CHAPTER THREE
DISTRIBUTED GENERATION AND RURAL ELECTRIFICATION

3.1 Introduction

This Chapter provides a preliminary assessment of the issues impacting the electrification of remote villages in Honduras. Within this scope, ECCC reviews the primary values of electrification, optional approaches to electrification, and provides an economic analysis for delivering electric power to remote villages.

This analysis began with an overview of problematic conditions, which exist within the country and the associated impact on providing electric power to remote villages. This chapter examines the potential for providing rural power separate from conventional grid extensions (i.e., employing distributed generation).

This task examines options for operating isolated power generation with minimal distribution systems at remote sites. A brief discussion on the potential for regionalized (multi-village) grids is included; more detailed analysis addresses the operation of minimal (30 kW) isolated generation systems using conventional (diesel engines) and alternative technology (microturbine generation systems). Furthermore, this analysis addresses installation costs, fuel considerations, operational issues, and considers optimized system designs dependent on intended power needs. These system designs include options to provide power for community and residential activities, and to provide minimum power sufficient for micro-enterprises and local industrial needs.

The overall project approach is to provide a more generalized process for providing electric power to the remote inhabitants of Honduras including suggestions for multi-faceted solution including utility grid extensions, regionalized-isolated grid systems, and individual remote village solutions. The goal of this approach is to ultimately develop a “coordinated plan” for systematically delivering electric power to large portions of the rural population with a timely, cost effective plan.

3.2 Motivations and Objectives of Rural Electrification

Honduras has managed to extend its public utility grid system into many rural regions, but most rural villages currently lack viable electric power. Some villages receive power from solar or battery augmented supplies, but these systems only offer basic functions. In fact, because such large portions of the population dwell in remote, rural areas, it is estimated that at least 35 percent of Honduras’ population, and perhaps as much as 40 percent; do not have access to any reliable form of electric power. As discussed in Section 2.2.3, ENEE conducted a study to determine the costs to connect 649 of these villages to the national grid. ENEE reports that it will not bring grid connections to villages where costs exceed US $500 per household. Almost 75 percent of the villages surveyed by ENEE have connection costs higher than the $500 threshold. It is estimated in Section 2.2.4 that at least 30 percent of the population will continue to live without electricity. This situation creates a series of problems, which impact everything from the
general quality of life within the country, to development constraints, and health and public safety issues.

3.2.1 T&D Issues Impacting Rural Electrification

In addition to the large percentage of the population who live without access to electric power, an overriding problem in providing that power is the rather inefficient utility operations providing services within the country. Combinations of large amounts of “illegal” (stolen) electric power connections, and inefficient transmission and distribution systems result in current system losses estimated above 18 percent (the overall losses are more likely to be near 26 percent; see discussion in Section 2.4.2). These associated issues cause significant concerns for extending power supply systems into remote areas due to the high costs of doing business in those regions. This situation can also be hampered by a combination of high costs associated with extending facilities into remote, geographically challenging regions, and with higher-than-average O&M costs for those systems. When coupled with anticipated system “losses” that are well above the already high national averages, extending grid electricity to remote areas is a daunting challenge.

The concept of providing remote village power separate from the national grid offers considerable economic and operational values depending on locations and characteristics of selected villages. With a national goal to electrify as much of the population in as quick and efficient a manner as possible, it is likely that a combination of options will prove to be the best solution. As discussed in more detail later in this report, a “packaged approach” consisting of national utility grid extensions, independent and regionalized mini-grids, and isolated individual village electrification may provide the best method to accomplish these goals.

3.2.2 Benefits of Rural Electrification (RE)

A lower level of economic and social development typically characterizes rural areas. Average rural incomes tend to be much lower than income levels in urban areas, and rural employment generally is based upon simple agricultural economies (with some minimal industrialized development typically associated with local agricultural activity) and is generally labor intensive.

In this report, the basic rural unit is addressed as a “village”, which is identified as a geographic area occupied by a population that forms a social unit, and which generally represents the lowest level of government administration. A village typically comprises a central core population of households and central community operations along with several scattered groupings of individual homes and isolated farmsteads all located within the loosely described village area boundary. The average number of households in a rural village varies considerably. Many isolated villages in Honduras are composed of less than 50 households, but some isolated Honduran villages contain hundreds of households.

From a global perspective, it has been determined that providing a reliable and cost effective source of electric power in remote communities can improve the overall quality of life and provide the primary basis for economic development and expansion. Initially, electrification
can increase the efficiency of basic agricultural operations while allowing associated industries to develop to refine these products and provide value added benefits for exports. As this development takes place, additional industrial operations have the potential for development expanding the economic base of the community. Of key importance, electrification can provide a substantial value in the health and educational developments of the community through advances in medical technology, food and medicine refrigerated storage, drinking water supply and treatment, communications, and electronic educational services (computers, video instruction, instructional aids, etc.). Overall, electrification will substantially increase the general quality of life in the community while providing a foundation for future economic development.

A primary objective of rural electrification (RE) is to support the development of rural areas by increasing the welfare of the people and stimulating the growth of economic activities. Rural electrification must be planned hand-in-hand with economic development in order to reach sustainability. Therefore, rural electrification should be an integral part of the Government’s rural development strategy, with a longer-term target set to deliver electric power to all villages to improve welfare, enhance income-earning capacity, and help alleviate poverty. Rural electrification improves overall welfare levels by providing reliable lighting sources, improved health care services, modern education tools (computer with wireless internet access), and other productive activities that will increase productivity and income levels of rural residents. In addition, rural electrification facilitates diversification of rural development and makes an important contribution to poverty reduction in these areas.

From a longer-term perspective, electrification makes it feasible to start the process of technology change by facilitating increased productivity and economic development. Productive uses are essential to establish the long-term economic viability and sustainability of rural electrification, particularly where associated costs to provide power are high. Increased productive uses contribute to higher benefits and lower consumer costs. Load development increases power capacity utilization of generation and distribution systems, and enhances the rate of return (ROI) by decreasing total costs for power in relation to the high fixed costs associated with these systems.

### 3.3 Optional Approaches to Rural Electrification

Devising a suitable process, which will deliver electric power to the remaining areas of Honduras, is a large task. Accordingly, there exist numerous methods, which could be employed to accomplish these goals. While this report considers a multi-faceted approach, it is by no means the only approach. A systematic method of delivering electric power to Honduras’ rural areas can be conducted in the following matter:

a. Perform a complete village-by-village & region-by-region assessment analysis consistent with the "village selection process" (See Section 3.3.1)

b. Divide villages & regions into a “prioritized arrangement” dependent on the results of the selection process to determine the order in which areas are electrified as the project progresses.
c. Using a combined technical and financial evaluation method, determine which of the following 3 methods best applies to the village or region in consideration:

Method 1 – National utility grid extension
Method 2 – Regionalized power generation with localized mini-grid
Method 3 – Self-contained individual village electrification

d. Finally, establish an ultimate plan to eventually incorporate many of the regionalized mini-grids and some of the individual village systems into the national grid system when economically justified using the regionalized generation plants as system support capacity in these remote areas.

The priority option should be to expand the existing national utility grid into those regions that can be more easily included and cost justified consistent with the established project schedule.

Independent regionalized and village electrifications in the most remote areas will be based on a “criteria selection scheme” that can best be justified technically and economically while simultaneously meeting the objectives related to the potential for future national grid connections.

### 3.3.1 Village Selection Process

The need for a well designed “village selection and prioritization system” is at the core of Honduras’ national electrification process. Using carefully planned criteria, each village should be systematically assessed to determine prioritization for both economic potential and technical costs associated with delivering electric power. Each village would be given a prioritization based on an economically justified, cost-benefit analysis. Those villages with the highest potential would be given higher prioritization.

Generally speaking, villages which have demonstrated a high potential for growth and/or economic development and which can meet predefined technical and socio-economic criteria will score high in the selection criteria process.

Typical criteria utilized in this selection process would seek to classify villages by:

Current development level within the village including:

- Source of income
- Level of production
- Level of modernization
- Existence of village institutions
- Education level
- Community spirit
- Availability of infrastructure including industrial development
- Anticipated growth potential given the village’s attributes
• Estimated power load based on projected commercial & industrial development
• Distance from established grid and/or proximity to other villages

Villages would be assigned a priority level and classified into one of the three electrification project options:

Method 1 – National grid extension
Method 2 – Regionalized, independent mini-grid
Method 3 – Isolated village

Based on the assessment process, priority is given to villages that indicate the following attributes:

• A high economic potential
• Contain important regional development such as small-scale industries or potential for productive commercial, political and/or industrial uses
• Proximity to an existing or planned national grid (national grid connection option)
• Proximity to other high priority villages (mini-grid option)
• A high priority village in remote location (isolated electrification option)
• Lower priority village in path of grid extension or within area of mini-grid region

Based on these assessment criteria, and using an example of selection for an isolated (independent) electrification project, high priority would be given to villages at the furthest distances from the national grid with the highest economic potential.

The assessment process would use least cost planning tools for selecting villages to be electrified. The process would use cost effective design and construction standards for implementation of electrification projects to improve project economics, reduce losses, improve quality of power in remote systems, and expand the use of low cost grid construction and isolated generation methods.

