems.

5 EXAMPLE ENERGY RETROFIT SUPPORT PROGRAMS

This report has detailed several options for improving the energy services at priority health facilities in Zambia. Although the prioritization of investments will need to be considered by the PEPFAR staff in the context of their overall programmatic objectives, notional activities that could be implemented within certain budget constraints are detailed below. (Table 4) At a minimum, PEPFAR/Zambia must ensure that the existing infrastructure/energy investments – such as laboratory equipment, solar systems and generators - which are currently being made by PEPFAR partners are sustainable.

There are three primary options for achieving this objective: 1) Build the capacity of existing PEPFAR partners to improve the effectiveness and sustainability of energy interventions, 2) contract with a separate firm that is a specialist in energy systems to address energy challenges across the PEPFAR/Zambia program and provide support to the MOH, or 3) a combination of both approaches.

In some PEPFAR countries, the energy challenge is so severe that option 2 and 3 are the only viable approaches. In Zambia, all three options should be considered. If PEPFAR/Zambia decides to continue supplying generators to district hospitals and believes that electrification of rural health facilities – to retain staff, power the smart care systems, and improve overall service levels – is a priority, than a dedicated program focused on energy is warranted. If activities are limited to the current modest level of partner activity in this area it is feasible that some targeted technical assistance to these partner organizations would be sufficient.

The base case outlined below envisions a program focused on building the capacity of PEPFAR partners and the MOH to address energy issues as well as some technical training for the cold chain engineers at the district level to expand their capacity to maintain rural energy systems. A limited number of facility retrofits could also be completed, either through existing partner's budgets or through separate dedicated energy funds.

A more substantial PEPFAR investment would allow an expansion of the program to include a robust training activity for district level technicians and an expansion of health facility retrofit activities. PEPFAR/Zambia could achieve a significant "bang for its buck" by retrofitting several of the non-functional solar systems observed at health facilities in Zambia. Many of these systems can be brought back on-line though the replacement of relatively inexpensive batteries and other components.

The budgets in Table 4 are based on estimates for the total cost for PEPFAR to implement the detailed activity. This contrasts to the cost estimates in the report which were primarily limited to equipment expenses. The costs below should be used only as rough estimates as actual program costs can vary significantly based on the implementing partner.

Implementation of the training program can be done very quickly utilizing a pre-existing USAID energy team contract with an appropriate implementing partner. USAID has established this contract specifically to provide support to PEPFAR country programs on energy issues. The USAID energy team has limited funds available that can be used to cost share some initial activities. If PEPFAR/Zambia decides to pursue such a program funds can be transferred into this mechanism for the implementation of the program. Alternatively, PEPFAR/Zambia could establish its own contract with a firm which specializes in infrastructure issues. This could be an attractive option if significant infrastructure projects, such as the construction of new buildings, and energy and water system retrofits are envisioned in the future.

Table 4: Notional budgets for energy retrofit programs.
Available Budget: $700,000

Program	Cost
Limited Training program for district technicians	$200,000
TA to PEPFAR partners and the MOH on Energy Issues	$100,000
Retrofit up to 5 smaller health centers, , and targeted upgrade of back-up energy systems at 2 larger health facilities	$400,000
Total	**$700,000**

Available Budget: $1.5 million

Complete the work described above plus:

Program	Unit Cost	Cost
Expanded program to improve energy services at rural health facilities (develop procurement guidelines and standards for MOH, periodic training for regional technicians, fund capital cost for retrofits of up to 20 facilities)		$800,000
Total		**$1,500,000**

CONCLUSIONS

Reliable electricity is a critical input to all levels of health care delivery in Zambia. Although Zambia is blessed with abundant and cheap hydropower energy sources, challenges resulting from power anomalies, intermittent power, and the limited coverage of the grid in Zambia affect several components of the PEPFAR program.

The PEPFAR/Zambia program has addressed some of these challenges in a limited way with mixed results. Implementing sustainable energy solutions for on or off-grid facilities requires proper system design, installation, operations and maintenance. Developing country health facilities typically do not have the funding or technical abilities to successfully complete any of these tasks so they must be considered in any infrastructure support program.

Significant financial resources are not required to implement a program with substantial impact. A PEPFAR program focused on retrofitting the energy systems at a few model facilities, building the capacity of the MOH, and establishing a trained support network of engineers would have a ripple effect across the entire network of health facilities by highlighting that cost effective solutions are viable and by providing the technical capacity to implement these solutions.

