Peru/Loreto RAPS Community Power Project

Project IMPLEMENTATION PLAN

Prepared for:
International Lead Zinc Research Organization
Research Triangle Park, North Carolina

Prepared by:
SWITCH Technologies, Inc.
Bethesda, Maryland

In conjunction with:
ORION Energy Corporation
Ijamsville, Maryland

June 1998

Peru / Loreto RAPS Community Power Project
Project Implementation Plan

Executive Summary

This Project Implementation Plan PIP) is the final step of Phase I to assess the potential for Remote Area Power Supplies (RAPS) in the Amazon Region of Peru. This study, funded by the International Lead Zinc Research Organization (ILZRO), attempts to define the specific activity to install the first RAPS systems following the agreement signed in June 1997 between the ministry of Energy and Mines (MEM) in Peru, the Solar Energy Industries Association (SEIA) and ILZRO.

The PIP is the business plan to design, manufacture, manage, install, operate and finance the first RAPS systems in the Amazon region of Peru. The document is produced as the blueprint of the project, so that all project participants would become signatories for the document, and to proceed with application for project financing from multilateral financiers, most specifically the Global Environmental Facility at the World Bank.

The Project Implementation Plan contains the following highlights:

- Project will consist of installing six 150 kWh/day power modules into two community power RAPS systems at Padre Cocha (300 kWh/day) and Indiana (600 kWh/day)
- Project is expected to cost $1.875 million (US $) for these systems, although options are provided for additional or alternative systems
- Modular community power RAPS systems will be integrated into existing electric networks and diesel generator sets
- Project will be managed by a Project Administrative Council (PAC) with representation from all project participants
- Project Administrative Council will select a Project Manager responsible for selecting prime contractors for project engineering and socioeconomic aspects of the project
- Project is scheduled for completion within eleven months after obtaining financing and selecting prime contractor
- RAPS power modules will be assembled in Peru, under the supervision of prime contractor, using local labor and parts where possible
- Local contractors for site preparation, transportation, construction, operation, and maintenance will be used
- Socioeconomic aspects are critical, and include load management plan, revenue collection, selection of productive uses, payment for institutional uses, and provisions for system maintenance and battery replacement
- RAPS projects are a good investment, they provide 24-hour electricity and will provide power at half the cost of an equivalent diesel generator set, independent of emissions benefits
- Emissions benefits (compared with a prime diesel system) exceed $2 million over the 20-year life of the project (using the latest emissions and cost estimates from US EPA and National Park Service)

The power designed are designed using modular building blocks. These building blocks include gelled VRLA batteries, a Power Conditioning System, a 15 kW(p) of PV array and a local control / monitoring system. A typical community power system will consist of one or more of these building blocks, along with an interface to the existing diesel generator, a supervisory control system, and a remote monitoring system.

A simple economic analysis indicates that the system will have a 12.8 year simple pay-back, based on a 50% capital buy-down and estimated project revenues. Project load increases could shorten this pay-back considerably. The system has 25% of the fuel consumption and 15% of the maintenance costs of an equivalent system based on a prime diesel generator.

Emissions analysis show that the proposed project will eliminate nearly 19,000 tons of CO_2 and over 900,000 pounds of NO_x, compared with an equivalent prime diesel generator. The total value for these savings is $2.7 million over the 20 year life of the project.

This Project Implementation Plan validates this project as a sound economic investment for the participants to provide electricity for economic development, reduce emissions in the Amazon region, and reduce the costs to the Peruvian government in supplying fuel and electricity to these remote villages.

1. Project Overview

1.1 Project Perspective

This plan represents the final step of Phase I to assess the potential for Remote Area Power Supplies (RAPS) in the Amazon Region of Peru. This study, funded by the International Lead Zinc Research Organization (ILZRO), was the third major activity following the agreement signed in June 1997 between the Ministry of Energy and Mines (MEM) in Peru, the Solar Energy Industries Association (SEIA) and ILZRO. This agreement seeks to evaluate the potential for RAPS for electrification of rural villages in the Amazon region. MEM's interest is to improve the socio-economics of indigenous people via electrification, reduce the cost of delivered electricity through privatization, reduce the fuel import requirements to the nation, and to contribute to national and international environmental goals. SEIA seeks to expand markets for photovoltaics, particularly in developing nations that can significantly reduce environmental impacts. ILZRO's goal is to introduce new battery technology especially into growing renewable energy markets that can provide worldwide environmental improvement.

This plan is the final activity of first phase of a three phase program originally envisioned as part of the MEM/SEIA/ILZRO agreement. The three phases originally planned include:

> PHASE I - Feasibility Assessment (including engineering, economics, socio-economics, policy implications, etc.)
>
> PHASE II - Hardware Validation (installation of RAPS at 2-4 sites in Amazon region, assessment of viability of RAPS sustained business)
>
> PHASE III - Replication (installation of RAPS systems at 100-200 sites as part of sustained business enterprise)

The first step was completion of a preliminary feasibility study entitled *Preliminary Design Analysis: Engineering Feasibility Study to Assess RAPS Potential in the Amazon Region in Peru* in January 1998. The second stage was an assessment of the socio-economic impacts of RAPS systems in Loreto and led to the report entitled *Socio-Economic Evaluation for Loreto Province, Peru Remote Area Power Supplies (RAPS)* completed in April 1998. This project plan provides the details of engineering design, project management, system operation and maintenance, and project costs that will be necessary to go forward with project financing and installation.

1.2 Site Selection

An assessment of project sites was conducted by MEM and ILZRO and reported in the report *Socio-Economic Evaluation for Loreto Province, Peru Remote Area Power Supplies (RAPS) prepared by Energia Total.* The study investigated nine (9) communities in the Loreto province and evaluated the locales based on political screening, geographical location (centralized vs. dispersed locations), financial rate of return, potential for productive uses. Condition of existing power system, management capabilities of local village, and start-up electrification opportunities. The study assumed a baseline engineering design from the feasibility study for a 300 kWh per day RAPS unit consisting of two 150 kWh per day modules. The final site selection recommendations allows for variation in size an productive use while remaining within a centralized geographic area and included:

One 300 kWh per day unit for Padre Cocha, a village of 250 consumers near Iquitos slated to receive a new diesel generator and electric system

Two 300 kWh per day units for Indiana, a well managed village with 380 consumers near Iquitos that has great potential for productive uses

One or two 300 kWh per day units for Mazan, a trading post village near Indiana, with 30 commercial and 30 residential consumers, that would benefit from increased electricity availability

One 150 kWh per unit for 7 de Febrero, a small community near Nauta.

One 150 kWh per day unit for San Francisco, a small community near Nauta.

1.3 *Estimated Loads at Selected Sites*

The Padre Cocha community is scheduled to receive a new power system consisting of a 100 kW diesel generator and a new distribution system. The estimated initial energy demand for Padre Cocha is 300 kWh per day, with a peak of 60-80 kW. Indiana has an existing 200 kW diesel generator and a three phase distribution system, with intermediate voltage (~ 30 - 60 kV) primary feeders from the generator and 480 Volt low voltage distribution lines. Indiana currently has power for five hours per night, and energy production is estimated at 500-550 kWh based on reported fuel consumption of 11 gallons per night.

The loads for these communities fall into four primary categories:

Residential – typically consisting of a number of small lights along with a TV, radio and miscellaneous small electrical loads such as fans.

Commercial – similar to a residential load, except that there may be slightly more lighting, and many establishments have a refrigerator for cooling food products and drinks.

Institutional – street lighting and water pumping / purification are the primary loads. Also includes health clinics, community centers, police posts, telecommunications systems and government schools.

Private – widely varying – ranging from private schools through small industrial establishments, and also potentially including small inns, restaurants and eco-tourism facilities.

The estimated load profiles that will be served by the RAPS systems installed for Padre Cocha and Indiana are shown in Figures 1 and 2.