ENEE’s efforts, as described in Section 2.2.3, provided a preliminary screening of some villages that could not be economically connected to the national grid. To avoid duplication of ENEE’s efforts, this report will use ENEE’s preliminary screening results and focus on electrifying the isolated, remote villages that were not included on ENEE’s rural village electrification list. It might prove economical (in remote areas) to establish an independent mini-grid comprised of multiple villages within a close proximity. This “mini-grid” would operate in isolation from the main grid, but this plan could also seek to ultimately connect any isolated villages to an independent, regional mini-grid with the potential of systematically connecting these “mini-grids” to the national grid in the future. Once connected, the isolated generation plants could continue to be used to support the national grid supply in these remote areas.
3.3.2 Isolated Village Approach

The isolated approach for remote village electrification would likely apply to a majority of smaller villages that are not in close proximity to other villages and would therefore not be considered for regionalized mini-grid connections. Approach for supplying power to these villages would vary from minimal critical supply applications to extended, full village power distribution schemes.

A minimal power supply scheme would likely supplement small solar powered battery based power supplies that are currently found in some individual houses. Most of the solar panels used in remote villages can provide approximately 100W power. This small amount of power is not sufficient for meaningful economic development. One hundred watts of power is sufficient to supply limited power for DC-operated radios, TVs, or small refrigerators. Since the minimum power scheme does not effectively stimulate economic development, this study does not look into solar power currently used by some villagers. Instead, the focus of this study is placed on installing minimal power that can be used to start some agricultural or industrial micro-enterprises with additional power for central village community lighting, some minimal commercial power for central village store(s) and some additional community power (for church and school facilities). In an ultimate village supply scheme, additional power would be available for homes in the core village area as well as some power for larger industrial operations in close proximity to the core village.

3.3.3 Potential for Regionalized Grid Approach

This remote power supply scheme includes a multi-village, regionalized distribution mini-grid with a single, centralized power generation plant. Villages would by necessity be required to be in reasonable proximity to each other and have sufficient power loads to justify the line work required for connection to the main power plant. Again, this process would be consistent with the “village selection and prioritization system” mentioned earlier. In Honduras, the lowest governmental administrative unit is the “municipality (municipalidad), which usually has political jurisdiction over and administers to several surrounding villages. The municipality is an ideal operational unit for regionalized mini-grid power generation and distribution systems.

Regionalized plants could vary significantly in size and geographic coverage area dependent on specific cost justification issues. The main objective in this scheme is to reduce costs by achieving some “economy of scale” in power plant size. Larger plants typically require less cost per unit of power delivered, and thus can be operated at substantial cost savings when compared with smaller units. These costs would be compared with investments in a wired grid system to connect each village to the plant. Typically, the distance between each village and the main plant would be less than five miles depending on terrain.

A small, regionalized grid would serve one community of three to four villages, which are in close proximity. Such a system may only require a 100 to 200 kW generation system. A much larger mini-grid system (500 to 1,000 kW and larger) might be justified to inter-connect dozens or more villages dispersed over larger areas, again dependent on cost justifications. Actual sizing would be dependent on geographical constraints, jurisdictional issues, and project
economics. All such “regionalized mini-grid systems” could eventually be systematically connected to the national grid once resources and technologies provide economic justification. Larger, regionalized power plants could remain in operation to provide distributed support for the national grid once interconnected.

3.4 DG Power Generation Options and Issues

Method two (regionalized power generation with localized mini-grid) and method three (self-contained individual village electrification) are both implementations of distributed generation (DG) approach. Distributed Generation is defined as generating power at or near consumption sites. DG is described in Section 2.1.5. Some of DG’s various assets with specific relation to rural electrification are:

a. Lower total capital costs compared with central power plants for dedicated and specific power needs,
b. Quickest method for adding power to areas without electricity,
c. Fewer capital costs of T&D facilities and lines,
d. Minimal T&D line losses,
e. Minimal costs associated with upgrades or repairs to T&D on existing system,
f. Provides stand-alone power options for remote areas where T&D infrastructure does not exist,
g. Greater flexibility and convenience in comparison to central plants to implement combined heat and power (CHP, or co-generation).

3.4.1 DG Options

While numerous options exist to supply power in isolated regions, technical and financial considerations often limit the selection process. Technical project constraints as to the amount of power required, the fuel source, reliability of the supply, and environmental impacts will all play roles in the final decision. Financial constraints will also play an important role in regards to marketability, and in competing with existing or alternative power supply options.

Renewable Energy

A primary consideration for any rural electrification project is the cost and challenge of fuel transportation. Renewable energy sources, with their sustainable and almost free fuels, are often options in rural electrification projects. Renewable fuel sources, which might be useful in rural electrification projects, include: solar, wind, small-scale hydro, geothermal, or even biomass depending on the exact location and circumstances. Typically, these alternate options will become more expensive as system output requirements and increased reliability requirements are encountered. These renewable technologies are assessed in Section 2.3. It is concluded that the renewable energy technologies applied in these remote regions can often supply minimal, but unreliable power. They can be employed as supplemental energy sources for generating electricity, but they are not suitable for use as reliable primary energy sources. In any event, these renewable fuel sources are viable options, which should be considered along with other new technologies, especially when they are designed as supplemental power supply sources in combination with more reliable power generation schemes.
Fossil Fuel Fired Engines

Conventional power generation in remote areas typically will consist of conventional power generation technologies including fossil-fueled reciprocating engines, steam turbines, and gas turbines. New technologies including fuel cells may provide opportunities in the future, but currently they tend to be too costly (see discussion in Section 2.3.9). The core focus of this project’s evaluation centers on the basic electrification of the smaller, isolated, remote village power supplies in the 25 to 50 kW range and will examine the standard application of diesel engine technology and the newer, micro-turbine technology.

The main issues impacting the application of both the diesel engine and microturbine are:

- Installed equipment costs
- Fuel supply constraints and associated costs
- Availability of O&M services and parts (and associated costs)
- Operational reliability and safety of the system

Table 3.1 compares economics and efficiencies of DG technologies including conventional Diesel engines, gas engines, simple cycle gas turbines, and microturbine and fuel cell technologies.

### Table 3.1 Economic Comparisons of Distributed Generation (DG) Technology

<table>
<thead>
<tr>
<th>Technology Comparison</th>
<th>Diesel Engine</th>
<th>Gas Engine</th>
<th>Simple Cycle Gas Turbine</th>
<th>Microturbine</th>
<th>Fuel Cell</th>
<th>Photovoltaics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size Range (kW)</td>
<td>20–10,000+</td>
<td>50–5,000+</td>
<td>1,000+</td>
<td>30 – 200</td>
<td>50 – 1000+</td>
<td>1+</td>
</tr>
<tr>
<td>Efficiency (HHV)</td>
<td>36 – 43%</td>
<td>28 – 42%</td>
<td>21 – 40%</td>
<td>25 – 30%</td>
<td>35 – 54%</td>
<td>N/A</td>
</tr>
<tr>
<td>Genset Package Cost ($/kW)</td>
<td>125 – 300</td>
<td>250 – 600</td>
<td>300 – 600</td>
<td>*350 - 750</td>
<td>1500 – 3000</td>
<td>N/A</td>
</tr>
<tr>
<td>Turnkey Cost–no heat recovery ($/kW)</td>
<td>350 – 500</td>
<td>600 – 1000</td>
<td>651 – 900</td>
<td>600 – 1100</td>
<td>1900 – 3500</td>
<td>5000 – 10000</td>
</tr>
<tr>
<td>Heat Recovery Added Cost ($/kW)</td>
<td>N/A</td>
<td>$75 – 150</td>
<td>$100 – 200</td>
<td>$75 – 350</td>
<td>Incl.</td>
<td>N/A</td>
</tr>
<tr>
<td>O&amp;M Cost ($/kW)</td>
<td>0.005 – 0.010</td>
<td>0.007 – 0.015</td>
<td>0.003 – 0.008</td>
<td>0.005 – 0.010</td>
<td>0.001 – 0.004</td>
<td></td>
</tr>
</tbody>
</table>

*Commercial target price
[Reference; Gas Research Institute: “Distributed Generation Forum”, 1999]

NOTE: This table is supplied for "base" reference (based on standard U.S. installations) only and is not directly used in this report:

1. The prices indicated in the above table for the micro-turbine are referenced as “target prices” projected in 1999. To date, the industry has not been able to significantly reduce price levels to this target price of $350 – $750 / kW.
2. Installed costs as utilized in this report are well above the table’s estimates (based on standard U.S. installations) primarily due to the smaller size of the installation where overheads make up a larger portion of the gross...
project, the inclusion of extended package costs as specified, and that the units must be shipped and installed in remote areas.

3. O&M costs used in this report are likewise higher than estimates in the table (based on standard U.S. installations) due to a combination of lower utilization and the remote nature of the application and service.

3.4.2 Power Demands

A primary project parameter is the determination of power supply requirements and the anticipated load factor of the system. Various estimates were prepared for supplying different levels of power to the typical village including:

- **Level - 1 (basic community services)**: includes medical, school, and community center power with options for a central village battery recharging station
- **Level - 2 (extended community services)**: including the above basic services in Level-1 as well as limited commercial power for central village store(s) and a core village street lighting system
- **Level - 3 (core village power)**: includes Level-2 services as well as a minimal power supply to core village homes with limited amounts of industrial power available to close proximity applications

3.4.3 Power Utilization Issues

Assumptions for power utilization indicate that initial levels of power usage could be low with a gradual increase as villagers realize the value and benefits of electricity and add lighting and appliances to the circuits. An objective for any rural electrification project would be the development of a load utilization plan, to promote the full utilization of power generation investments by attempting to maximize the amount of power being supplied on a continuous basis. Some considerations here would be for "off-peak" battery charging power stations and options for refrigerated storage that could be programmed for "off-peak" operations. Through better utilization (increased and more level loading throughout each 24 hour day), the generation system could operate more efficiently and overall costs associated with the project could be reduced.