APPENDIX I: FACILITIES VISITED

The assessment team visited the following sites:

Eastern Province: Chongwe Health Center, Kachololа Health Center, Nyimba District Hospital, Mtherese Health Center, Chadiza Health Center, Chadiza District Hospital, Chipata District Hospital, Katete District Health Office, St. Francis District Hospital

Southern Province: Mazabuka District Hospital, Gwembe District Hospital, Monze Mission Hospital, Sinezongwe District Hospital

Copperbelt: Mikata Health Center, Kanyenda Health Center, Kasamba Health Center, Mutundu Health Center

APPENDIX 2: Laboratory Equipment Power Requirements

Power Quality Conditions

There are several types of power anomalies that can cause problems in the laboratory. These are:

- Intermittent Power
- Improper Voltage
- Improper Frequency
- Improper Grounding and Wiring

Many of these conditions overlap and can occur simultaneously. The following is a brief discussion of each of these conditions and what specific problems they cause in the laboratory. This information is drawn from discussions with lab techs in several countries, as well as meetings with the laboratory equipment repair personnel in Zambia and Haiti.

Intermittent Power:

It is commonplace for developing country grid power to experience frequent outages. This is often the result of load shedding resulting from chronic generation capacity shortfalls or service outages resulting from failure of specific generation, transmission, or distribution equipment. Power outages can be scheduled or random, and can last for a few seconds to months.

If no back-up power supply exists for the laboratory, all automated tests stop when the power goes out. If power cuts are frequent and prolonged, these delays can severely impede the workflow of the laboratory and complicate diagnosis and treatment.

Power outages can also be a problem for the accuracy of some laboratory infrastructure. For instance, one model of the CD4 machine has an internal clock that, at a pre-programmed time, goes into a cleaning cycle. This is most often done during night time hours, and requires that power is present so it can "turn itself on" and go through the cleaning cycle. When the power is disconnected from the lab, this cleaning cycle does not take place, compromising the validity of test results.

Extended power outages also complicate storage of cold-chain dependent reagents and blood.

Improper Voltages

Laboratory equipment is designed to work at a certain voltage (e.g. 230VAC) with a tolerance range of 5% or 10%.

Most equipment manages fairly well in voltage ranges of plus or minus 10% of nominal design voltage.

However, it is not uncommon in many locations to see voltage sags of much more than 10%. Different equipment performs differently at abnormally low voltages.

Equipment with motors and compressors will tend to wear out much sooner when they are continuously faced with operating at low voltages. Equipment associated with computers, – like power supplies - will also experience a high failure rate at low voltages. The efficiency of refrigerators is also significantly compromised at low voltages.

Some test equipment, such as many CD4 models, will give the lab technician a report that the test failed due to low voltage, and the test would need to be repeated.

Besides voltage sags, there are voltage spikes. Voltage sags are usually low voltages that last for an extended period of time. Voltage spikes are extremely high voltages that come through the lines momentarily for a variety of reasons. Often these can be caused by the grid or a generator being abruptly disconnected without warning. Voltage spikes will cause problems to all sensitive electronic equipment, including CD4 machines, blood chemistry machines, and hematology machines.

Improper Frequencies

Like voltage tolerances, different pieces of equipment have different sensitivities to "out of spec" frequencies.

Biomedical Engineers in several countries have reported frequency variations to be especially problematic for any equipment which relies on lasers, such as the CD4 machines. When frequencies get too far out of range, the tests results are affected and the equipment can be damaged.

Low frequencies can be caused by a power generation problem with the national grid. But more likely, a low frequency problem is caused by a generator that has not been maintained and is running slower than it should be, thus putting out a low frequency power supply.

Improper Grounding and Wiring

The concept of the ground wire is fairly recent, and in many developing country health facilities it is not installed. (Even where the receptacle has three prongs, there is often no ground wire installed.)

The common problems with the installation of the wiring are that (a) the hot and neutral wires are reversed, (b) there is no ground wire, and (c) the ground wire is not connected properly at the main service. Until the advent of sensitive electronic equipment these wiring details did not cause many problems. But now, much of the equipment depends on the proper orientation of the hot and neutral conductors, as well as the proper existence and connection of the ground conductor.