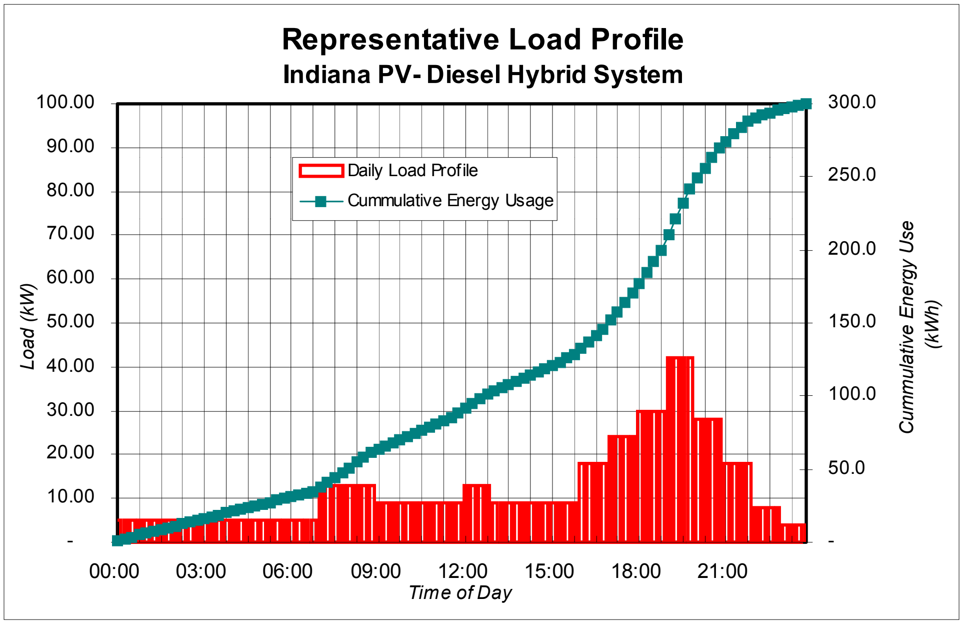

Figure 1 -- Padre Cocha Load Profile

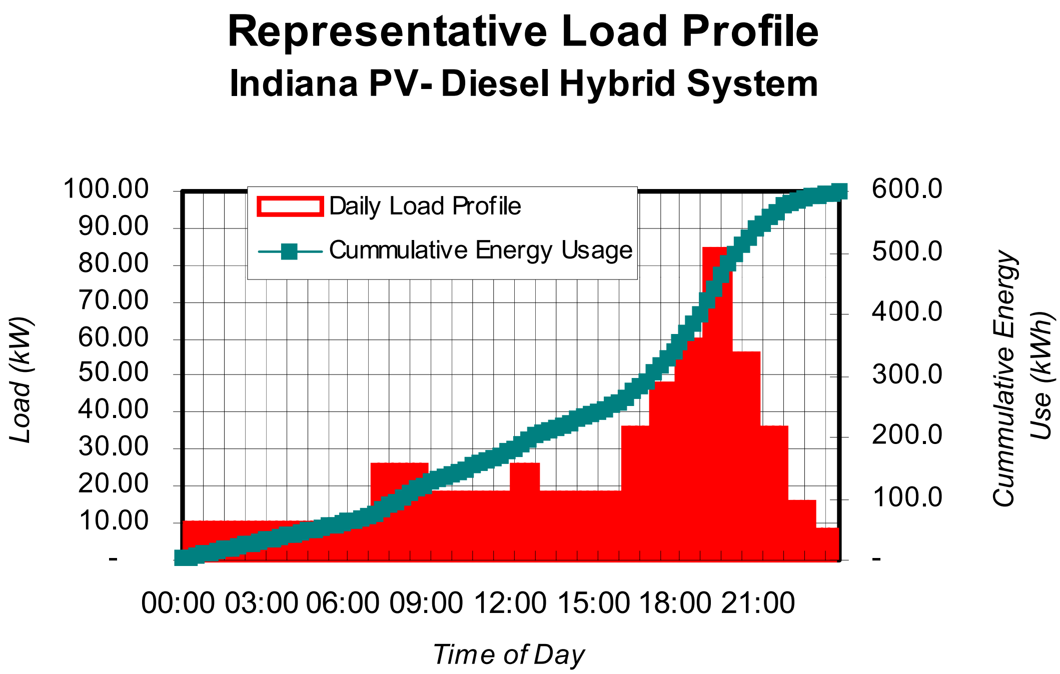

Figure 2 - Indiana Load Profile

1.4 *Planned Project Installations*

Project funding limitations as well as other limitations have reduced the baseline project scope to include:

- one 300 kWh per day RAPS system for installation at Padre Cocha. The unit will include two 150 kWh RPS-150 power modules and two 15 kW photovoltaic arrays integrated into a newly installed 100 kW (estimated size) diesel generator and electric grid.
- one 600 kWh per day RAPS system for installation at Indiana. This system will include four 150 kWh per day RPS-150 power modules and four 15 kW photovoltaic arrays integrated into the existing 200 kW diesel generator and electric grid.

The "Project Costs" Section discusses other project alternatives.

2. Engineering Design

2.1 RPS-150 Packaged Power Module

2.1.1 Configuration

The “RPS-150” module consists of a battery system, power electronics and controls package housed in a 6 meter (20 ft) ISO shipping container. This unit will be connected to a PV array and to the existing diesel generator. In normal operation, the load will be run off of the battery, with the PV array providing recharge as available and the diesel providing recharge as required. See section 4 for a detailed description of the system performance.

These modules are designed to be paralleled, and the proposed systems will use 2-4 of these modules to supply the 300-600 kWh per day load.

Module Specifications:

- Battery Bank – 750 Ah @ 240 VDC (or equivalent), consisting of two parallel strings of 375 Ah.
- PCS (Power Conversion System) -- 40 kW bi-directional inverter with sine wave output. Unit parallels with other inverters as well as with a diesel generator.
- PV array – up to 50 kW(p) of PV array (18 series, 18 parallel of nominal 50 W(p) modules)
- Control / Monitoring System -- Monitors battery string voltage, string current and temperature, PV array voltage and current, ambient temperature and other system parameters to determine Battery SOC and recharge requests.

2.1.2 Battery

The battery bank consists of two parallel strings of 375 Ah cells, for a total of 750 Ah at 240 VDC.

The battery is a gelled electrolyte battery, specifically designed for heavy cycling renewable energy applications.

Cycling is specified to 2,500 cycles to 50% DOD, which translates to approximately 7-8 years of battery life.

2.1.3 PV Array

The PV array for the baseline module is sized to provide approximately 40% of the annual energy to the load. The nominal array size is 15.3 kW. The exact configuration of the array will depend on the battery voltage, PV module size and power electronic details.

For the purposes of this analysis, it is assumed that the battery will be 240 VDC nominal, and that an array of 18 series modules (at approximately 17.0 V max power point) will provide sufficient voltage to charge this array. The proposed array for the baseline system will consist of 17 parallel strings (a string is defined as a series connection of modules) of 50 W(p) nominal modules. Total array current is approximately 50 amps. This array will be divided into two sub-arrays. The power module will designed to accept up to four sub-arrays for future expansion.

(Note - If different modules are used, the total rating of the array will remain the same, with a change simply in the number of parallel strings. Similarly, if a higher battery voltage is used, there will be more modules in each series string, and less in parallel.)

The array will be mounted on a fixed-flat plate structure, elevated at least one meter from the ground to allow for bush growth. The array will be tilted at approximately 15 degree, facing the equator.

2.1.4 Power Electronics

The proposed system design requires a sophisticated power electronics package to supply power from the system to the community. This “Power Conditioning System” or PCS will act as both battery charger and inverter, and will be able to parallel both with like units and with a diesel generator, as well as to run in “current regulated” or standalone mode.

One PCS will be installed in each “RPS-150” power module. Each PCS will be connected to the battery and to the output bus.

Specifications for the PCS are:

- Rating – 40 kW / 50 kVA
- Surge – 200% for 5 seconds
- Battery Input - 240 VDC
- AC Output - 3 phase, 240 / 415 volts or equivalent
- Power Quality - Utility grade sine wave (5% THD, etc)
- Efficiency – more than 90% at 50% load and higher
- Units will be able to synchronize to and operate in parallel with one or more like units
- Unit will be able to synchronize to and operate in parallel with a diesel generator
- Unit will be able to operate as a battery charger (reverse power flow mode) when in parallel with a diesel generator
- Unit will have serial data bus for data transfer and control inputs

2.1.5 Controls / Monitoring

The control system will consist of a hierarchical distributed control system , with different elements responsible for specialized tasks. Typical configuration for each “RPS-150” module will include a PCS controller, a battery monitor, a PV Charge controller and a “Module Controller.” These controls will be linked via an industrial RS485 serial communications network.