One key utilization objective would be to meet a targeted load factor of say 60 percent (i.e. power plants would be utilized at an average of 60 percent continuous load, based on its peak output capacity). This is primarily accomplished through a comprehensive load-scheduling scheme where villagers actively participate. Scheduling certain loads for specific times to "fill-in-the-gaps" will improve the load factor, reduce required capacity and improve project economics.

3.4.4 Fuel Supply Issues

The country of Honduras has no fossil fuel supplies or (piping) distribution systems in place, which makes fuel supply and associated costs the single most important issue when using anything other than renewable energy supplies as a fuel source. Currently, generation sets in Honduran remote villages do not have much choice but to utilize liquid fuels, which are readily
available and transported easily. Liquefied petroleum gas (LPG) or propane gas are potential options, but they are not economically competitive.

In addition, the nation’s roads in the remote areas addressed in this project are minimal, and there is no existing rail network. This becomes critical when it must be considered that all fuel for these remote generation facilities must be transported to the villages. This factor alone significantly decreases the reliability of the project while increasing costs substantially.

**Fuel cost** – Assuming a bulk fuel governmental contract for delivered diesel fuel supplied to the villages at a cost of US $1.25/gal and using fuel criteria for a typical diesel engine (with electrical efficiencies of ~33 percent HHV*), fuel costs can be estimated at roughly US $0.0925/kWh. Obviously, fuel costs represent the largest financial responsibility in providing power to remote villages. Should fuel costs rise above this assumed value in Honduras, it will make the fuel cost become a more dominant component of the overall cost.

**Fuel Storage** – In an associated attempt to reduce fuel costs and improve system reliability, it is recommended that these remote power plant facilities be equipped with at least 15-day fuel tank storage (preferably longer). An economic analysis of storage equipment investment vs. fuel & transport costs should optimize this sizing. In addition to cost savings, longer storage will allow the village to sustain power during periods of severe weather when roads may become inaccessible. As with all project equipment, fuel storage systems should be standardized by design to allow bulk purchases for optimal price and installation savings.

### 3.4.5 System Reliability Issues

As already discussed in the previous section, fuel supply constraints will present a significant reliability issue. Similarly, issues such as spare parts and trained labor to service the equipment available in these remote areas will reduce system reliability. By stocking routine spare parts on site, (and/or at regional supply locations) and training local villagers in minimal O&M requirements, some of these issues can be significantly reduced.

Equipment selection and suppliers can contribute greatly to a project’s success. By selecting higher quality equipment and coordinating supply and service agreements with vendors who have an established presence in the country, these concerns can be minimized. As in the fuel supply issue, it is recommended that the government coordinate this activity to ensure proper supply and service agreements are provided with the equipment and orders are placed as “bulk purchase” contracts to ensure best possible prices.

The actual choice of equipment can play a critical role in project reliability. Careful selection of higher quality, proven operational equipment with strong service records and full vendor performance warranties will inherently provide for reduced downtime and increased reliability.

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* HHV is the high heating value of the fuel, which includes the energy released when water vapor condenses to liquid water.
3.5 Engine Based Generation Options for Micropower

The two engine based options examined in this report are a small diesel engine and a microturbine. Numerous manufacturers of diesel engines exist, and specifications and costs were discussed with a number of them, including Caterpillar, Cummins and Perkins. The diesel engines in this ~35 kW size range are prevalent and specifications between quality manufacturers are extremely consistent. While a few commercial microturbine manufacturers, Capstone, Ingersoll-Rand, and Elliot are in current operation, the main supplier today is Capstone. The Capstone model 330 was considered for this study. This section provides a general review of the features and pros and cons of reciprocating engines and microturbines.

The definition of microturbine has not been unified. The term “microturbine” was first used by a group of MIT researchers in the early 1990s for developing a button-size (5 mm in diameter) turbine for the U.S. military. After 1995, the USDOE and power industry have loosely applied "microturbine” to small gas turbines of less than 1 MW. Lately, micropower and microturbine have been applied to generators producing less than 200 kW of power. This report prefers to adopt this latest definition.

Among various DG applications, micropower is a low cost solution to boost microeconomic development in many rural areas. As mentioned in Chapter 2, reciprocating engines have been the only choice for micropower generation until recently with the emergence of microturbines. Microturbines should help broaden the market for DG applications along with the existing technologies of reciprocating engines. Microturbines have some unique features, which provide for variety in customers’ selections, but microturbines cannot replace all merits of conventional reciprocating engines.

The advent of microturbines has stimulated new improvements for reciprocating engines. These micropower improvements can provide cost-effective thermal and electric energy, while reducing overall energy losses and emissions. Nevertheless, micropower has yet to acquire any substantial market share within the industrial sector, despite off-the-shelf availability of reciprocating engines and microturbines. Both systems can generate cost-effective power for specific applications, but several barriers often prevent micropower from offering the best option for small scale, remote-location DG solutions. The following are some of the barriers:

- Economics
- Product performance and availability
- Awareness, information and education
- Utility policies and regulation
- Planning, zoning and codes
- Environmental regulation
- Support market infrastructure

In addition to overcoming price concerns, regulation confusion and uncertainties often intimidate potential end users.


3.5.1 Micropower Status

Product Performance and Availability

Notable advances in technology, mostly in microturbine technology, have lowered the size threshold for commercially viable power generation equipment. Each of these technologies, however, offers advantages and disadvantages in specific site situations. The technology challenges can be categorized in these areas:

1. Reliability and Efficiency – meeting an electric efficiency goal of at least 30 percent is a challenge for microturbine technology. Field reports indicate that the current efficiency level ranges from 15 to 20 percent.
2. Commercial availability – reciprocating engines and large-sized gas turbines are the only non-renewable technologies fully commercialized.
3. Performance Considerations – the lack of technology maturation underlies the ability of microturbines to meet cost performance targets. Maintenance practices are still being developed as field experience grows, and a lack of standardized maintenance practices and confidence on longer-term maintenance costs tend to delay applications of this technology.

Awareness, Information and Education

The market has yet to acquire a good understanding of the range of benefits associated with micropower technology. These undermine the use of microturbines and reciprocating engines in DG projects. Not realizing the full benefits of micropower decision makers often opt for a more traditional solution, purchasing needed power from the grid. They often make the mistake of focusing on capital costs rather than life-cycle costs.

Utility Policy and Regulation

Many utilities have designed backup power rates that penalize “part-time” costumers. While these rates may accurately reflect the higher cost of “reserving” power capacity for these part-time costumers, they effectively act to restrain micropower implementation.

Interconnection is another critical issue. Utilities usually require interconnection design to incorporate relaying on the utility side of the meter to ensure that the grid is protected from any problems caused by DG. This interconnection requirement raises the cost of DG, and in most cases it represents as much as 15 to 20 percent of the installed cost of the on-site generation package.

Planning, Sitting and Zoning

Local zoning policies, building codes and standards, and other issues including union labor (in the U.S.) and 24-hour attended operations affect micropower projects, regardless of the technology used.
Environmental Regulations

Micropower projects, as with any other power generation project, require site permits. To this end, environmental impact studies are required. Microturbines have advantages over reciprocating engines on emissions controls. Microturbine manufacturers are trying to capitalize on this by marketing microturbines as a “green” power generation technology. Broadening the green renewables standard to encompass an overall efficiency standard would likely provide a boost to microturbine penetration in the DG market.

Supporting Market Infrastructure

A lack of established distribution channels for microturbines has lessened their current impact on the DG market. Reciprocating engines offer an advantage with extensive dealer and service network available, a ready supply of trained diesel engine mechanics, and a stockpile of spare parts available worldwide. However, some microturbine manufacturers, who are eager to secure a larger market share of DG, are planning to take advantage of the already well-established worldwide network of diesel engine dealerships. Many diesel engine representatives are welcoming microturbines as new products for their customers. However, most diesel engine representatives have yet to establish microturbines promotions. They are waiting more future developments in the microturbine industry before offering these products in their sales and service portfolios.

For micropower to realize its full potential to meet the energy needs of industrial facilities and isolated sites, a number of technology improvements are needed in order to compete with conventional options. Achieving improvements such as increased electrical efficiencies, reduced maintenance, greater reliability, and lower emissions – all at lower costs – still requires substantial research and development on the maturity of these technologies.

