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Renewables for Sustainable Village Power

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RENEWABLES FOR SUSTAINABLE VILLAGE POWER

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Introduction

In 1994, the National Renewable Energy Laboratory (NREL) formed a Village Power Group dedicated to matching renewable energy (RE) technologies with rural energy needs in the international market. While classic rural electrification consisted of extending the national grid and/or providing diesel gensets to remote, concentrated communities, it became clear that RE solutions had both economic and environmental advantages over conventional electricity in many remote communities. The key elements of NREL's Renewables for Sustainable Village Power (RSVP) program were a multidisciplinary team, an application- and village-need-driven focus, a technology-neutral approach, a broad set of in-country activities, the development of complimentary partnerships, and the evolution of an integrated approach. The essential activities of the RSVP team included developing applications, testing systems, mapping resources, analyzing options, initiating pilot projects, and conducting outreach, training, and information activities. This paper describes these activities, updates the lessons learned, and proposes an integrated approach as a model for rural electrification with renewables.

Applications Development and Systems Testing

Figure 1. Battery-Charging System

Village life is centered around energy-driven applications, such as water supply, lighting, communications, recreation, health services, education, food supply, and enterprise. Currently, these social and quality-of-life needs are supported either marginally or adequately by electricity or non-electrical energy forms. NREL's role has been to adapt RE technologies to the application or vice versa. NREL has worked with industry on several applications, including ice making, water purification and desalination, battery charging, and water pumping. In 1999, NREL helped design, test, and commercialize village-based wind or photovoltaic (PV) centralized battery-charging stations that could provide basic home lighting and communications needs at the lowest cost.

Because ice adds commercial value to village enterprises, NREL provided technical assistance to companies that were awarded Small Business Innovation Research (SBIR) Phase 2 projects in this area (see Lynntech, Inc. and Yankee Environmental Systems, Inc. 1999).

To help electrification sector officials and non-government organizations (NGOs) understand the use and economics of renewables for village applications, NREL continued developing its application guidebook series, publishing a Spanish version of the Health Clinic guidebook, and developing guidebooks for rural schools, microenterprise, and water pumping. These guidebooks include a description of energy needs, RE system basics, an analysis of energy options, institutional considerations, case studies, lessons learned, references, and a bibliography. The guidebooks were co-authored by the Village Power (VP) team and by international application specialists.

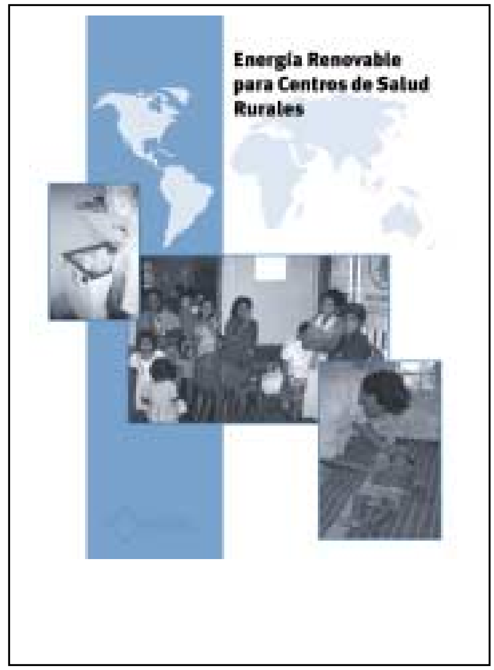

Figure 2. Cover of Spanish Version of Health Clinic Guidebook

Because systems need to be robust to provide reliable service in remote villages, NREL continues to work with industry to test essential components and systems at the National Wind Technology Center (NWTC). With the development of the Hybrid Power Test Bed (HPTB), it is possible to simulate village loads, as well as solar and wind resources, to evaluate system and component control logic and hardware in typical village situations. Providing feedback from these tests to designers and manufacturers results in more appropriate and robust RE solutions. The characterization of component performance parameters is used in computer models to more accurately represent the commercial products in application settings.

Figure 3. Rural Health Clinic Replication

A particular emphasis at NREL is the development and characterization of RE-diesel hybrid village power systems. In 1999, the VP team replicated three village hybrid systems at the NWTC to compare performance with the same systems that have been deployed in international rural settings, including Chile, Mexico, and Alaska. Two particular projects of note include testing the Alaska high-penetration wind-diesel control system prior to its installation in Wales, Alaska, and the rural health clinic replication.

To understand the performance of field systems, we emphasize performance data collection and the associated data acquisition system

(DAS) protocol and analysis. In 1999, we installed various types of DASs, both on-site and remote reporting, on our NWTC and field pilot systems. NREL initiated an international collaboration on field performance data collection, analysis, diagnostics, and archiving of direct-current (DC)-based village hybrid systems. Several international workshops were organized to share results and discuss issues.