Each community power system will have a single diesel generator, which will have its own automatic start controller.

Each community power system will have a single supervisory controller which will act as the overriding controller for the system, and will also provide single point data logging and remote monitoring interface.

2.1.6 Packaging

The RPS-150 power system equipment will be housed in a 6 meter (20 ft) ISO standard shipping container (outside dimensions 6m x 2.6m x 2.6 meter with doors on either end). The container will have two strings of batteries, one PCS and the appropriate control electronics. One master module per system will also have the system bus for interconnection of the diesel generator, and load output combiner circuit, along with the supervisory control and monitoring system.

The diesel generator will be housed in its existing structure.

The PV arrays will be mounted in a separate array field, with power wiring to the appropriate module.

The system enclosure will be designed so that it is completely pre-assembled and tested before shipping to the site, and can simply be mounted on a concrete pad. The array support structures will be specifically designed to minimize use of concrete through a pier-based design.

2.2 Community Power Plant Design

2.2.1 Configuration

Each RAPS Community Power System will consist of the following subsystems:

- One or more RPS-150 Power Modules
- Diesel Generator Interface / Switchgear for existing diesel generator
- Supervisory Controller / Main Power Bus
- Remote Monitoring System

The RPS-150 is described above.

The following sections describe the other subsystems.

2.2.2 Generator Interface

This subsystem consists of controls and switchgear required to provide the following functions:

- Automatically start the diesel generator
- Monitor the generator for faults
- Monitor generator output to allow the PCS to synchronize the generator
- Provide power transfer switch and over-current protection for the generator.

2.2.3 Supervisory Control System

The supervisory control system consists of a system controller that has access to all of the individual subsystem controllers. In this system, it will monitor any installed RPS-150 power units via their subsystem controllers, and will also communicate with the diesel generator controller described above.

The supervisory controller will perform the primary control loop, and will also be responsible for all data logging required for the system.

The supervisory controller will also serve as a single point communications interface between the system and the outside world, via both a local user interface panel and the remote monitoring system described below.

The main power bus will allow connection of the PS-150 modules and the diesel generator to the main community feeder. It will also provide for future expansion of the system by allowing additional RPS power modules and larger generators to be connected to the system.

2.2.4 Remote Monitoring System

The remote monitoring system will consist of a satellite link between each of the remote community power systems and one or more central host computers. The remote systems will gather system data during the course of normal daily operation. The host computer will automatically download this data each night, and will process it for maximum usefulness.

The system will produce a daily summary report, with baseline data on each system. If additional information is required, the system operator will be able to access the actual 15 minute data logs for each system.

The system operator will also be able to call each system and get actual operational status of the system. In addition, the operator will be able to change system setpoints and to force operation of certain functions (such as generator start) in order to test the system.

Although the exact communications system has not yet been selected, it is anticipated that we will use one of the new LEO (low earth orbit) global coverage satellite systems. The host software will be designed so that the data can be access from any site with the appropriate passwords.

2.3 Community Power Plant - Padre Cocha (300 kWh per day)

The Padre Cocha Community power system will consist of the following subsystems:

- (2) RPS-150 Power Modules
- Diesel Generator Interface / Switchgear for existing 100 kW generator
- Supervisory Controller / Main Power Bus
- Remote Monitoring System

2.4 Community Power Plant – Indiana (600 kWh per day)

The Indiana Community power system will consist of the following subsystems:

- (4) RPS-150 Power Modules
- Diesel Generator Interface / Switchgear for existing 200 kW generator
- Supervisory Controller / Main Power Bus
- Remote Monitoring System

2.5 Community Power Plant – Mazan (300 - 600 kWh per day)

The Indiana Community power system will consist of the following subsystems:

- (2) or (4) RPS-150 Power Modules
- Diesel Generator Interface / Switchgear for existing diesel generator
- Supervisory Controller / Main Power Bus
- Remote Monitoring System

2.6 Community Power Plant – 7 de Febrero (150 kWh per day)

The 7 de Febrero Community power system will consist of the following subsystems:

- (1) RPS-150 Power Modules
- Diesel Generator Interface / Switchgear for existing 60 kW generator
- Supervisory Controller / Main Power Bus
- Remote Monitoring System

2.7 Community Power Plant – San Francisco (150 kWh per day)

The San Francisco Community power system will consist of the following subsystems:

- (1) RPS-150 Power Modules
- Diesel Generator Interface / Switchgear for existing 40 kW generator
- Supervisory Controller / Main Power Bus

- Remote Monitoring System

3. Project Implementation

3.1 Organizational Structure

The implementation of a successful project will require a well organized project organization with clear lines of authority. The project will be directed by a “Project Administrative Council" made up of representatives of the project funding contributors. Oversight will be provided by a Project Manager, appointed by the Council.

A prime contractor with the ability to design, manufacture, and install the RAPS systems will manage the entire technical portion of the project. The prime contractor will select appropriate subcontractors for appropriate tasks, especially local tasks. The prime contractor will report directly to the Project Manager appointed by the Administrative Council.

Successful completion of this project will also require coordination with other agencies and entities within Peru and elsewhere

3.2 Prime Contractor - Project Implementation

The project will be managed by a single engineering prime contractor, who will be responsible for:

- system design
- establishing and maintaining the project schedule
- purchasing all components and maintaining cash flow
- management of all subcontractors
- preparation of quality control, testing and commissioning plans
- preparation of status reports and coordination with the Project Administrative Council (via the Project Manager)

A large part of the work will be performed by subcontractors in Peru, including:

- Site survey and community awareness meetings
- Assembly / testing of RPS-150 power modules
- Site preparation and installation of PV arrays
- Installation / commissioning of systems
- Operation and maintenance for the systems

The prime contractor will have a full time project manager for the duration of the project, and will also use in-house project engineering, CAD and software development resources. The project manager will also be responsible for supervision of assembly and installation tasks in Peru, in coordination with the local subcontractor(s).

3.3 Project Schedule

The proposed project will take approximately eleven (11) months to implement, and will include four major phases:

- Engineering Design / Community Preparation

- Assembly and testing of initial power system in US
- Assembly and testing of remaining power systems in Peru
- Installation and commissioning of systems

Although the initial design and fabrication of the first system will take place in the US, the majority of the work for this project – from site survey and community awareness meetings to fabrication of the majority of systems – will take place in Peru.

The following schedule and outline provide the details for the specific project tasks to be undertaken.

Peru RAPS Schedule

	Month 1	2	3	4	5	6	7	8	9	10	11
Phase I – Final Engineering Design											
Prepare final engineering design.	■	■	■								
Prepare final software specifications (control and host/monitoring).		■	■								
Prepare draft operations / billing plan.			■								
Finalize satellite data link design.			■								
Get firm commitments from all vendors, including cost and delivery.	■	■									
Set up subcontracting arrangements and tasks for Peru.		■	■								
Major Components design review.		x									
Identify any long-lead items and order.		■									
Do final site surveys and draw up detailed site plans.			■								
Do formal energy survey at each site.			■								
Hold village seminars to raise awareness and set rules			■								
Finish with design review in Peru.			x								
Coordinate with other agencies as necessary.			■								
Ship Peruvian materials to US for first two units.			■								
Prepare Energy Management Plan.			■	■							
Phase II - Production – Unit 1											
Order materials, specifying shipment to either Peru or USA.			■	■	■	■					
Fabricate Unit 1, test, complete "as-builts" and ship to Peru.						■	■				
Develop quality control plan for Peruvian-built system.							■				
Develop commissioning tests and procedures.							■				
Get shop in Peru ready to build units.						■	■				
Begin site preparation at all sites.							■	■	■	■	
Begin testing of satellite data link.								■	■	■	
Phase III - Production – Units 2 - 6											
Build units 2-6, and test per QC plan.								■	■	■	■
Continue site preparation at all sites.									■	■	■
Begin implementing energy management plan.										■	
Begin training for maintenance contractor.										■	■
Phase IV - Installation – Sites 1-2											
Install PV array at site 1.								■			
Install 2 units at first site.									■		
Connect to diesel generator and perform commissioning test.										■	
Install satellite monitoring system and begin commissioning.										■	■
Install PV array at site 2.									■		
Install system at site 2.										■	
Connect to diesel generator and perform commissioning test.											■

The primary tasks for each of these phases are described in the subsections below.