3.5.2 Reciprocating Engines

Reciprocating engines have long been used for electricity generation. They have gained widespread acceptance in almost every sector of the economy and are used for applications ranging from back-up units and stand-alone local power generators to base load electric power plants. Almost all reciprocating engines used in power generation including micropower are four-stroke and water-cooled diesel engines. Diesel fuel and natural gas fired engines are in widespread use, but it is becoming increasingly difficult to site diesel generator sets, especially in large sizes, because of strict emissions laws. Most natural gas units are stoichiometric (i.e. complete combustion with 100 percent theoretical air). However, newer units, especially in the larger sizes, focus on lean-burn technology that allows for increased efficiency and lower emissions. Lean-burn technology employs excessive air (i.e. more than theoretically required) to reduce combustion temperature and hence reduce NO\textsubscript{x} formation. To improve the performance of reciprocating engines, some important development issues are summarized in Table 3.2.
Table 3.2 Development Issues for Micropower Reciprocating Engines (USDOE)

<table>
<thead>
<tr>
<th>Issues</th>
<th>Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stoichiometry</td>
<td>Much current development work is centered on lean-burn technologies for natural gas engines. Lean-burn engines have much higher efficiencies than conventional stoichiometric engines. They also offer lower NO\textsubscript{x} emissions, mostly because of reduced peak combustion temperature. Research is ongoing to achieve cost effective NO\textsubscript{x} emissions catalysis for lean-burn engines.</td>
</tr>
<tr>
<td>Ignition</td>
<td>High efficiency engines will operate at higher-pressure levels that will require high-energy spark ignition systems. Glow plugs and lasers are being tested as ignition sources for natural gas engines. Laser offers potential to improve fuel efficiency and lower emissions by improving ignition timing and placement. This can also reduce maintenance requirements and increase overall unit reliability.</td>
</tr>
<tr>
<td>Combustion</td>
<td>Combustion chamber design is important to the efficient and complete combustion of fuels and the reduction of NO\textsubscript{x} emissions. Advances such as a pre-combustion chamber to mix air and fuel or partially combust fuel before introducing it into the main combustion chamber may be key to a successful low NO\textsubscript{x} lean-burn engine.</td>
</tr>
<tr>
<td>Cylinder Head/Valves</td>
<td>Cylinder head and valve design has significant influence on engine power output, efficiency, and emissions. Intake systems need to provide substantial airflow to produce proper airflow patterns to facilitate combustion. Exhaust systems must be designed to allow the exhaust to be pumped out of the cylinder with a minimum of work and heat transfer to the cylinder head and coolant.</td>
</tr>
<tr>
<td>Fuel Injection/Timing</td>
<td>How and when fuel is injected into the cylinder play important roles in fuel combustion. Therefore, it influences power output, efficiency, and emissions.</td>
</tr>
</tbody>
</table>

3.5.3 Microturbines

Microturbines are an emerging class of small-scale power generation technology. The basic technology used in microturbines is derived from aircraft auxiliary power systems, diesel engine turbochargers, and automotive designs. Most microturbine units are currently designed for continuous-duty operation and are recuperated to obtain higher efficiencies. Microturbines have good fuel flexibility. These units can burn both gaseous and liquid fuels including natural gas, diesel, kerosene, and synthetic gases obtained from gasifying coals, biomass, or wastes. Some important development issues for Microturbines are listed in Table 3.3.
### Table 3.3 Development Issues for Microturbines

<table>
<thead>
<tr>
<th>Issues</th>
<th>Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recuperation</td>
<td>Recuperators are air-to-air heat exchangers that use microturbine’s hot exhaust gases to preheat inlet air after it has been compressed. They are key to electrical efficiencies in microturbines. With recuperators, electric efficiency in microturbines is usually raised up to 26 to 32 percent, without them it ranges from 15 to 22 percent.</td>
</tr>
<tr>
<td>Single Shaft vs. Split Shaft</td>
<td>The development of single-shaft microturbine has allowed for simpler design and construction. This might lead to reduced unit maintenance. However, split-shaft design is necessary for mechanical drive applications.</td>
</tr>
<tr>
<td>Air Bearing vs. Oil-Lubricated</td>
<td>Microturbines are high-speed – 40,000 rpm or higher – rotating machines that require high-reliability bearing systems. Systems with air bearings eliminate the oil system and are simpler. They require less maintenance and have no parasitic oil pump load. However, oil bearings generally last longer and are perceived to be less prone to catastrophic failure.</td>
</tr>
<tr>
<td>Gasifiers</td>
<td>Gasifiers produce gaseous fuel from solids, such as coal and biomass. Small-scale gasifiers for use with microturbines are still in the development stage. Gasifiers could help microturbines gain wider market acceptance, especially where there is no fuel supply infrastructure such as in remote areas.</td>
</tr>
<tr>
<td>Power Electronics</td>
<td>Costs for electronics for power conditioning and grid connection is high. Standard interconnection or mass production may help reduce the price.</td>
</tr>
</tbody>
</table>

### 3.5.4 Comparisons of Price and Performance: Reciprocating Engines vs. Microturbines

Price and performance data on reciprocating engines are very well established. However, data for microturbines are based on a limited number of projects. Thus, comparison of price and performance should be done with cautions. The data presented in Table 3.4 were collected from a number of manufacturers and distributors.

An unproven track record is one of the challenges facing microturbine manufacturers. More operational hours and better reporting data are needed to prove this technology’s worth in the field. Microturbine is still an emerging technology and has had very limited field-testing. Limited data on longevity, actual efficiencies, and O&M costs of tested units, although available from the manufacturers, remains to be proven. This makes an accurate comparison between this technology and established technologies difficult. Comparison of critical issues are discussed below:
Table 3.4 Costs and Performance of Microturbines and Reciprocating Engines

<table>
<thead>
<tr>
<th>Technology</th>
<th>Reciprocating Engine</th>
<th>Microturbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>30 – 60 kW</td>
<td>30 – 200 kW</td>
</tr>
<tr>
<td>Installed Cost (US $/ kW)</td>
<td>200 – 800</td>
<td>350 – 900</td>
</tr>
<tr>
<td>Electric Efficiency (LHV)</td>
<td>27 – 38%</td>
<td>15 – 320%</td>
</tr>
<tr>
<td>Overall Efficiency</td>
<td>~ 80 – 85%</td>
<td>~ 80 – 85%</td>
</tr>
<tr>
<td>Variable O&amp;M (US $/kWh)</td>
<td>0.0075 – 0.02</td>
<td>0.004 – 0.01</td>
</tr>
<tr>
<td>Footprint (ft²/kW)</td>
<td>0.22 – 0.31</td>
<td>0.15 – 0.32</td>
</tr>
<tr>
<td>Emissions</td>
<td>NOₓ (lb/kWh)</td>
<td>CO (lb/kWh)</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.022 – 0.025</td>
<td>0.001 – 0.002</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.0015 – 0.037</td>
<td>0.004 – 0.006</td>
</tr>
<tr>
<td>Fuels</td>
<td>Diesel, NG, gasoline; larger units can use dual fuel (NG/Diesel) or heavy fuels</td>
<td>NG, Diesel, kerosene, naphtha, alcohol, flare gas</td>
</tr>
</tbody>
</table>

1 Cost varies significantly based on site and interconnection requirements, as well as unit size and configuration.
2 Assuming using for Combined Heat and Power (CHP)

**Installed Cost** – Installed cost is always the first consideration for many sites. It drives the economic consideration of on-site generation. Reciprocating engine manufacturers must continue to reduce prices in order to stay competitive in the DG market. Microturbine manufacturers must meet their cost targets to gain significant market share. Microturbines, on average, are currently more expensive by two to three fold than reciprocating engines, but are projected to become more cost competitive in the near future.

**Efficiency** – Currently, reciprocating engines have about three to four percent advantage in efficiency over microturbines of similar power rating. Increasing electric efficiencies in microturbines to 40 percent or higher will almost certainly require effective recuperation or multi-stage designs. Traditional designs of recuperators will make microturbines heavy, bulky and uneconomic; therefore, innovative ideas are required to design and manufacture small-sized recuperators matching the merits of current microturbines. This is crucial to microturbine success in the DG market. In rural areas with limited road accessibility, efficiency will affect the amount of fuel used. In turn, this will not only affect fuel costs and fuel transportation schedules, but it also will influence the size of fuel storage tanks, which can cost up to 20 percent of the initial capital costs on a project.

**Emissions** – Microturbines, like larger turbines, have a strong advantage over reciprocating engines in terms of emissions. Reciprocating engines have almost an order of magnitude higher CO and NOₓ emissions than microturbines. The emissions from Microturbines are getting better and moving toward single digit (ppm). As emissions standards become increasingly stringent, microturbines will offer a clear advantage over reciprocating engines.

**O&M** – Reciprocating engines require more periodic and more technically involved maintenance than microturbines. Microturbines have inherited lower O&M requirements than reciprocating
engines because of their simpler design and few moving parts. For example, one microturbine manufacturer claims that its products require almost no maintenance in the first 8,000 hours other than changing air filters. However, longevity of the main components of microturbines is yet to be fully proved. In rural areas, service calls are not only very expensive but also subject to the possibility of slow responses.

**Acoustics** – Microturbines emit low noise around 65 db (within five feet), which is much quieter than reciprocating engines. Inside a building, acoustic noise is an important issue. Although the noise problem can be resolved by constructing a soundproof enclosure surrounding the engine, this will increase installation costs and lead to reduced efficiency due to increased temperature inside the enclosure and increased cooling loads for the engine. In rural areas, noise is less of a problem since the engines can be housed in sheds adjacent to the buildings with DG power requirements.

**Fuel Flexibility** – Diesel engines typically burn diesel, although natural gas is also a feasible fuel. Microturbines are more fuel flexible. They can burn both gaseous and liquid fuels including natural gas, diesel, kerosene, naphtha, alcohol, flare gas, LPG and synthetic gases obtained from gasifying coals, biomass, or municipal wastes. The potential of integrating a gasifier with a microturbine provides promising future for electrifying rural areas using indigenous biomass as a sustaining fuel source. However, it requires at least a decade of R&D before the system can be commercialized and economically viable.