All of the equipment suppliers interviewed stressed that proper grounding was important for proper equipment operation. Some equipment depends on the proper wiring to use voltage reference points, which it then uses to calibrate and control its tests.

On-site options for providing reliable power to health facility laboratories.

Point of Use Conditioning

Economical point of use conditioning can be provided for individual pieces of equipment. These devices are voltage regulators and UPS systems. To perform both functions properly will generally require two separate pieces of equipment.

Point-of-use UPS systems are recommended for all sensitive equipment

Larger system wide UPS systems are another option when grid outages are short and/or a back-up generator is available.

Generator Back-Up

Generators are primarily protection from power intermittency. They should be part of every critical hospital power design. Generators can introduce their own power quality issues in terms of voltage and frequency problems if not properly maintained.

Power quality problems can arise when a generator is abruptly switched off. This can cause voltage and frequency spikes that damage sensitive laboratory equipment. This can be corrected by installing proper switches and training operators to switch off the power supply prior to turning off the generator or by the use of an Automatic Transfer Switch.

Inverter / Battery System:

An Inverter / Battery System performs the function of a UPS system that is designed to power several pieces of equipment for up to several hours. (in comparison, a point of use UPS system is generally designed to keep the equipment energized for about 10-20 minutes)

A standard Inverter / Battery system is connected to whatever AC grid is available when it is available. (National grid or generator.) During this time that input power is available, this power is sent straight through the inverter / battery system to power the loads, and is also used for maintaining a full charge on the battery bank. Therefore, during this time, whatever power quality problems exist in the AC power that is connected, are passed through to the equipment. So, a standard inverter / battery system should not be thought of as protecting lab equipment from power quality problems. This is not an issue if the battery inverter system is powered with solar/PV – as discussed below.

Inverter / Battery System with No Contact Inverter:

A modification of the standard inverter / battery system includes having one or more inverters (depending on total load) that are not connected to the AC power supply. This means that the power going to the loads fed by these inverters will always come strictly from the batteries and through the inverter – thus being pure power. Grid power is still used to charge the batteries. This is a good solution to areas that have problems with voltage and frequency on the grid. (see wiring diagram (link) for example non-contact inverter setup in Haiti)

Stand Alone, Off Grid Solar Power Systems:

While generally not appropriate for large district hospitals that are connected to the grid, an off-grid solar system will provide high quality electricity to laboratory loads, assuming that a pure sine wave inverter is selected. With no connection to a grid or to a generator, the power created from the solar / battery / inverter system will have excellent voltage and frequency characteristics. Of course, the wiring from the inverter to the loads has to be done correctly.

Appendix 3: Health Center Power Supplies in Example Districts

Two of the districts visited on the assessment provided detailed reports of the power situation at the facilities in their area of responsibility. Other districts gave us the information in general terms with no report. The following tables summarize this information.

Chongwe District				
Facility	**Radio Present?**	**Radio Status**	**Electricity**	**Elec. Status**
Chainda RHC	No		Grid	OK
Chalimbana RHC	No		Grid	OK
Kabeleka HP	No		None	Need solar
Chinyunyu	Yes	Not working	Solar	Not working
Chongwe RHC	NO		Grid	OK
HAHC Mpanshya	Yes	Not working	Solar/Diesel	OK
Kampekete	Yes	Not working	None	
Kanakantapa	No		Grid	OK
Kankumba RHC	Yes	Not working	Solar	Working
Kasisi RHC	Yes	Not working	Grid	OK
Katoba	No		None	Need Solar
Lukwipa RHC	Yes	Not working	None	Need Solar
Lwimba RHC	Yes	Not working	Solar	Working
Mpango RHC	Yes	Not working	Solar	Not Working
Mwalumina RHC	Yes	Not working	Solar	Not Working
Ngwerere RHC	Yes	Not working	Grid	OK
Nyangwena RHC	Yes	Not working	Solar	Working
Palabana RHC	Yes	Not working	Grid	OK
Rufunsa RHC	Yes	Not working	None	Need Solar
Shikabeta RHC	Yes	Not working	None	Need Solar
Waterfalls RHC	No		Grid	OK
Zasti RHC	No		Grid	OK
Kasenga HP	No		None	Need Solar
Chikumbi HP	No		None	Need Solar
Ngwerere HP	No		None	Need Solar
Chitemalesa HP	No		None	Need Solar
Chongwe DHO	Yes	Not working	None	Need Solar