3.3.1 Phase I – Final Engineering Design

1. Prepare final engineering design. (Emphasis on local content.)
2. Prepare final software specifications (control and host/monitoring).
3. Prepare draft operations / billing plan.
4. Finalize satellite data link design.
5. Get firm commitments from all vendors, including cost and delivery.

6. Set up subcontracting arrangements and tasks for Peru.
7. “Major Components” design review. (This allows ordering of major components in time to speed production of the prototype. Major components are specifically the battery, the control electronics, and the power electronics.)
8. Identify any long-lead items and order.
9. Do final site surveys and draw up detailed site plans.
10. Do formal energy survey at each site.
11. Hold community seminars to raise awareness and set rules (no electric frying pans, etc)
12. Finish with design review in Peru. Coordinate with other agencies as necessary.
13. Ship Peruvian materials to US for first two units.
14. Prepare Energy Management Plan.

3.3.2 Phase II - Production – Unit 1

1. Order materials, specifying shipment to either Peru or USA.
2. Fabricate Unit 1, test, complete “as-built” documentation and ship to Peru.
3. Develop quality control plan for Peruvian-built system.
4. Develop commissioning tests and procedures.
5. Get shop in Peru ready to build units.
6. Begin site preparation at all sites.
7. Begin testing of satellite data link.

3.3.3 Phase III - Production – Units 2 - 6

1. Build units 2-6, and test per QC plan.
2. Continue site preparation at all sites.
3. Begin implementing energy management plan.
4. Begin training for maintenance contractor.

3.3.4 Phase IV - Installation – Sites 1-2

1. Install PV array at site 1.
2. Install 2 RPS-150 units at first site (I recommend one Padre-Cocha)
3. Connect to diesel generator and perform commissioning test.
4. Install satellite monitoring system and begin commissioning of remote monitoring.
5. Install PV array at site 2.
6. Install system at site 2.
7. Connect to diesel generator and perform commissioning test.

A more detailed description of certain tasks is provided in the sections below.

3.4 Formal Site Survey / Energy Survey

One of the most important tasks in the first phase will be a formal site survey, including both a physical survey of the site proposed for the power system installation and a more detailed survey of the loads proposed to be connected to the system. The sites to be chosen for the power systems should include enough additional land for expanded PV arrays and additional power modules to cope with future expansion. Considerations for the location of the present diesel generators will also have to be taken into account. There is some possibility that the generator at Indiana may need to be relocated because of its location in the middle of expanded community housing development. It is also very important at this point to identify the primary loads on the power systems, especially institutional loads which may have been ignore up to this point. This information will be used to coordinate the energy conservation plan, which is a critical part of this project. The "Energy Conservation" section of this project implementation plan has a more detailed discussion of these issues.

3.5 Community Awareness Campaign

Community involvement will be another critical area for the success of this project. While the community will not be directly involved in the design or fabrication of these systems, they will be intimately involved in the use of the systems, and therefore involved in energy conservation, system expansion and system maintenance issues.

Therefore, it is important to involve the communities and especially community leaders in the early stages of the project, in order to instill realistic expectations for system performance and to gather feedback at a time when it can still affect system design / project planning.

These discussions will need to cover tariff structures, energy conservation, community involvement and system limitations. The discussions can be held at the same time as the site / energy surveys in the first phase of the project.

3.6 Power System Assembly / Testing

The RAPS systems for this project have been designed as modular power units in order to facilitate standardization between sites and future expansion. Since all maintenance for these system will be handled out of Peru, it is critical that the local participants be involved both in the fabrication and installation of the systems. However, because much of the technology is being supplied out of the US, it is necessary to maintain a large degree of involvement of the prime contractor / system integrator.

For this reason, we have proposed that the system design and fabrication / testing of the first power be carried out in the US. This ensures that the system design will operate as specified under rigorous manufacturing and testing conditions.

This power module will then be shipped to Peru, where a facility will have been established to replicate the power modules for the additional community power systems. Obviously, this will take a great deal of coordination between the prime contractor / system integrator and the local manufacturing sub-contractor.

Project coordination will be the primary responsibility of the project manager (PM). The PM will be responsible for the development of production / quality control (QC) plans, along with factory testing plans. During the installation phase (see below), the PM will be responsible for overall crew supervision (through the subcontractor) as well as installation schedules and commissioning test plans.

3.7 Site Preparation / Installation / Commissioning

The installation phase for each community consists of four separate tasks including:

1. Site Preparation
2. PV array installation
3. Power Module Installation

4. System Commissioning

The project schedule calls for site preparation and array installation for the first site to be carried out while the power modules are being manufactured. Installation of the power system and commissioning will be carried out while the modules for site two are being assembled, and while the initial site prep for site one is being done.

The following sections describe each of the four tasks in more detail.

3.7.1 Site Preparation

Clearing and general leveling of land used for the power system. The initial site survey will identify the array field site and the location of the power modules. Although the array field does not need to be completely level, it should be reasonably level from east to west and either level or sloping downward to the north in a N-S orientation.

The array is configured as a number of smaller sub-arrays and strings, so the exact physical configuration of the array can be matched to the site with a fair amount of flexibility. Because the site is fairly near to the equator, shading of rows will not be a major factor, and will allow a small array field than would be required in a high latitude site. Underground wiring and conduit runs will also be planned at this time, both for array wiring, and for wiring between the RAPS power modules and the diesel generator.

3.7.2 PV array installation

The array mounting structure has been designed to minimize use of imported materials (especially concrete and structural metal beams), while maintaining the strength required to sustain operation during high wind conditions.

The array structure will be a pier-based system, with groups of modules wired in 18 module series strings and an appropriate number of parallel strings. The array field will include full grounding of structures as well as lightning / electromagnetic protection for the array field. Individual panels will be wired and pre-tested before mounting in order to minimize on-site installation errors. Diagnostic voltage / current checkpoints will be available for individual strings, partial sub-arrays and sub-arrays. Fuse / isolation and surge grounding protection will provided for each individual series array string.

3.7.3 Power Module Installation

Once the arrays has been installed and tested, the power modules will be installed. Since the battery / inverter power modules will have been assembled and completely tested prior to installation, this process should only take a couple of days after the modules arrive on site. The power modules require a simple concrete footing / foundation and are not especially sensitive to level installation. The power modules will require connection to :

- the PV sub-arrays
- other power modules
- the diesel generator
- the community distribution grid

During this phase, the automatic start and monitoring controls will need to be retrofitted onto the existing generators. The installation / commissioning plans will include detailed tests to be undertaken at each stage of the installation.

3.7.4 System Commissioning

Once the power modules have been installed and connected to the existing diesel generator, the system will be tested, first individually (PV system and diesel generator separately) and then in complete coordination. During later stages of this task, the community may experience intermittent power generation period during the day, when the generator is not normally operating. These test periods will be used to evaluate the full system operation versus predicted loads, etc. Once the system controls are operating reliably, the system will be allowed to operate in fully automatic mode for increasing periods of time, eventually culminating in a full-load operational commissioning test of the system lasting approximately one week. Training for the maintenance contractor will be undertaken during the installation / commissioning phase, and once the full load test is completed, the system will be turned over to the final customer.

4. System Operation / Maintenance

4.1 Typical Operation

Each community power system is designed to supply twenty-four hour, utility grade power to the community loads. The system operates primarily off of the battery during the day and night periods. Energy from the PV array is used to offset the load and recharge the battery when available.

The diesel generator run at full load in the evening to supply the system energy peaks. Any excess energy is used to recharge the battery. Typical generator operation under design conditions will be limited to 2-3 hours per day, beginning at around 6-7 p.m.

Power is supplied to the community through a 3 phase distribution network. Individual customers will have energy limiting meters, and loads such as streetlights will have timers to limit operation. (See section on Energy Management.)

The primary operating costs are for operation of the diesel generator. Since the amount of energy available from the solar array is fixed (limited), the generator must supply any excess energy used by the community. If the load is greater than the design load, the excess will be supplied by simply running the generator for slightly longer each evening. Conversely, if actual community energy consumption is less than the design, the generator will be used proportionately less.