**Size and Weight** – At the same power capacities, microturbines are typically 40 percent smaller and lighter than diesel engines. The vertical designs of Capstone models make them have 45% of the footprint of a typical diesel engine.

![Figure 3.1 A Capstone Microturbine (left) and an Elliot Microturbine (right)](image-url)
**Useful Thermal Output** – To increase total utility of the fuel energy, the waste heat of engines can be effectively used for other purposes, usually for heating or drying, which are typically accomplished by generating superheated (dry) steam. The combined output of heat and electric power (CHP) is also called co-generation. The total energy conversion efficiency of CHP can be easily accomplished between 80 and 95 percent. Micro engines can also be used for micro-CHP. The waste heat of a reciprocating engine is disposed of as hot exhaust gas and hot water. The exhaust gas temperature of a small reciprocating engine is usually low and can barely make low pressure steam. Microturbines’ waste heat is disposed only through exhaust gas, which has higher temperature at, e.g. 320°C, than the exhaust from a reciprocating engine at, e.g. 150°C. Therefore microturbines have an advantage over reciprocating engines in CHP applications. In Honduras, coffee growers in remote areas could use waste heat from microturbines to dry newly picked coffee cherries within the first four hours after picking to improve the quality of coffee beans. The drying process can be automated by using conveyors to transport coffee cherries, courtesy of electric motors. This potential application for coffee growers will be discussed in detail in Section 4.6.

In summary, an increasing number of microturbine and reciprocating engine packages are available for micropower DG applications. Reciprocating engine manufactures are working on more efficient, lower emissions, lower cost units with less periodic maintenance requirements. To accomplish this, developments in advanced combustion systems, higher compression ratios, improved ignition systems, and better modeling, sensor, and controls are needed. Microturbines also offer good options, but they face a battle for commercial acceptance because of a lack of commercially installed projects. Installed cost, efficiency, and reliability need to improve to accentuate microturbines’ advantages over competing technologies. To achieve such improvements, microturbine manufactures are focusing on lower cost production of recuperators, power electronics, and gas compressors as well as high temperature resistant materials to improve overall efficiency. Based on the information in this section, an engineering and cost analysis of using micropower is conducted for a remote village in Section 3.8.

### 3.6 Power Distribution System Considerations

Design of the village power distribution system can range from a very simplistic, single-phase (1-Ø) system for community lighting and basic appliances, to a much more complex, three-phase higher voltage system capable of supporting small industrial loads and being distributed across a much larger area. Safety, costs and reliability will be the parameters that determine equipment selection and wiring configurations ultimately utilized. This report does not propose any specific design but does offer some generic considerations and a discussion of associated issues.

For practicality, distribution design should be maintained within nationally accepted ratings, i.e. to provide either 120/240 V, 1-Ø, 3 wire or the slightly more versatile 277/480 V, 3-Ø, 4 wire configurations. With the intent of ultimately using the power to promote industrialized economic development in the region and to perhaps move power a few kilometers to capture industrial electrification, the 480 V, 3-Ø system will likely provide the most versatility and capabilities to support the overall project's objectives. The primary drawback to this system is
that a step-down transformer will likely be required to accommodate the 120 V small appliance and miscellaneous residential load requirements.

The following two sections look briefly at distribution system considerations for isolated, remote villages on an independent mini-grid. Most of the internal village distribution system configuration is consistent with the regional system except that power comes in from a mini-grid in the regional system instead of being generated locally as in the remote village system.

3.6.1 Isolated Village Distribution System (minimal and extended cases)

Internal to the village, the electrical distribution system will accept power from the generator (or the incoming mini-grid's regional generation plant) and distribute it throughout the village area to satisfy power requirements. Power loads range from 120-V small appliances (computers, television, VCR players, residential lighting, etc.), to 240-V larger commercial applications (refrigeration, water pumps, etc.), and ultimately to even larger, more powerful 480-V industrial motor drives (conveyers, compressors, pumps, etc.).

Figure 3.2 provides a generic diagram as to the typical layout of the proposed village power system and possible distribution configuration.

![Simple Power Distribution Schematic](Figure 3.2: A Typical Village Power System Layout)
As seen in Figure 3.3, the main power generator can be connected to supply a multitude of voltage outputs in either or both 1-Ø or 3-Ø configurations when used with a system step-down transformer(s).

In a more detailed schematic, Figure 3.4 shows the electrical distribution system's components and basic switching and protection devices. [NOTE: specifications in this diagram are presented for discussion only, not for the actual project.]

As discussed in the previous sections, the village will likely want to encourage remote homes to use batteries as their power supplies to take advantage of the central village battery charger station. The batteries are typically lead acid; deep-cycle rated, with outputs of 12 volts and approximately 40 amp-hrs. Another value to this concept is that the charger station can be programmed to charge during low load and/or off-peak times in order to help support the overall system utilization (load factor). Figure 3.5 presents a simple diagram of a central village battery charging station.

**3 Ø Schematic: Stand Alone Generator Connection for Three-Phase Loads**

**(NOTE: Total Single Phase Unbalanced Load May Be Limited By Generator Rating.)**

**1 Ø Schematic: Stand Alone Generator Connection for Single-Phase Loads**
3.6.2 Regionalized Distribution System

The independent, regionalized mini-grid system previously discussed would consist of a larger, centrally located generator (likely 100 to 500 kW) that is strategically placed in a region which is within reasonable distance to a number of villages and industrial development sites. The
value to this design is the economies of scale and operating efficiencies of the main generator although drawbacks include the wire and pole systems that must be installed to physically connect the villages to the generation plant.

A detailed analysis of this design must be performed to optimize the generator sizing and plant location in contrast to the line extension costs associated with the mini-grid. A key value to this mini-grid system is that it can later be connected to the national grid with these larger generators left in place to provide distributed support for the grid system in the remote areas. Therefore, most all the infrastructure and investment in this system can continue to be utilized even after connection to the national grid.

Another key value to this approach is that it adds more system capacity and flexibility to promote and sustain increased industrialized development because power is generally available through a much larger region with sufficient diversification to accept more system loading. Figure 3.6 provides a rough diagram as to the concept behind this regionalized, mini-grid system.

Figure 3.6: Conceptual Drawing Of Regionalized, Mini-Grid System
3.7 Financial Considerations Impacting Rural Electrification

3.7.1 Overall Cost Issues and Considerations

From a national perspective, major issues impacting rural electricity delivery and management are:

- Securing adequate resources for investments that are economically justified but offer minimal financial viability
- Expanding electrification through cost effective, designs and installations
- Defining and implementing methods for rural grid and power plant management, maintenance and services that do not overextend available resources
- Maximizing local participation and cost sharing
- Designing tariff structures that recover appropriate costs without distorting price incentives for local generation and for efficiency

The electrification process will encompass a multi-level cost valuation plan including the following elements:

1. That a careful village selection and prioritization process as presented in Section 3.2.1 of this report would be consistent with the criteria that the villages selected for initial participation would have a potential for economic development so as to ensure that energy consumption will be sufficient to justify the investment in economic terms
2. That the connection of villages to the grid would be the least-cost solution to supply electricity
3. That the selection would be done following a process whereby local groups, i.e. local community and households, will have an opportunity to participate
4. That all the villages proposed will be selected based on reasonable economic rates of return

To ensure that the least cost project solution is realized, a combination of the following should be utilized in all phases of actual project construction and operations:

- Standardized design and equipment selection
- A careful choice of uniform specifications
- Centralized procurement for equipment, materials, and contract services

While investments in rural infrastructure need to be responsive to local needs, the villages proposed for electrification should confirm their desires to receive electric power, and they should agree to pay reasonable connection charges for capital costs associated with service drop connections to village power supplies and for internal household wiring and/or equipment needs.

Costs to install, maintain, and operate the proposed remote generation and mini-grid electrification options presented in this report will likely be higher than average costs to supply power in centralized urban areas. However, it is important to keep in mind that conventional grid supplied retail power in rural areas is typically two to three times higher than those in urban areas due to inefficient or poor technical grids and management systems.
It must also be kept in perspective that the primary objective of the remote village electrification process is to contribute to the development of economic activities in rural areas through the productive uses of electricity. This objective has far reaching values for the national economy outside the simple investment return on the electric facilities installed. Productive uses are essential to establish the long-term economic viability and sustainability of rural electrification, particularly where costs can be high. Increased productive uses contribute both to higher benefits and lower costs. Continued load development increases capacity utilization of the high fixed cost investments and therefore enhances the economic rate of return, as long as the tariff covers at least the variable cost of electricity generation. As such, the suggested tariff structure should not exceed the variable costs of generation, which are typically fuel and some O&M costs. It is strongly recommended that infrastructure costs for the capital equipment installations should be recovered through other mechanisms (e.g. through the Central Bank loans with credits from IDB, World Bank, EU, etc) so as not to have restrictively high power costs which might not be affordable to a majority of villagers thereby defeating the entire purpose of such a program.

3.7.2 Generation Cost Issues

The generation plant (diesel engine or micro-turbine) as considered here consists of the installed engine-generator, the fuel storage and supply system, the auxiliary systems (battery, starters, and chargers, cooling systems, muffler, remote start, control & monitoring system, and primary switchgear associated with the generator) as well as complete installation with appropriate foundations and enclosures.