Katete District		
Facility	**Electricity Source**	**Remarks**
Chilasa	Solar	Solar Fridge with 7 panel system.
Chimtende	Solar	Not working – needs batteries
Chimtengo	Grid	
Chimunsi	Grid	
Chindwale	Solar	Radio only
Chinkhombe	Solar	New – 1-65W panel for Maternity Lighting Only
Chitawe	Soalr	Solar Fridge with 7 panel system
Hahc	Grid	
Kafumbwe	Solar	For 5 lights – lights not functioning
Kafunkha	Solar	Radio only
Kagoro	Solar	Recent Install by LWF – for Outpatient Block Only
Kakula	Solar	Radio Syst Works: Staff House System does not work
Kamiza	Solar	Not functioning – Charge Controller and Battery
Kamphambe	Solar	Radio and Solar Fridge
Kasamba	Solar	Not working – lightning and theft problems.

Katete Urban Clinic	Grid	
Mindola	Solar	Radio Only
Mng'omba	Solar	Radio Only
Mphangwe	Grid	
Mtandaza	Solar	Systems for Radio and fridge and Lighting: none are working
Mtetezi	Grid	
Mthunya	Solar	For Maternity Block: Not working. Radio system is working. Staff Housing system not working
Undi	Grid	
Vulamkoko	Solar	Pump system working with one panel stolen. Radio system works. One staff house working.
Nyembe	Solar	Radio works. One lighting block working.

Besides the detailed information we received at Chongwa and Katete Health District offices, we also received input from three other district offices relating to the power situation at their health centers. These districts along with the information from Chongwa and Katete are summarized below.

District	No. of HC's	No. on Grid	No. on Solar Working	No. on Solar Not working	No. with No Power
Chongwa	30	12	3	3	11
Katete	26	7	10	4	5
Mazabuka	45	10	0	0	35
Gwembe	9	4	4	5	
Sinezongwe	14	5	3	3	3
Total	**124**	**38**	**20**	**15**	**54**
Percentage		**31%**	**16%**	**12%**	**44%**

If we were to assume a total of 1,500 health centers throughout Zambia, we might extrapolate from these numbers that about half of them have no electricity. Additionally, another 16% of the remaining facilities have solar systems that are said to be working but in reality probably include varying stages of workability, and can not be expanded for any additional services.

This would indicate that there are approximately 1,000 health centers which currently have no available power supply for additional loads.

Appendix 4: Smart Care Expansion: Options for Rural Health Centers

Situation Summary

The Smart Care system is designed to electronically store a patients medical history on a smart card, which is retained by the patient. Patients are then able to go to any health facility, with their smart card, and the health facility will be able to read all of the pertinent treatment information on site. After being treated, the health facility updates the smart card and the central data system.

Discussions with various CDC personnel indicate a desire to expand the Smart Care system to as many health facilities as possible, including health centers.

The Smart Care system requires a smart card reader and a computer. At the sites where we saw the system deployed, it was operating from a standard desk top computer, with a large monitor, and a USB – connected smart card reader.

The Smart Care system requires electricity in order to function. It needs to be functioning whenever the clinic is operating, which would imply that the computer would need to be running about 8 hours/day.

The previous appendix gives a sampling of the power situation at the health centers in Zambia. Considering that there are 72 district hospitals, (most of which are on the grid) and between 1500 and 1700 health centers, (with as many as 2/3 NOT on the grid) it is clear that there are far more health facilities in Zambia without power than those that have power.

One misconception encountered was that if a health center has a solar system, then it "has electricity" and a Smart Care system can then be deployed there. In fact, we were told about one such system in the Sinezongwe Health District where a Smart Care system was recently sent to a health center because it had a solar system.

Solar systems are designed for specific loads. Adding another computer, operating all day, to an existing solar system would, in most cases, cause it to fail. Therefore, to the extent that the Smart Care system is to be deployed in locations that are not currently on the grid, a plan has to be developed to assure that these systems will have a power supply.

Power Solutions for the Smart Care System

Grid Connected Facilities

For the Grid connected facilities, there is not much of a problem. However, in order to protect the equipment, a point of use UPS system should be considered part of the package. In areas where the voltage problem is severe, a point of use voltage regulator should be considered as well.

Off-Grid Facilities

Where there is no electricity, or an existing solar system, there are two choices to provide power for the Smart Care system: Connect to the existing solar system, or provide a separate power supply for the Smart Care system.