Diesel generator operating costs can be broken down into two categories – fuel and maintenance. In addition to generator operating costs, the system will require a small level of normal maintenance, primarily related to the batteries. System maintenance functions will be provided by a subcontractor.

The batteries have an estimated lifetime of eight years, so the escrow for battery replacement can be considered an operating cost.

Finally, there will be costs associated with system administration.

Each of these costs is discussed in the sections below.

4.2 Fuel Usage / Costs

Fuel consumption for a 300 kWh per day community power system is estimated to be 32,800 liters per year. Fuel consumption for the 600 kWh per day system is double that, or 65,600 liters per year. Average daily fuel consumption is approximately 90 liters for the smaller community and 180 liters for the larger community.

This fuel is typically delivered in 200 liter drums, so the smaller community would use approximately 14 drums per month (1/2 drum per day), while the larger community will require 28 drums per month (slightly less than one drum per day).

The costs for fuel vary considerably, based on raw fuel costs and delivery costs, so we have used an average delivered cost of $0.60 (1.60 Soles) per liter, or $2.31 (6.2 soles) per gallon. (Note – US$1.00 = 2.70 soles)

Annual fuel costs at the 300 kWh/day community are approximately $20,000. Fuel for the larger system will cost approximately $40,000 per year. More detailed numbers are used in the economic analysis section.

4.3 System Maintenance - Generator

The primary maintenance required for the generator is oil changes, which are required every 250 hours. Since the engine runs slightly less than 3 hours per day, the generator will require only four oil changes per year.

Top end overhauls (decarbonizations) are required every 2,000-3000 hours. Since these engines are run at high loads, this will not be much of a problem, so the higher number is used. This translates to a top end overhaul once every three years.

Full overhauls are required every 6,000-10,000 hours. Once again, since the engines are run fully loaded, the higher value is more appropriate, so an overhaul will be needed once every 10 years. The life of a diesel generator is 20,000 to 40,000 hours, so the generator will easily last over the project lifetime of the system, due to reduced operating hours.

Experience in Loreto indicates that the typical generator maintenance costs are approximately $1.50 per hour of operation, so total costs are approximately $1,500 for each system. This includes labor and small parts (air and fuel filters, new starter batteries, etc).

The 100 kW generator in the smaller system uses approximately 15 liters of lube oil per oil change. At four oil changes per year and $1.50 per liter, oil costs will be $90 per year. The 200 kW generator in the larger uses has twice the oil sump capacity, so oil costs in that system will be approximately $180 per year.

4.4 System Maintenance - Other

Battery maintenance and other systems tasks can be performed every three months during oil changes. This primarily involves checking connections and taking individual cell readings of the system battery. The costs are more a function of the number of visits, rather than amount of equipment. This task can be done at the same time as the regular generator maintenance visits.

Another facet of system maintenance is the removal of brush growth from the array field. This must be done at regular intervals to prevent shading of the array. This task can be subcontracted to a local community entity.

Estimated costs are $500 per year both either system, including both parts and labor.

4.5 Battery Replacement Escrow

The batteries in the RSP-150 power modules will need to be replaced every 8 years or so. In order to ensure that the money is available to do this, and escrow fund should be set up so that 1/8 of the cost of replacement batteries is set aside each year. This money can be placed in a separate account, and can earn interest during the escrow period. When the time comes to replace the batteries, the money will be withdrawn and used to purchase the new batteries.

Obviously, it is in the best interests of the system administrators to maximize the life of the battery, since a change in the time required for battery replacement would have a significant financial impact. For example, if the batteries could be used for an extra year, a 300 kWh / day system with an $85,000 battery cost and a $10,000 annual escrow at 5% interest would see an increase of over $14,000 in the bank account at the end of the 9^{th} year.

The battery escrow should also be based on a percentage of revenues, rather than a fixed amount. This way, if the batteries need to replaced earlier due to increased cycling (which is due to increased load), the funds will already be in place because of increased revenues. Similarly, if the batteries are coaxed to last longer, the increased funds could be used to purchase a slightly larger battery.

4.6 System Administration / Revenue Collection

Although the system does not require a full time operator, tasks such as connections, revenue collection and general administration must be provided on an ongoing basis, and this function can be combined with a task to monitor the system and contact the appropriate authorities if there is a problem.

The administration tasks will be administered by a micro-enterprise located at a very local level. Each community may have its own enterprise, or there may be a regional enterprise with overall responsibility for a small cluster of systems. This enterprise could potentially be a non-profit business, a for-profit business or a co-operative.

The system administration tasks include:

- Revenue collection – this is done either through a pre-payment plan, or through a periodic billing schedule (monthly, quarterly and semi-annually / seasonally are all possibilities)
- Management of connections – adding and removing customer connections, servicing existing connections when problems occur, etc.
- Management of fuel deliveries and maintenance subcontractor
- Management of battery escrow funds and the battery replacement task in year 8.
- Financial and physical planning for future expansions due to load growth

4.7 Recycling Plan

There are two primary items in the RAPS system, which will require recycling for environmental purposes – the batteries and the used engine lube oil.

4.7.1 Battery Recycling

The batteries are made largely from lead, so it is critical to the environment that they are disposed of properly. This task will be done when the new batteries are purchased and installed. Typically, the battery installer will remove the old batteries and bring them to a recycling center. Since all of the batteries will be replaced at the same time, it should be easy to ensure that they are properly removed from the community.

The financial incentive to do this recycling comes from the fact that the used batteries have a significant salvage value. The system administrator will arrange to use some or all of the salvage value to pay for the transportation and installation of the new batteries and the costs of transporting the old batteries to the recycling facilities. This arrangement is typically made with the battery dealer when the new batteries are purchased.

4.7.2 Lube Oil Recycling

Disposal of used lube oil from the diesel generators has traditionally been a problem with remote generators. This used oil is generated every time an oil change is performed, which is 35 times per year for a continuously operating diesel generator. For a 200 kW generator with a 30 liter oil sump, the annual production of waste oil is 1,000 liters, or 5 full drums.

Because of the dramatic reduction in the operating hours of a hybrid, only four oil changes are required per year. Total production of used oil is 60 liters per year at the 300 kWh per day community and 120 liters per year at the larger community.

Disposal of used oil traditionally has been done in one of three methods: removal of oil from site for recycling, burning of used oil by dripping it into the fuel supply of the generator, and pouring it into the ground.

Obviously, the latter method is totally unacceptable for environmental reasons. The second method is also unacceptable because of increased emissions from the generator, so the only reasonable choice is to collect the oil and transport it to a centrally located recycling facility (in Iquitos). Because of the small amounts of oil produced, this can easily be done once per year during one of the fuel delivery or maintenance visits.

The system administrator should have a written procedure with the maintenance subcontractors with a specific check-off to ensure that the oil is recycled in this manner. Along with the oil recycling procedure, the fuel delivery or maintenance subcontractors should also be required to remove all used fuel drums from the site during each visit.

5. Emissions Analysis

5.1 Methodology

5.1.1 Diesel Generator Emissions

According to National Park Service documents, a moderate sized diesel generator produces the following emissions per 1,000 US gallons of fuel used:

- 11.9 tons of Carbon Dioxide (CO2)
- 575 pounds of Nitrous Oxides (NOx)
- 22 Pounds of Total Suspended Particulates (TSP) (smoke)
- 49 pounds of hydrocarbons (HC)
- 28.5 pounds of Sulfur Dioxides (SO2)
- 812 pounds of Carbon Monoxide (CO)

In order to estimate emissions for the proposed project, we simply multiply fuel consumption (in 1,000s of gal per year) by the values listed above. The total emissions can then be calculated both on a yearly basis and a "total system life" basis. This ignores the benefits of running a diesel generator at full load versus partial load, but it gives a conservative estimate of the savings.

Notes:

- CO2 is the major greenhouse gas.
- NOx, SO2 and HC are the major contributors to ozone creation and "acid rain" type of pollution.
- Hydrocarbons and smoke (TSP) represent more of a localized irritant / hazard.
- Carbon monoxide is more of a problem for systems in enclosed spaces (such as generators inside of mines…).