Diesel Engine System Estimate

The diesel engine represents a well-established technology, which has a long track record of proven performance in power generation applications. The engines are available from a wide variety of suppliers and are supported for O&M services throughout the world. Capital costs for the engines are competitive and they typically represent the lowest dollar investment cost for a given power output. Normal O&M costs for the engines are generally reasonable although considerable routine maintenance is required and the engines must be brought down periodically for this service. For the village power applications under consideration, this normal maintenance will increase operational costs but should not seriously affect the reliability of the plant since maintenance can be scheduled to minimally impact power supply.

Diesel engines also represent a fairly efficient form of power generation when viewed as a simple cycle operation of less than 4 MW (see Section 2.2.3). One of the largest drawbacks for diesel technology is that fuel costs tend to be higher than equivalent natural gas supplies in areas where natural gas is available (in Honduras, natural gas is currently not a fuel option), and environmental emissions can be high.

Even in small engine sizes such as the nominal 35 kW units considered, the conversion efficiency is rated at approximately 33 percent (HHV) of fuel input (full load ratings with no system loads or deration applied). This roughly equates to an effective heat rate of about 10,342 btu/kWh, or about US $0.092/kWh. (W/diesel estimated at ~140,000 Btu/gal).
Budgetary quotes discussed with diesel engine vendors were consistent. For a nominal 35 kW rated peak supply (rated ~ 32 kW ISO prime duty at a 0.8 PF: ~ 40 kVa, with a rated output at 277/480-V, 4 wire, 3-Ø), the engine-generator package was estimated at US $12,000 to $15,000 including outdoor enclosure with fire & safety features. Inclusion of a heavy duty cooler (remote) and a 15 - 30 day fuel tank (~ 500 gal.) and fuel handling system was estimated at an additional US $5,000 or about US $17,000 to $20,000 for total system equipment. Installation, design, shipping, taxes & handling were estimated at another US $3,000 to $5,000 dependent on location and specific circumstances. Therefore, a complete “diesel generator project” is roughly estimated at about US $20,000 to $25,000 not including the village distribution system or any extended environmental permit/remediation issues (see Table 3.5). Price also does not include any extended service agreements or spare parts.

Table 3.5 Installed Cost for a Diesel Generation System

<table>
<thead>
<tr>
<th>kW Unit Cost (US $)</th>
<th>Installation Cost (US $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ 703/kW</td>
<td>20,000 to $25,000</td>
</tr>
</tbody>
</table>

As can be seen in Figure 3.7 diesel engine unit costs ($/kW) drops considerably as power output increases from the smaller units as evaluated in this section to units in excess of 250 kW. It should be kept in mind that the independent, regionalized mini-grid systems discussed in Section 3.2 would likely employ these larger, more cost effective engine-generator systems. Of course the distribution system costs associated with the mini-grid approach is considerably more expensive than that of the isolated village system.

![Figure 3.7: Diesel Engine-Generator Installed Plant Costs Microturbine System Estimate](image)

The microturbine engine represents a relatively new technology for power production applications. While the base technology has been deployed for decades in larger gas turbine systems, the microturbine utilizes a number of technology changes (special bearings and recuperators to name a couple), which combine to make the equipment a different technology.
While the gas turbine has a record of proven performance in power generation applications, the modern micro-turbine has only been applied for about three years with a limited number of operational units in operation. The engines are available from a limited group of manufacturers and support for O&M services in remote operations is unclear.

Capital costs for the engines are still fairly high even though manufacturers continue to claim targets of roughly 40 percent of current costs. Current investment cost for a given power output in a microturbine would be considered on the higher range of acceptable. Normal O&M costs for the engines are claimed to be extremely low with only limited routine maintenance required at 8,000-hour operational intervals. For the village power applications under consideration, this maintenance will decrease operational costs and should improve the overall reliability of the plant. However, obtaining emergency service and spare parts given the limited distribution channels could represent a critical problem.

The microturbine engine is not nearly as efficient as the diesel engine in simple cycle operation. Like the diesel engine, a drawback for this technology is that fuel costs for diesel tends to be higher than equivalent natural gas supplies in areas where natural gas is available (in Honduras, natural gas is not a fuel option), and environmental emissions can be high. An inherent problem with mass flow compressor based engines like the micro-turbine is that they are extremely affected by ambient air temperature and elevation at the operation site. Given Honduras’ high temperatures, the microturbine will likely lose up to 15 percent of its output capacity at 86º F, as can be seen in Figure 3.8 below.

![Derating for Ambient Temperature](image)

The derating charts for Model 330 liquid fuel

**Figure 3.8: Capstone Model 330 Micro-Turbine Operational Specs**

In the engine size considered for this project (nominal 30 kW), the Capstone model 330 was evaluated with a conversion efficiency rated at approximately 23 percent (HHV) of fuel input (full load ratings with no system loads or deration applied). Unfortunately, similar to the engine's power output, its efficiency is also affected by ambient conditions and this efficiency drops to about 19 percent (HHV) at 86º F (see Table 3.6 and Figure 3.9). This roughly equates to
an effective heat rate of about 17,963 Btu/kWh, or about US $0.16/kWh - U.S. (w/ diesel estimated at ~ 140,000 btu/gal).

Table 3.6 Capstone Microturbine Model 330

<table>
<thead>
<tr>
<th>Capstone Model 330 Microturbine Recuperated / Liquid Fuel (5 psig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Output (±/- 1 kW)</td>
</tr>
<tr>
<td>Thermal Efficiency (±/- 2%)</td>
</tr>
<tr>
<td>Fuel Flow, kJ (Btu)/h</td>
</tr>
<tr>
<td>Heat Rate, kJ (Btu)/kWh, LHV</td>
</tr>
<tr>
<td>Exhaust Temperature, °C (°F)</td>
</tr>
<tr>
<td>Exhaust Heat Energy, kJ (Btu)/h, LHV</td>
</tr>
<tr>
<td>Exhaust Emissions, NOx ppm</td>
</tr>
</tbody>
</table>

Nominal Net Efficiency vs Net Power at ISO Conditions

Figure 3.9: Capstone Model 330 Normal Efficiency vs. Power Output at ISO Conditions

Budgetary quotes discussed for the Capstone Model 330 microturbine generator package rated 29 kW supply (rated ~ 29 kW ISO net at a 0.8 PF: ~ 36 kVA, with a rated output at 277/480-V, 4 wire, 3-Ø), the microturbine generator package was estimated at US $31,000 to $35,000 including outdoor enclosure with fire & safety features. Inclusion of a 15 - 30 day fuel tank (~ 500 gal.) and fuel handling system was estimated at an additional US $3,500 or about US $34,500 to US $38,500 for total system equipment. Installation, design, shipping, taxes &
handling were estimated at another US $4,500 to $7,000 dependent on location and specific circumstances. Therefore, the complete “microturbine generator project” is estimated at about US $39,000 to $45,500 not including the village distribution system or any extended environmental permitting -remediation issues (see Table 3.7). Price also does not include any extended service agreements or spare parts.

Table 3.7 Installed Cost for a Microturbine Generation System

<table>
<thead>
<tr>
<th>29 kW Microturbine Complete Packaged System Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation Cost (US $)</td>
</tr>
<tr>
<td>39,000 to $45,500</td>
</tr>
</tbody>
</table>

Because of the high costs associated with the microturbine system combined with the higher fuel cost requirements as presented earlier, it is unlikely that under these current cost parameters that the system can be considered competitive with the diesel engine. This is especially true when vendor support and service in Honduras is not well established and will likely be supplied from the U.S. It should be noted that the high initial cost issue is projected to decrease substantially during the next few years although little reduction has been seen recently. Similarly, Capstone likely will establish vendor reps for service and equipment support in Honduras should equipment be installed within the country.

3.7.3 O&M Cost Issues

Estimates for O&M costs vary considerably depending on how and where the engines are operated and how well they are maintained. Because of the extreme remote applications considered in this project, total O&M cost estimates have been increased substantially [see Table 3.1].

Table 3.8 indicates 10 year averaged O&M estimated for the systems evaluated, assuming an annualized load factor of 30 percent.

Table 3.8 O&M Costs for a Diesel and a Microturbine Generation System

<table>
<thead>
<tr>
<th>O&amp;M cost component</th>
<th>Diesel Engine (35kW)</th>
<th>Microturbine (30kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O&amp;M cost component</td>
<td>US $0.030/kWh</td>
<td>US $0.020/kWh</td>
</tr>
</tbody>
</table>
3.7.4 Fuel Cost Issues

Fuel supply issues were discussed in detail in Section 3.4.4. Diesel engine operational issues were discussed in Section 3.7.1 with fuel utilization efficiency estimated at 33 percent HHV (ISO full load ratings with no system loads or deration applied). This roughly equates to an effective heat rate of about 10,342 Btu/kWh, or about US $0.092/kWh using a delivered diesel cost of US $1.25/gal (w/ diesel estimated at ~ 140,000 Btu/gal).

Microturbine operational issues were discussed in Section 3.7.1 of this report with fuel utilization efficiency estimated at 23 percent HHV-ISO and derated to 19 percent HHV at 86° F (See Figure 3.8). This roughly equates to an effective heat rate of about 17,963 Btu/kWh, or about US $0.16/kWh - U.S. using a delivered diesel cost of $1.25/gal (w/diesel estimated at ~ 140,000 btu/gal). The fuel cost estimates are shown in Table 3.9.