Connect to the Existing Solar System

As stated above, an additional computer can be connected to an existing solar system ONLY if the solar system was designed for more loads than it has connected. We did not see any such systems. We doubt if there are any, as the normal case is that the systems are designed for very specific loads, with conservative estimates of the times that these loads will be on.

There is one condition that would allow connection to an existing solar system, and that is where the existing solar system has failed and the panels can be salvaged to supply power for the Smart Care system. This would involve:

- Site Assessment to determine if there is an existing solar system that can be salvaged and upgraded.
- Specific site design to allow for Smart Care system.
- Determination if other loads will be allowed to be connected to this system.
- Appropriate design work
- Submission of documents for bidding
- Installation and training work.

It would probably be more cost effective to come up with a solution that would allow the Smart Care system to be deployed without going through the above procedure. This would require a separate power supply system specifically for the Smart Care system.

Dedicated Power Supply System

The communication radio systems are provided with a solar system designed to power only the communication radio. The successful vaccine refrigerator program was designed to power only the vaccine refrigerator. A similar power supply solution for the Smart Care system can be included as one of the solutions to powering this equipment

To make such a power supply system as economical as possible, the Smart Care system's electrical loads have to be made as efficient as possible. This means using the most energy efficient computer that we have available to us. This would be a laptop or solid state desktop computer, specifically configured for the Smart Care system, with features that reduce its power consumption.

For example, a standard desktop computer, similar to what is being deployed now for the Smart Care system consumes about 150 watts of power. On an eight hour shift, this is 1,200 watt-hours of energy consumption. This could require a 400 to 500 watt solar panel system, which is quite costly (average in Africa of $15 – $20 per Watt installed).

Specially configured laptops, with no CD drive, DVD drive, etc., are available that consume less than 60 watts. A 50 watt computer (with no printer), used for an 8 hour shift would consume 400 watt-hours, and could be powered by a 130 watt solar panel and appropriate equipment.

It is our recommendation that before proceeding to deploy the Smart Care system en masse, in areas without grid electricity, that the program takes the following steps:

- Determine first if the system is going to be utilized in these areas with no grid electricity.
- Determine if the system needs to run 8 hours/day or something less (or more).
- Look at the minimum computer requirements to make the system work.
- Determine if a printer is necessary.
- Add up all of the watthour energy requirements of the system.
- Design a solar system that will provide this energy

Once this is completed, the system needs to be designed and installed in a very robust fashion, with a lot of attention paid to all of the details that are known to make a system last. These details include things such as:

- Sturdy, and theft resistant mounting for the solar panel(s).
- Properly sized cables to eliminate voltage drop.
- Heavy duty enclosures for all equipment with strain relief connectors for cabling.
- Maintenance free battery in a locked enclosure.
- Good training in the required operation and maintenance of the system.
- Regular checking to be sure that the system works and is not being abused. (used for other loads)

Appendix 5: Example case studies – District Hospital and Rural Health Center

Chipata Hospital

Overall Power Analysis

Chipata Hospital is on the national grid, but sees frequent power outages. It has a recently installed 220 KW SDMO generator for backup power. The generator was supplied by the PEPFAR program and is currently only to the laboratory and the operating theater.

The laboratory is a large, full service facility, with CD4, Hematology, Blood Chemistry and Blood Bank equipment typically found in a provincial hospital. When the grid power is disconnected, they lose power until the generator is manually started.

The generator was provided with an Automatic Transfer Switch, but this switch no longer functions, and the generator needs to be started manually when grid power is lost, and then another operator function is required to switch back to the grid when the grid power returns.

Due to apparent cost, there is no current maintenance program for the generator in place. The hospital administrator indicated that it was too costly to have the generator maintained by a private sector company, and the local hospital technicians did not have the required training to perform the maintenance themselves.

Recommendations:

Laboratory:

The lab power supply is already backed up by the emergency generator. A survey should be made to determine that all of the sensitive equipment is connected to a point-of-use UPS system, and a voltage regulator.

The wiring should be checked to determine if the facility wiring is done correctly. This would be to assure that the hot and neutral conductors are not reversed, and that the ground conductor is present, and properly installed.

Hospital General:

At this point, (according to statements by the staff) the generator is running at only about 25% of its capacity, while many areas of the hospital are without electricity when the grid goes down. We have learned that this is more of a procedural issue than a technical issue.