5.1.2 Cost of Emissions

For life cycle costing, a cost per unit quantity can be assigned to the most important emissions. The National Park Service of the US recommends the following values for emissions:

- SO2 – US$0.75 per pound (ref. US National Park Service)
- NOx -- US$3.75 per pound (ref. US National Park Service)
- CO2 -- US$25 per ton (ref CONAM)

5.2 Emissions Analysis – RAPS and Prime Diesel

5.2.1 Background

The proposed project consists of one 300 kWh per day system and one 600 kWh per day system (or a similar combination). This analysis has been prepared based on this specific project.

Total fuel consumption for two prime diesel systems would be 430,500 liters per year (104,800 gal / yr).

Estimated fuel consumption for the two proposed RAPS hybrid systems is 98,350 Liters per year (25,500 gal / yr).

5.2.2 Greenhouse Gas (CO2) Emissions

Estimated CO2 emissions are as follows:

Communities with prime diesel	–	1,247 tons (US) per year
Communities with hybrid system	–	304 tons (US) per year
Net Savings	–	943 tons (US) per year
Life Cycle Savings	–	18,866 tons (US) over project lifetime

5.2.3 Total Emissions Analysis

System Descr	*Fuel/yr (Liters)*	*Fuel/yr (US gal)*	*CO2 (tons)*	*NOx (lbs)*	*TSP (lbs)*	*HC (lbs)*	*SO2 (lbs)*	*CO (lbs)*
DEG Total per yr	403,545	104,817	1,247	60,270	2,306	5,136	2,987	85,111
Hybrid Total per yr	98,352	25,546	304	14,689	562	1,252	728	20,743
Savings per year	305,193	79,271	943	45,581	1,744	3,884	2,259	64,368
Proj Savings - 20 yrs	*6,103,860*	*1,585,418*	*18,866*	*911,615*	*34,879*	*77,685*	*45,184*	*1,287,360*

5.2.4 Costs of Emissions

System	*CO2*	*NOx*	*SO2*
DEG Total per yr	$31,183	$226,011	$ 2,240
Hybrid Total per yr	$7,600	$55,084	$546
Savings per year	$23,583	$170,928	$1,694

5.2.5 Lubrication Oil Consumption - Proposed Systems vs. Prime Diesel

Lubrication Oil usage is based both on fuel consumption (0.1% of fuel consumption) and on maintenance intervals.

This usage of lube oil represents both additional pollution as well as disposal problems with used lube oil.

Assuming oil change intervals at 250 hours, and a lube oil capacity of 15 liters for a 100 kW engine and 30 liters for a 200 kW engine:

Lube oil consumption:

Communities with prime diesel	–	400 Liters per year
Communities with hybrid system	–	100 Liters per year
Net Savings	–	300 Liters per year
Life Cycle Savings	–	6,000 Liters over project lifetime

Oil Changes

Communities with prime diesel	–	35 oil changes per year * (15 + 30) = 1,575 Liters per year
Communities with hybrid system	–	4 oil changes per year * (15 + 30) = 180 Liters per year
Net Savings	–	1,395 Liters per year
Life Cycle Savings	–	27,900 Liters over project lifetime

5.3 Life Cycle Cost Analysis

Emissions costs can be considered as a separate cost addition to the standard life cycle costs of a system (i.e., capital costs, fuel costs, maintenance costs and non-recurring costs), so it is appropriate to address them separately. Moreover, the emissions costs are really based on a perceived “value,” rather than an actual expenditure of the customer, so it is proper that they be calculated separately.

Essentially, emissions costs are very similar to recurring system costs such as fuel or maintenance. In our analysis, fuel costs and maintenance costs are both inflated annually, at a rate somewhat less than the total discount rate. Fuel costs are inflated slightly higher than non-fuel (maintenance) costs, reflecting a perception that fuel costs traditionally lead inflation of overall costs.

Emissions are closely related to fuel costs, and therefore, the first inclination is to inflate them at the rate for fuel costs. Upon closer examination, this turns out to be a highly conservative estimate. Ten years ago, there were relatively few concerns about the costs of various emissions to the environment, and twenty or thirty years ago, the concept was practically unknown. Yet in the late 1990’s, there is a great deal of concern over the effects of emissions, resulting in increasingly high values being placed on emissions. In life cycle cost terms, this is similar to an inflation rate which exceeds the discount rate, thus increasing the real-money value of emissions over the life of the project. However, since this trend is so young, it is unwise to move too far in that direction, and the decision to inflate emissions values at the same rate as fuel costs is a conservative first step.

The life cycle cost analysis is as follows:

Life cycle cost for systems using prime diesel generators -- $3.60M or $0.55 per kWh produced.

Life cycle cost for systems using RAPS -- $0.88M or $0.13 per kWh produced.

Total savings by using RAPS -- $2.72M or $0.41 per kWh produced.

6. Energy / Load Management Plan

6.1 Background

One of the fundamental differences between diesel generator-based systems and renewable energy systems is that the former have traditionally been limited by power loading factors, while the latter are limited by daily energy consumption factors. This effect is increased by the fact that diesel generators are high non-linear in terms of price to power ratios.

A diesel generator, once it is installed, benefits operationally by moderate to high loading of the engine. Although this higher loading causes increased fuel consumption, it dramatically reduces carbonization within the cylinder and valve heads, and thus in general allows engines in generators to last longer.

This technological effect, along with the tendency to oversize generators and the limited run time associated with many generators, tends to encourage waste of energy during operational hours, in order to minimize carbonization and subsequent increased maintenance on the engine.

When converting to energy-based systems (i.e. hybrid renewable power plants), the emphasis shifts from power usage to energy usage This makes it important to concentrate on maximizing the amount of service deliver for the least amount of energy – which is the definition of energy conservation.

The following sections discuss the principle of energy conservation as they apply to the major types of loads in a hybrid power system, and as they apply to future load growth. The section concludes with a proposal for an energy management plan associated with installing hybrid power systems in Loreto, Peru.

6.2 Energy Conservation - Residential Loads

Residential loads in remote power systems can be divided into three general categories:

1. Lighting loads
2. Miscellaneous electrical loads (TVs, radios, fans, small appliances, etc.)
3. Cooking loads involving resistive heating (e.g. – electric kettles, electric rice cookers, electric frying pans, etc)

Lighting loads are best addressed by conversion to fluorescent lights – which deliver many times the amount of light for each kWh of electrical consumption. However, compact fluorescent lamps (CFLs) are many times more expensive than their counterpart incandescent bulbs.

The second category of loads is miscellaneous loads, primarily entertainment (TVs and radios), comfort (small fans) and convenience (small electrical appliances -- not used for cooking). In this category, the best energy saving technique is simply to limit consumption – i.e., don't leave the TV on if you are not watching it.

The third group of loads – resistive cooking devices, are simply not compatible with power-limited / energy-based renewable energy power systems. Traditionally, these devices are used either early in the morning (breakfast) or at dinner time, and their resistive nature translates to very high power demand peaks, which are difficult to supply with an isolated renewable energy-based power system. The best methods to limit use of this class of appliances is to install power limiting devices on the service entrance.

One way to deal with all of the above concerns is simply to provide each household with a device that provides not only power limiting functions (as in a traditional circuit breaker entrance to a house in the US), but also energy limiting functions. The customer would pay for a fixed amount of energy per day, and would have to make their own decision on how to use it. For example, if they are allotted 250 Wh per day and choose to use four 60 W incandescent bulbs, they will get approximately 1 hour per night of light.

However, if they use 11W fluorescent bulbs, the could have four bulbs for four hours per night and have enough energy left for running a TV or radio. Similarly, if they conserved lighting energy, they could have enough left to run a radio and / or fan during the next day.

Residential load management could be accomplished via a small energy limiting meter at the service entrance to each house. This meter could be programmed either for pre-payment or post payment options, and would be programmed to deliver a fixed number of energy units per day, with reset each evening to ensure at least a limited amount of lighting energy available.

6.3 Energy Conservation - Commercial Loads

Small commercial loads (such as retail shops) have many of the same constraints as residential loads, except that they often need to operate refrigerators during the day as well. These customers could use the same types of energy limiting meters as residential customers, except with higher energy setpoints (and consequently higher tariffs).