<table>
<thead>
<tr>
<th>Table 3.9 Fuel Costs for a Diesel and a Microturbine Generation System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Engine (35kW)</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>O&amp;M cost component</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

3.8 Example Case: Las Marías Village

ECCC identified four villages for an initial pilot study. Villages considered were: Las Marías in the Department of Olancho, Ironía, in the Department of Colón, Las Dificultades in El Paraíso, and San Ramón in Lempira. Safety concerns and certain recommendations from Honduran nationals prevented ECCC personnel from visiting three of the four villages, but ECCC did make a visit to Las Marías.

3.8.1 Description of Las Marias Village

In order to evaluate DG options for rural electrification projects, ECCC sent two Honduran engineers, Mr. Marlon Yushan and Ms. Trisia Barahona, to the village of Las Marias, which is located in the northeast of the Department of Olancho, approximately 200 kms from Tegucigalpa. This village is located near the Rio Platano Biosphere; access is limited, and throughout most of the year, it is necessary to drive a 4x4 vehicle because of poor road conditions beyond the municipality of Dulce Nombre de Culmi.
Las Marías’ isolation required that ECCC hire a local guide from Dulce Nombre de Culmi to take them to village. Many of the villages near Las Marías are similar in size and geography. There are six villages near Las Marías, which are connected by a dirt road, and another half dozen or more villages in the area with limited or no road access. These villages are governed by municipality of Dulce Nombre de Culmi. Access to the village and location play an important role in deciding what kind of power generation technology is to be used in rural electrification projects. Limited access imposes constrains on fuel and parts delivery as well as on maintenance personnel who would need access to the generator sets for scheduled and emergency repairs.

The population of Las Marías is 587. The majority of its residents’ are between the ages of 15 and 49 (see Table 3.10). There are 101 houses, each with an average of six people per household. The houses are scattered in a circular pattern with most of the houses built of brick and concrete blocks, but there are also 24 houses built of wood. The villagers have a good sense of community. They collaborate with neighboring villages in social projects such as a running water project with the village of La Iglesia, a transportation project with the village of La Nueva Esperanza, and on an education project with the village of Las Arenas. They are also part of an agri-forestry cooperative, which includes 16 other villages.

Table 3.10 Las Marías Population Distribution

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 4</td>
<td>76</td>
</tr>
<tr>
<td>5 – 14</td>
<td>196</td>
</tr>
<tr>
<td>15 – 49</td>
<td>268</td>
</tr>
<tr>
<td>50 or Older</td>
<td>47</td>
</tr>
<tr>
<td>Total</td>
<td>587</td>
</tr>
<tr>
<td>Houses</td>
<td>101</td>
</tr>
</tbody>
</table>

USAID project number 522-02731 helped build the only school in Las Marías. Local residents are expanding the educational complex with two more classrooms. However, there
remains a need for at least four additional classrooms. A total of 240 students attend the school on a regular basis. There is one health clinic, one Catholic and one Protestant church, and a health clinic is staffed with a full time nurse and a nurse assistant. There is also a doctor who visits the clinic once a month. A local store provides village residents with most of their basic goods and foodstuffs. Las Marías represents a typical Honduran village with a core village area containing many of its homes, a school, a health clinic, a church, a community center and a village store. The core portion of the village is approximately 1,000 feet across and there are scattered homes outside that core area. Figure 3.11 provides a rough diagram of a typical village for consideration (Note: this representation is not to scale nor is it intended to represent a particular village).

Figure 3.11: Typical Village Representation: No Power

Public transportation to the village is limited. A bus line serves the village with one round trip per day. Average family income is Lps. 150 (US $10) / month / per family during months of low economic activity. There is virtually no criminal activity in this community. Economic activities in the village are mainly centered on agriculture and forest projects. These activities range from coffee growing to raising pigs and dairy farming. There is a forest management project in place; as one of the major economic activities in the village is lumber processing. Another project being developed in the village is a chlorine water purification system.

The Honduran government is relocating other families to Las Marías in an effort to prevent people from moving into the Rio Platano Biosphere Reserve. Regardless of this government relocation, there is no electric power available to residents or any plans to extend the national grid to the village. Las Marías is on the list of villages surveyed by ENEE that will not be considered for connection to the national grid (see Section 2.2.3) because the expansion costs exceed US $500 per household.
As a result of this expected increase in population due to the government relocation plan, and with the potential of new economic activities following electrification, Las Marías was selected as a candidate for a rural electrification case study employing DG technology. Dulce Nombre de Culmi is the municipality, which has administrative jurisdiction over Las Marías. Any electric power project in this area has to have the approval and support of this municipality. Dulce Nombre de Culmi is connected to the national grid; however, its electric power is neither reliable nor stable.

Car batteries are used throughout the village to power radios, TVs, and other household appliances. However, recharging these batteries is a problem, since there is no recharge center in the village. The batteries must be brought to Dulce Nombre de Culmi for recharging or they are recharged locally using solar energy. Only ten families have been able to afford the purchase of solar panels. Batteries recharged by solar power are typically undercharged, which results in limited power availability. Furthermore, during cloudy or rainy weather, power usually is not available. Solar panels are expensive and high-grade batteries are difficult to find in Honduras.

Potential impact of electric power on economic development:
(Residents of Las Marías listed the following items as potential benefits from electric power.)

- Provide refrigeration for milk or dairy processing
- Improve coffee production and quality (would eliminate need to transport coffee to separate locations for processing after harvest)
- Improve management of cattle farming and beef production using electrical wire fences.
- Increase production of cutting and sewing workshops
- Add new options for wireless communication
- Maintain optimal conditions at health centers
- Establish technical school specializing in wood industrialization
- Increase production at corn mills
- Develop food concentrates for hog farms

3.8.2 Load Profile (Las Marías Village)

Information collected at Las Marías was used to establish energy consumption needs for three levels of importance as shown in Table 3.11. Level 1 comprises health, education, and community activities. Level 2 comprises street lighting and commercial needs. Level 3 includes household consumption, but electric power consumption for this level represents an estimate because of a lack of information regarding household appliances, if any, throughout the villages’ houses. Total electric power consumption for all levels is close to 19.5 kW. This total electric power consumption does not include energy needed for economic development or losses for electric distribution and inefficiencies.

The village electrification plan does not intend to distribute electricity to all houses in a village or region. In fact, the main scope is to provide electric power for economic development. In many cases it may make more sense for villagers to acquire at least two batteries (at least one in use while a second is in charging station) at a cost of approximately US $100 or less. This will certainly be much less expensive than extending the power distribution system to all homes and then converting the low voltage wiring to accommodate 120V power. Most of the social benefits
of the project will come to the villagers through the enhanced community operations and industrial power development that electrification will provide. Accordingly, the health clinic, school and community centers (including the church) are priority connections to the system. Table 3.11 provides some insight into the internal electrification process for a village as stipulated by “Levels 1, 2 & 3.”

As noted in Table 3.11, the core community load will likely be less than 10 kW. When small power systems were evaluated it was determined that costs for most systems under 50 kW were rather expensive on a unit ($/kW) basis. In fact, there really isn’t much difference in total installed costs between a 20 kW and a 35 kW systems. Assuming a 30 kW, constant-duty generation system is deployed; there would be ample capacity to support commercial and industrial loads for economic development activity. A generator would be sized accordingly and loads would be assessed if a specific industrial site were prepared to utilize village power directly. For preliminary purposes, the 30 kW size is deemed as a minimal consideration.
### Table 3.11 Las Marías Village Estimated Non-Industrial Power Consumption

<table>
<thead>
<tr>
<th>Las Marías Village</th>
<th>Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health Clinic</td>
<td>1</td>
</tr>
<tr>
<td>Refrigerator (1)</td>
<td>600</td>
</tr>
<tr>
<td>Freezer (1)</td>
<td>800</td>
</tr>
<tr>
<td>Fan (2)</td>
<td>100</td>
</tr>
<tr>
<td>Lighting (5 bulbs)</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>1,600</td>
</tr>
<tr>
<td>School</td>
<td>1</td>
</tr>
<tr>
<td>Computer (8)</td>
<td>4,800</td>
</tr>
<tr>
<td>Lighting (10 bulbs)</td>
<td>200</td>
</tr>
<tr>
<td>Ceiling Fan (4)</td>
<td>200</td>
</tr>
<tr>
<td>TV &amp; VCR (1)</td>
<td>160</td>
</tr>
<tr>
<td>Total</td>
<td>5,360</td>
</tr>
<tr>
<td>Civic Center</td>
<td>1</td>
</tr>
<tr>
<td>Computer (1)</td>
<td>600</td>
</tr>
<tr>
<td>Lighting (4 bulbs)</td>
<td>80</td>
</tr>
<tr>
<td>Cell phone/Fax (1)</td>
<td>50</td>
</tr>
<tr>
<td>TV &amp; VCR (1)</td>
<td>160</td>
</tr>
<tr>
<td>Total</td>
<td>890</td>
</tr>
<tr>
<td>Church</td>
<td>1</td>
</tr>
<tr>
<td>Lighting (10 bulbs)</td>
<td>200</td>
</tr>
<tr>
<td>Ceiling Fan (4)</td>
<td>200</td>
</tr>
<tr>
<td>Total</td>
<td>400</td>
</tr>
<tr>
<td>Level 1 Total</td>
<td>8,250</td>
</tr>
<tr>
<td>Outdoor Lighting</td>
<td>10 bulbs</td>
</tr>
<tr>
<td>Total</td>
<td>800</td>
</tr>
<tr>
<td>Commerce</td>
<td>1</td>
</tr>
<tr>
<td>Store average consumption</td>
<td>500</td>
</tr>
<tr>
<td>Total</td>
<td>500</td>
</tr>
<tr>
<td>Level 2 Total</td>
<td>1,300</td>
</tr>
<tr>
<td># of Houses in the village</td>
<td>101</td>
</tr>
<tr>
<td>Average consumption</td>
<td>100</td>
</tr>
<tr>
<td>Level 3 Total</td>
<td>10,100</td>
</tr>
<tr>
<td>Total</td>
<td>19,650</td>
</tr>
</tbody>
</table>
Figure 3.12 provides a graphical representation of the loadings presented in Table 3.11, which helps to display the available loads for economic development even when village power has been extended beyond the core community supplies. Two curves were generated to better visualize the load profile on this generator set. The first one shown in Figure 3.12 includes all three levels of power consumption. The available power for industrial use is shown as the difference between the total installed capacity (30 kW) and the total community and commercial loads. An energy consumption management program can be devised to make most of the installed capacity available 24 hours of the day. Figure 3.12 shows peak non-industrial loads happening at 8 a.m. and 4 p.m. between 8 a.m. and 4 p.m. demand stays almost constant. When industrial demands are larger than the available capacity in Figure 3.12, for example during coffee harvesting and processing season, Level 3 demands (approximately 10kW) will be first interrupted from the grid and be replaced by battery power. At night, the power can be used to recharge batteries. Keeping the engine running full loads will allow the engine to operate at the highest efficiency.