Resource Mapping

One of the most serious barriers to the rural application of renewable energy, and to wind energy in particular, is the lack of reasonable quality resource data. Without a firm idea of the resource at the

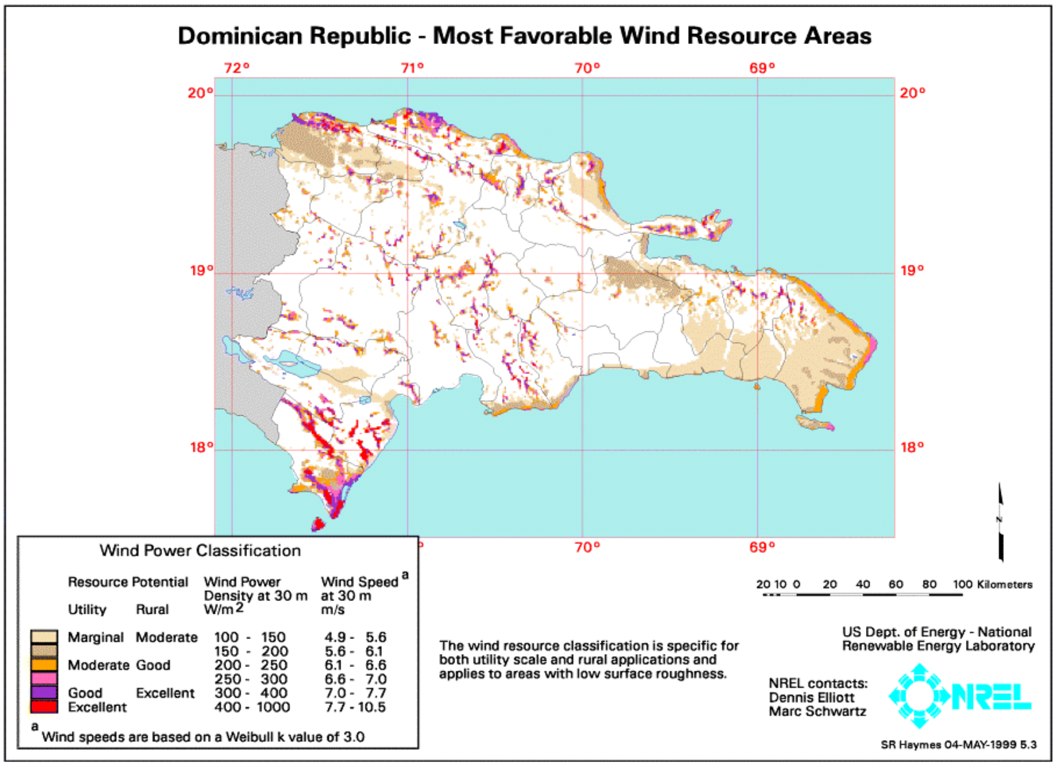

Figure 4. Wind Resources in the Dominican Republic

village site, rural electrification officials apply the low risk (although not the low cost) conventional energy solution. NREL has developed a computer-based wind mapping methodology that combines digital topographical data with climatological wind data to generate regional wind maps (1-km^2 resolution). These maps are useful for educating regional officials about the extent of the wind resource as well as for highlighting areas where wind-energy-based solutions are appropriate. In 1999, NREL developed full country wind resource atlases for the Philippines, the Dominican Republic, and began one for Mongolia. These maps supplement previous maps developed for portions of Mexico, China, Indonesia, and Chile. Solar resource mapping activities are being carried out for the Philippines, Mexico, and portions of China.

Analysis of Options

The inadequacy of the currently available analysis tools to effectively compare renewable and conventional options is partly responsible for the perpetuation of conventional solutions. NREL developed a set of tools that allows objective, economic comparisons of energy systems for individual buildings and interconnected (isolated mini-grid) facilities to grid extension, using conventional and/or renewable sources. The computer models are called HOMER (generation system optimization and comparisons) and ViPOR (mini-grid system optimization and comparison to individual systems). A third model, Hybrid2, was developed for detailed hourly performance analysis for the serious hybrid-system analyst. The VP team uses these models to analyze and present options to regional officials and rural electrification providers. Through these collaborative analyses, the team can demonstrate the relative economics and service quality that different solutions offer. The models all require estimates of load profiles, renewable resources, and costs; and they offer a wide assortment of output presentation graphics. NREL is actively training rural energy analysts in the application of these tools. In 1999, representatives from the Philippines, China, Australia, Chile, and Brazil were trained to use HOMER. Licensing information and trial versions of HOMER and ViPOR can be accessed at: www.nrel.gov/international/homer and www.nrel.gov/international/vipor