6.4 Energy Conservation - Institutional Loads

Institutional loads fall into three major categories:

1. Infrastructure loads such as streetlights and water pumping
2. Social loads such as community centers
3. Government loads such as public schools, health clinics, and police stations

The primary effort in this area will be to manage the streetlights. This will involve replacement of existing bulbs with high efficiency fluorescent bulbs, and addition of timers to street lights to allow operation for only the critical hours of the evening / early night.

The schools, community centers and other similar users will have to deal with energy conservation much the same as the residential users – they will be allotted a reasonable energy budget, and will make decisions on whether to “live within” the budgets using existing equipment, or whether to convert to high efficiency lamps, etc. to allow longer operation of their facilities.

6.5 Load Growth Management

Load growth is an inevitable consequence of providing power in any situation. In a community power scenario, there are three main areas of load growth:

- increase in average residential and/or commercial loads
- additional residential and commercial customers
- addition of industrial / productive use customer

The RAPS hybrid power system has been designed to accommodate up to 50% growth above the design load using additional equipment, and virtually unlimited growth via addition of new power modules.

If the load grows under the present system, the diesel generator will simply run longer each night to accommodate the extra kilowatt-hours. However, beyond a certain point, this puts too much stress on the batteries and on generator run time.

The next option is to add PV to the existing modules.

The next option is to add new power modules. These could be either additional RPS-150 battery/inverter/PV modules, or base-load generator modules. The final choice would be based on the current system economics.

However, because system expansion is capital intensive, it is important to try and limit residential load growth until the system revenues can support the investment in new equipment and/or increased operational expenses.

Productive-use load growth should be encouraged as long as the tariff structures are set up so that this segment pays a real value for their electricity (as opposed to what may be subsidized value for residential users). The extra revenue gained by signing up productive-use customers (which may include private schools, eco-tourism facilities, ice making plants or other small local utilities) must be sufficient to allow expansion of the power system to accommodate long term load growth.

6.6 Energy Management Plan

In order to make this project a complete success, an energy management plan will be required to deal with the conservation and load growth issues described above. This plan must developed in cooperation with community participants, as well as with agencies within Peru who have performed similar energy management activities. Many difficult decisions will be required, so it is important that participants at each level of the project have input.

We recommend that the Project Administrative Council work with the appropriate authorities in Peru to ensure that this vital task be carried out.

7. Project Costs

7.1 Overview

There are three primary cost categories associated with installing RAPS at remote communities:

- Equipment Costs
- Non-Equipment Project Costs
- Local Assembly and Installation

Each of these categories is discussed below

7.2 Equipment Costs

The equipment costs are based on the amount of equipment supplied. These costs include PV modules, structures, batteries, power electronics, control electronics, switchgear, equipment enclosures and remote monitoring equipment.

Each community power system is made up of one or more RPS-150 modular power units, plus a generator interface, supervisory controller and remote monitoring system. The last three items are essentially supplied at a fixed cost per system, no matter how many RPS-150 power modules are being used, so the system cost is calculated by adding these fixed costs to the cost of the number of power modules installed

The following table shows a cost breakdown for the three sizes of power systems:

		Padre Cocha	*Indiana*	*Mazan*	*7 de Febrero*	*San Francisco*
	Item	*300 kWh/d*	*600 kWh/d*	*600 kWh/d*	*150 kWh/d*	*150 kWh/d*
1	Battery	$77,000	$153,500	$153,500	$38,500	$38,500
2	PCS / Inverter - 40 kVA	$85,500	$171,000	$171,000	$43,000	$43,000
3	PV Array + structure	$189,500	$379,000	$379,000	$94,500	$94,500
4	Controls / Switchgear	$67,000	$110,000	$110,000	$47,000	$47,000
5	Shelter & Access	$43,000	$85,500	$85,500	$21,500	$21,500
	Totals	***$462,300***	***$899,600***	***$899,600***	***$244,650***	***$244,650***

7.3 Non-Equipment Project Costs

These costs include:

- project management - prime contractor
- non-recurring engineering (including controls programming)
- shipping (both international and local)

The project management and engineering costs are fixed (or nearly so) for a given project, regardless of how many power systems are being installed. For example, it will take a project manager most of a year just to get all the pieces in place to build and install power systems. The variable labor costs of doing additional systems are relatively minor. This makes a large project more cost effective than a pilot project. In addition, after the pilot project, many of the non-recurring engineering costs are minimized, reducing the cost per system substantially.

Shipping costs are variable, depending on the number and size of systems being installed. These costs include shipment of the major components and equipment shelters, as well as local transport to get the finished power systems to the site

7.4 Local Assembly and Installation

Assembly, testing, and installation costs are all variable, depending on the number and size of systems being installed. These costs are primarily labor costs, although foundations for the equipment shelters are included.

The assembly of RPS-150 modules will be done in Peru (except for the first unit), so this will require the services of a subcontractor who is familiar with electrical assembly. This process will be supervised by the prime contractor's project manager in coordination with a contractor supervisor. This process will also include testing of the unit at the assembly site in Iquitos.

Installation and commissioning of the power systems includes four basic tasks:

- construction of PV array foundations and mounting / wiring of PV array
- transport of the RPS-150 power modules to the site
- connection of power modules to PV array, diesel generator and grid
- commissioning of power system

7.5 Proposed Project Budget

The following section looks at three project alternatives.

The baseline project installs six RPS-150 modules in two communities – Indiana and Padre Cocha. This was designed to use the highest priority communities from the socio-economic report, and yet keep the project budget under $2 million.

The first alternative supplies the same number of power modules, but spreads them out over four medium and small systems.

The second alternative looks at the cost of supplying power to all systems recommended in the socio-economic report. This option shows the effect of reduced overhead, since the project management budget is only slightly larger than the baseline proposal.

Other combinations are also possible, depending on the budget available.

7.5.1 Baseline Project – Padre Cocha / Indiana

Power systems in Padre Cocha (300 kWh/day) and Indiana (600 kWh/day).

- Equipment Cost - Padre Cocha $462,300
- Equipment Cost - Indiana 899,600
- Project Engineering / Management / Travel 285,600
- Local and International Shipping 69,000
- Assembly and Installation 86,000
- Host Computer and Satellite Link 12,500
- Data Analysis 50,000

- ***Project Total*** ***$1,877,000***

The following table shows equipment costs broken out by component:

	Item		
1	Battery	$	230,500
2	PCS / Inverter - 40 kVA	$	256,500
3	PV Array + structure	$	568,500
4	Controls / Switchgear	$	177,000
5	Shelter & Accessories	$	128,500

7.5.2 Alternative 1 - Padre Cocha / 7 de Febrero / San Francisco / Mazan 1

This alternative uses the same number of RPS-150 modules, but divides them among two medium (300 kWh/day) and two small (150 kWh/day) power systems, rather than one large and one medium system in the baseline proposal.

- Equipment Cost - Padre Cocha $462,300
- Equipment Cost - 7 de Febrero 244,650
- Equipment Cost - San Francisco 244,650
- Equipment Cost - Mazan 1 462,300
- Project Engineering / Management / Travel 285,600
- Local and International Shipping 69,000
- Assembly and Installation 102,000
- Host Computer and Satellite Link 12,500
- Data Analysis 50,000
- ***Project Total*** ***$1,945,000***

The following table shows equipment costs broken out by component:

	Item		
1	Battery	$	231,000
2	PCS / Inverter - 40 kVA	$	257,000
3	PV Array + structure	$	568,000
4	Controls / Switchgear	$	228,000
5	Shelter & Accessories	$	129,000

7.5.3 Alternative 2 - Indiana / Padre Cocha / 7 de Febrero / San Francisco / Mazan 1&2

Power systems in Padre Cocha (300 kWh/day), Indiana (600 kWh/day), Mazan (600 kWh/day), 7 de Febrero (150 kWh/day), and San Francisco (150 kWh/day).