We recommend that the procedural issue be resolved and that more loads are connected to the generator in order of priority. For optimal operations, the generator could be loaded to about 80% of its output rating.

Generator:

The Automatic Transfer Switch should be fixed. (This process was underway during the assessment visit and CDC staff promised to follow up.)

A service should be performed on the generator right away (it would be good to do this when the ATS is fixed to save the travel costs.) A regular maintenance program should be established with an outside firm if there is no one on staff that this function can be delegated to.

Mtherese Rural Health Center

It was reported that Mtherese RHC was a good example of a health facility operating on solar power. The systems had been installed relatively recently (2005) with the support of an NGO.

Overall Power Analysis

Mtherese has three solar systems:

- A 5-panel system that was intended to power a vaccine refrigerator and other loads.
- A 1-panel system that was intended to power the communication radio
- A 3-panel system that was intended to power one of the staff houses.

5-Panel System

The panels on this system are 125 Watts each. One of the panels is destroyed by what appears to be a large rock.

The charge controller appears to be operating, but marginally. The batteries (100Ah battery bank) are not well maintained and have large amounts of sulfation on them.

The staff said that the system used to power the vaccine refrigerator and lighting. It can no longer power the vaccine refrigerator, and it will only power the lights for a very short period of time. (~ half hour).

The panels and batteries, when installed, were very good equipment. The batteries appeared to be some of the best available. The charge controller is an inexpensive model.

The wiring was not installed in a professional manner. The charge controller was not installed in a professional manner. The batteries were installed in a wooden box, (which is good) but access could not be restricted because the batteries needed to be accessible for maintenance.

For all practical purposes, this is a 5-panel system that does not work.

1-Panel System for the communication radio

This system was working. The battery (3K Deep Cycle) was installed under the desk on the floor with a cardboard box around it. The charge controller was fastened directly to the wall.

It appeared (but could not be verified) that there were no other loads connected to this system. (There are some cell phone chargers operating on a file cabinet adjacent to the radio, but these are most likely fed from the marginal 5-panel system described above).

3-Panel System for the Staff Housing

All three panels are installed, and appear to be in good shape, but the system is not working.

The charge controller quit working some time ago, and has been removed.

The batteries are heavily sulfated and have not been maintained for many months.

Recommendations

5-Panel System.

Four of the five solar panels could be put to use on this system. However, the project should start from the beginning with a design that makes sense, and fits into the charging ability of the 4 panels.

A determination should be made as to whether this system will power a vaccine refrigerator or general lighting, but it should not be permitted to power both. It is possible that these panels could be used to power two systems – one of which could power a smart care system.

Following this design, all new charge controller, batteries, hardware, and cabling would need to be purchased. Then the installation should take place in conjunction with training for the local installers and whoever will maintain the system.

Maintenance-free batteries should be used, and installed in a locked box. A charge controller that has internal protections (without fusing) from short circuits, overloads, and reverse polarity should be used, and installed in a heavy duty plastic box with a clear lid.

Cables should be sized to limit voltage drop to 2%, and a combiner box should be used where the panels are paralleled. All connections to the junction boxes should have strain relief connectors.

The wiring to the loads should be installed in a professional manner, and in a way to limit any addition of loads to the system.

1-Panel System:

Provide a better battery box for the 3K battery, and assure that there are no other loads connected to the system. Provide onsite training to explain why no other loads should be connected to this system. Provide training to demonstrate the maintenance necessary to keep this system working.

3-Panel System:

The three solar panels are re-usable. Everything else is not. Similar to the recommendation in the 5-panel system, a design should be done that utilizes the output of these panels. The new equipment should be purchased and installed in the same durable fashion as described above.

These recommendations basically are to take the existing solar panels, and building them into a new system (except for the radio system). This will be a very cost effective use of the equipment. Currently, there are at least 7 – 125W solar panels doing nothing at this site and past experience indicates that if not fixed these panels will eventually be stolen.

In any solar system, the cost of the solar panels represents at least half of the cost of the system. So, in this case, half of the systems are in place, waiting to be completed.

It is likely that this example and solution can be replicated in hundreds of facilities throughout the country, and it would be a worthwhile effort to conduct a specific training program on how best to take the equipment that is in place (and not working) and convert it to functional systems which will be sustainable over the long term. Cold-chain technicians are present in many districts and, with proper training and additional staffing, could provide necessary maintenance for these systems.

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