**Total Installed Capacity & Load Profiles**

![Graphical representation of load profiles](image)

*Figure 3.12: Proposed Las Marías Village Load Profile: Total load represents non-industrial load including core community and commercial demands*
Figure 3.13 provides a progressive display of village electrification drawings as shown below, which indicates the “3 Levels” of electrification as discussed previously.

Figure 3.13: The “3-Level” Power Demands Modeled for Las Marías Village Electrification Project

3.8.3 Basic Project Economic Analysis

The remote village of Las Marías described earlier in this report was considered for a cursory economic analysis based on the two engine options evaluated thus far. A brief summary of power generation costs for the 30 kW system is outlined in Table 3.12.
<table>
<thead>
<tr>
<th></th>
<th>Diesel Engine</th>
<th>Microturbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost (Sec. 3.7.2)</td>
<td>US $22,500</td>
<td>US $42,250</td>
</tr>
<tr>
<td>Valuation of Electric Power Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital cost component*</td>
<td>US $0.034/kWh</td>
<td>US $0.063/kWh</td>
</tr>
<tr>
<td>Fuel cost component (Sec. 3.7.4)</td>
<td>US $0.092/kWh</td>
<td>US $0.160/kWh</td>
</tr>
<tr>
<td>O&amp;M cost component (Sec. 3.7.3)</td>
<td>US $0.030/kWh</td>
<td>US $0.020/kWh</td>
</tr>
<tr>
<td>Total Cost Estimate</td>
<td>US $0.156/kWh</td>
<td>US $0.243/kWh</td>
</tr>
</tbody>
</table>

[* Assumes 10 percent ROI with a 100 percent equity investment over a 15 year project period. All values assume average annual capacity utilization of ~30 percent (~ 10 kW). No ax or depreciation considerations.]

The above cost estimate does not include any costs associated with installation and O&M of the distribution system. While the cost estimate for this system was outside the scope of this project it is understood that the system would be consistent for either engine option and the total associated costs would increase accordingly by constant values in each column. However, in an attempt to provide some valuation to this issues, a rough estimate is considered for the basic distribution system in the core village area which does not include street lighting systems, metering installations, or any modifications to existing structures to accommodate power supplies (structural wiring issues). The ultimate distribution system will really depend on the exact equipment selections, number of installations, and distances involved. For crude estimate purposes, the central panel-switching-transformer system with enclosures and installation for the 25-kVA capacity is estimated at roughly US $5,000. The actual wired circuits to the core village end use installations with appropriate switching and protection is estimated at an additional US $4,000 resulting in a complete core system of approximately US $9,000. Using economic criteria similar to the generation's capital investment would require an additional US $0.0135/kWh or US $0.015/kWh total including O&M. Including these distribution cost estimates would increase the total cost of power supplied from the system as shown in Table 3.13.
<table>
<thead>
<tr>
<th>Description</th>
<th>Diesel Engine</th>
<th>Microturbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost (Sec. 3.7.2)</td>
<td>US $22,500</td>
<td>US $42,250</td>
</tr>
<tr>
<td>Valuation of Electric Power Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital cost component*</td>
<td>US $0.034/kWh</td>
<td>US $0.063/kWh</td>
</tr>
<tr>
<td>Fuel cost component (Sec. 3.7.4)</td>
<td>US $0.092/kWh</td>
<td>US $0.160/kWh</td>
</tr>
<tr>
<td>O&amp;M cost component (Sec. 3.7.3)</td>
<td>US $0.030/kWh</td>
<td>US $0.020/kWh</td>
</tr>
<tr>
<td>Distribution component</td>
<td>US $0.015/kWh</td>
<td>US $0.015/kWh</td>
</tr>
<tr>
<td>Total Cost Estimate</td>
<td>US $0.171/kWh</td>
<td>US $0.258/kWh</td>
</tr>
</tbody>
</table>

[*Assumes 10 percent ROI with a 100 percent equity investment over a 15 year project period. All values assume average annual capacity utilization of ~ 30 percent (~ 10 kW). No tax or depreciation considerations.]

Comparisons between diesel engines and microturbines – Cost analyses show that diesel engines are about 34 percent less expensive than microturbines. However, other considerations such as environmental issues, transportation difficulty, and ease of O&M could impact these results and could make microturbines a better option. For example, microturbine usually do not require maintenance in the first 8,000 hours operation, and microturbine maintenance requires minimum efforts such as changing air filters instead of requiring special training for regular maintenance of diesel engines. A less expensive diesel that requires more frequent maintenance may not be an ideal option in remote areas. This is similar to making a decision on whether paying an additional 35 percent is worthwhile to buy a more dependable car. Hence, it should be noted that the appropriate selection of the engine type depends on many other factors of each site in addition to economic considerations.

Comparison between isolated DG (Method 3) with national grid extension (Method 1) – This rough comparative analysis will consider the average cost for delivered retail power in the nation at approximately US $0.085/kWh. If it is considered that remote power delivery including transmission grid extension costs, standard central plant generation costs, and gross system losses could be 1.5 to 2.5 times this value, this yields a rough, comparative “market” price of about US $0.128/kWh to US $0.212/kWh for remote power delivery from the national grid. Even though the total costs of extending the national grid to this village is lower than using DG, it should be noted that extension of the national grid would require the entire village to consume electricity at approximately 2kW per household. This would require capital costs of about US $200,000 to add 200kW to ENEE’s power generation capacity for this village instead of 30kW. Furthermore, T&D costs will be at least another US $50,000 (based on US $500 per household). This would bring the initial capital cost to an unaffordable US $250,000 to extend the national grid to Las Marías. This comparison is not conclusive, but it does help put these estimates in perspective.
3.9 Conclusion

The preliminary evaluation for remote village electrification as presented in this report indicates that isolated village power generation can provide a viable option to extending utility grids into remote regions where transmission construction costs and system losses can be prohibitively high.

A systematic approach to evaluating villages and regions for inclusion in one of three electrification methods is presented whereby villages with optimal economic development potential can be electrified either through (1) national grid extensions, (2) independent, regional mini-grid systems which supply centrally generated power to multiple villages in a confined region, or (3) isolated, stand-alone generation for a single village. The method used to electrify the village is dependent on an optimization process to provide the most cost-effective supply to a given village in a given location.

A closer analysis of engine based, remote generation for the isolated village method was conducted using diesel engines and micro-turbines. Results of this analysis indicated that under present criteria, the standard diesel engine would likely be a preferred choice and would provide power at a considerable discount to the micro-turbine. Total generation costs for the nominal 30 kW diesel engine was estimated at roughly US $ 0.156/kWh; the cost for 30 kW of microturbine-generated power was estimated at US $0.243/kWh. Although the diesel engine based system appears to be the most applicable and cost effective for the circumstances considered in this report, other considerations such as environmental issues and ease of O&M could impact these results and could make microturbines a better option.

3.10 Recommendation for Future Work

While working on this project, ECCC considered a number of potential related projects. This associated work would have bearings on the current USAID-funded project, and would be necessary in order to provide a more detailed analysis of the issues presented in this report. These associated projects are:

Phase 2 Development of Remote Village Electrification

A proposed second phase of this project would act as an extension of the work begun during Phase I. It would provide a detailed engineering design followed by actual installations in selected villages.

Evaluation of Independent, Regional Mini-Grids

As presented in this report, an alternate option for remote village electrification involves the systematic use of independent, regional mini-grids. The proposed project would provide a preliminary analysis of the issues contrasting the development of independent mini-grids in regional electrification as contrasted with extension of national utility grid systems into these remote areas. Comparisons would include economic feasibility and functional studies including adaptability for future integration of these mini-grids into a national grid system.