- Equipment Cost - Padre Cocha $462,300
- Equipment Cost - Indiana 899,600
- Equipment Cost - Mazan 1&2 899,600

- Equipment Cost - 7 de Febrero 244,600
- Equipment Cost - San Francisco 244,60
- Project Engineering / Management / Travel 304,800
- Local and International Shipping 138,000
- Assembly and Installation 182,000
- Host Computer and Satellite Link 12,500
- Data Analysis 50,000
- ***Project Total*** ***$3,450,000***

The following table shows equipment costs broken out by component:

	Item		
1	Battery	$	461,000
2	PCS / Inverter - 40 kVA	$	513,500
3	PV Array + structure	$	1,136,500
4	Controls / Switchgear	$	381,000
5	Shelter & Accessories	$	257,000

8. System Economics

8.1 Background

The following sections contain three separate analyses for estimating the system economics of the proposed RAPS power systems:

- Life Cycle Energy Costs
- Simple Pay-back analysis for a typical Community Power System
- Incremental DEG and PV energy costs for system expansion

When doing any economic analysis, there are a multitude of variables, including:

- capital costs (varies with number of systems installed in a single project, and may be tied to loan rates, etc.)
- fuel costs (fuel price varies over time)
- maintenance costs (varies over time as well as with number of system installed)
- system growth (energy supplied)
- non-linear costs (oil price fluctuations, etc.)

Thus, the costs / benefits for a project involving installation of a small number of prototypes may be significantly different than the cost / benefit analysis for a project involving dozens of systems. For this reason, all the following economic analysis are based on the assumption that at least 10 power systems will be installed per project, within a confined geographic location. They also assume operation of a significant number (10-50) of power systems within a specific region.

The life cycle costs are calculated according to standard techniques. The final result is expressed as cost per kilowatt-hour over the life cycle term. This is compared with a continuously operating "prime" diesel generator system configured to deliver the same amount of energy.

The pay-back looks at the costs and project income for a typical year of operation, then estimates a "simple pay-back" (in number of years) for the hybrid system.

The incremental cost analysis looks at the effects of varying the load by 25%, and then supplying the additional energy with either extended diesel operation or additional PV array.

8.2 Life Cycle Methodology

The life cycle cost analysis compares a 300 kWh per day RAPS to an equivalent 300 kWh per day prime diesel system. The full life cycle cost analysis is included in the Appendix.

The capital costs are for equipment only, they do not include shipping, installation or project management.

8.2.1 Economic Factors

Economic Factors

LCC Period	20 years
Discount Rate	10%
General Inflation	8%
Fuel Inflation	8%

Fuel Cost	$0.60 / Liter

8.2.2 LCC - Baseline RAPS System

Installed System Cost (Including Diesel Generator)	$554,000
Annual Fuel Usage	32,784 Liters
Annual Fuel Costs	$19,670
Annual Diesel Hours	1,004
Annual Maintenance Costs	$2,006
Battery Replacement Costs (at years 8 and 16)	$74,000
Total Life Cycle Energy	2.19 Million kWh
Total Life Cycle Costs	$1,024,868
Life Cycle Energy Cost	$0.468 per kWh

8.2.3 LCC - Prime DEG

Installed System Cost (Including Dual Diesel Generators)	$145,000
Annual Fuel Usage	134,515 Liters
Annual Fuel Costs	$80,700
Annual Diesel Hours	8,760
Annual Maintenance Costs	$13,140
Generator Replacement Costs (at years 8 and 16)	$120,000
Total Life Cycle Energy	2.19 Million kWh
Total Life Cycle Costs	$1,914,820
Life Cycle Energy Cost	$0.874 per kWh

8.3 Simple Pay-back Analysis

8.3.1 Consumer Energy Use

The socio-economic analysis performed by Energia Total, Ltd. listed a set of assumptions for residential, commercial and productive use consumers. We have added a fourth category – institutional loads (streetlights, schools, etc.), and adjusted the productive use numbers down slightly.

Using the example provided by Energia, this analysis discusses a 300 kWh per day RAPS system, with a net delivered energy of 270 kWh per day (10% losses). The same techniques could be applied to individual systems, or to a larger scale project involving multiple systems.

The assumptions for energy use are:

- Residential - Low: 15 kWh/mo.
- Residential - Medium 30 kWh/mo.
- Residential - High: 80 kWh/mo.

- Commercial - Medium 100 kWh/mo.
- Commercial - High: 200 kWh/mo.
- Prod. Use - Medium 400 kWh/mo.
- Prod. Use - High: 800 kWh/mo.
- Institutional - Streetlights: 800 kWh/mo.
- Institutional - Other: 400 kWh/mo.

The assumptions for number of customers are:

- Residential - Low: 50
- Residential - Medium 75
- Residential - High: 25
- Commercial - Medium 3
- Commercial - High: 2
- Prod. Use - Medium 1
- Prod. Use - High: 1 (could be a combination of more than one user)

The total energy budget is thus 270 kWh per day (300 kWh per day produced by the power system, less 10% losses).

8.3.2 Consumer Energy Cost Assumptions

System Cost

(qty 10 x 300 kWh power systems -- includes project overhead and installation)

Item	*Cost*	
Equipment ($462K * 90%)	$416,000	
Project Overhead + Installation	$78,000	per system
Total Cost per System	$494,000	

Income Factors

Initial Payment Per Cons.	$30.00
Service Charge	$10.00
No. kWh w/ Service Charge	15
Cost per Additional kWh	$0.53

Simplified Costs

Initial Cost	$494,000
Fuel Cost	$19,670 per year

Maintenance	$1,506
Battery Escrow	$10,000

8.3.3 Annual Income vs. Annual Operating Costs

This section covers the total income and operating costs for a typical RAPS system.

Total Energy Use / Income

Category	*No. Users*	*kWh/mo/user*	*$/mo/user*	*$/yr*
Res - Small	50	15	$10	$6,000
Res - Med	75	30	$18	$16,155
Res - Large	25	80	$44	$13,335
Comm - Med	3	100	$55	$1,982
Comm - Large	2	200	$108	$2,593
Productive - Med	1	400	$214	$2,569
Productive - Large	1	800	$426	$5,113
Institutional	1	1200	$638	$7,657
			Total Income -- Baseline Year	*$55,403*

Operating Costs

Item	*Unit*	*Qty*	*Unit Cost*	*Net Cost*
Fuel	Liters	32,784	$0.60	$19,670
Engine Maint.	hrs	1,004	$1.50	$1,506
System Maint.	visit	4	$250.00	$1,000
Battery Escrow	ea.	1	$10,000.00	$10,000
System Admin	person	1	$4,000.00	$4,000
			Total Annual Expenses	*$36,176*

Net Annual Income *$19,226*

8.3.4 Simple Pay-back Analysis

The simple payback of the system is simply the net cost of the system divided by the net income.

Installed Cost per Unit	$494,000
Capital "Buydown" @ 50%	$247,000
Net Capital Cost	*$247,000*
Net Annual Income	*$19,226*
Simple Pay-back	12.8 years

This analysis ignores load growth. However, this topic is covered in the following sections on Incremental Energy Costs. A more detailed business analysis would also include cost of financing, estimated cash flow, internal rate of return, etc.

8.4 Incremental Energy Costs

8.4.1 Load Growth and Incremental Energy Costs

When the load grows, the tariff structure must be able to accommodate the costs of generating the extra energy. This energy can be supplied in one of two ways – either by simply letting the diesel generator run longer hours each evening, or by installing additional PV capacity. The following sections look at the incremental costs of supplying the energy via the diesel or expanded PV array.

8.4.2 Load Increase - 25% Supplied by PV

If the system load increases by 25% to 375 kWh per day, the array would need to be increased by approximately 16 kW to maintain the diesel generator at the original fuel consumption. Assuming an installed cost of $7.00 per watt, the net cost would be $112,000. Lifetime (20 year) AC energy contribution would be approximately 500,000 kWh (assuming degradation to 80% of net power after 20 years), so the net cost of the PV energy would be $0.22 per kWh.

8.4.3 Load Increase - 25% Supplied by DEG

Increasing the load to 375 kWh per day without additional PV causes the diesel run time to increase by 320 hours over the baseline system, and fuel consumption to increase by 10,500 Liters per year. Additional energy contribution is 27,400 kWh. Additional fuel cost is $0.60 per liter, or $6,300. Additional maintenance at $1.50 per hour is $480. Total additional cost is $6,780 per year, or $0.25 per kWh. Note that addition of emissions costs to this number would increase it by up to $0.55 per kWh of diesel energy.