In 1999, the VP team applied Hybrid2 to projects in the Philippines, Argentina, Chile, Mexico, the Dominican Republic, China, Russia, Nepal, and Native American lands. Many of these projects involve potentially retrofitting diesel mini-grids in remote villages to either reduce the dependence on diesel or to expand the service to 24-hour power at a nominal marginal cost. With thousands of such mini-grid installations throughout the developing world, many opportunities exist. Currently, there are approximately 250 Hybrid2 users around the world; the model software and documentation are available for a nominal fee to cover transaction costs and can be accessed at: www.ecs.umass.edu/mie/labs/rerl/hy2/intro.htm . NREL contracts with the University of Massachusetts to provide user support and periodic upgrades.

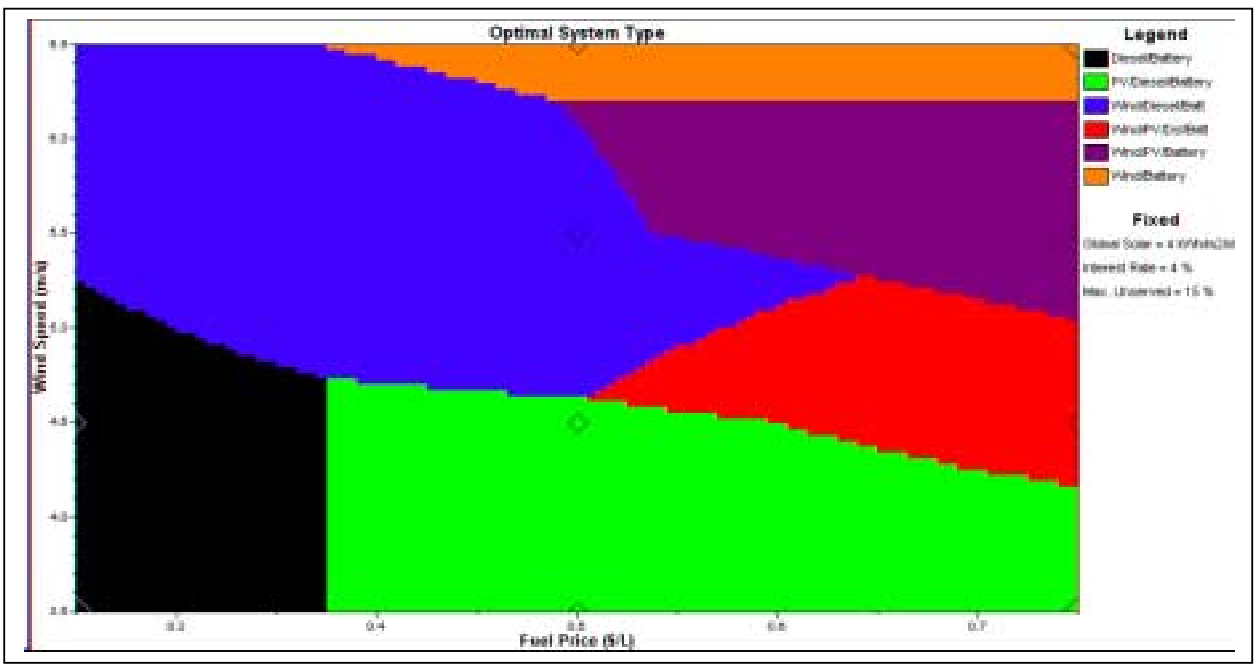

Figure 5. Sample HOMER Output Showing the Effects of Wind Speed and Diesel Fuel on Power System Architecture.

Pilot Projects

An important element in RSVP is developing pilot projects. Over the years, these have proven to be the most instructive activities for country rural electrification communities, the equipment suppliers, the development agencies, and the technical assistance community. The value of the pilot projects is threefold: it demonstrates that the technology works (or doesn't work); it provides a model to measure the economic costs and benefits against conventional options; and it tests the institutional infrastructure required to sustain the operations. NREL's early VP efforts emphasized designing, purchasing, and installing the appropriate RE-based solution. The focus was on load estimation, resource assessment, and operational efficiency. While most of these pilots were successfully commissioned, several of them experienced a range of technical and institutional problems. Subsequent efforts included more emphasis on training various levels of operational and design personnel, as well as more attention to institutional issues, such as tariff design, metering, maintenance contracts, policy support, and installing more pilot projects. To demonstrate these concepts, four pilots will be highlighted: Chile, Mexico, Ghana, and Alaska.

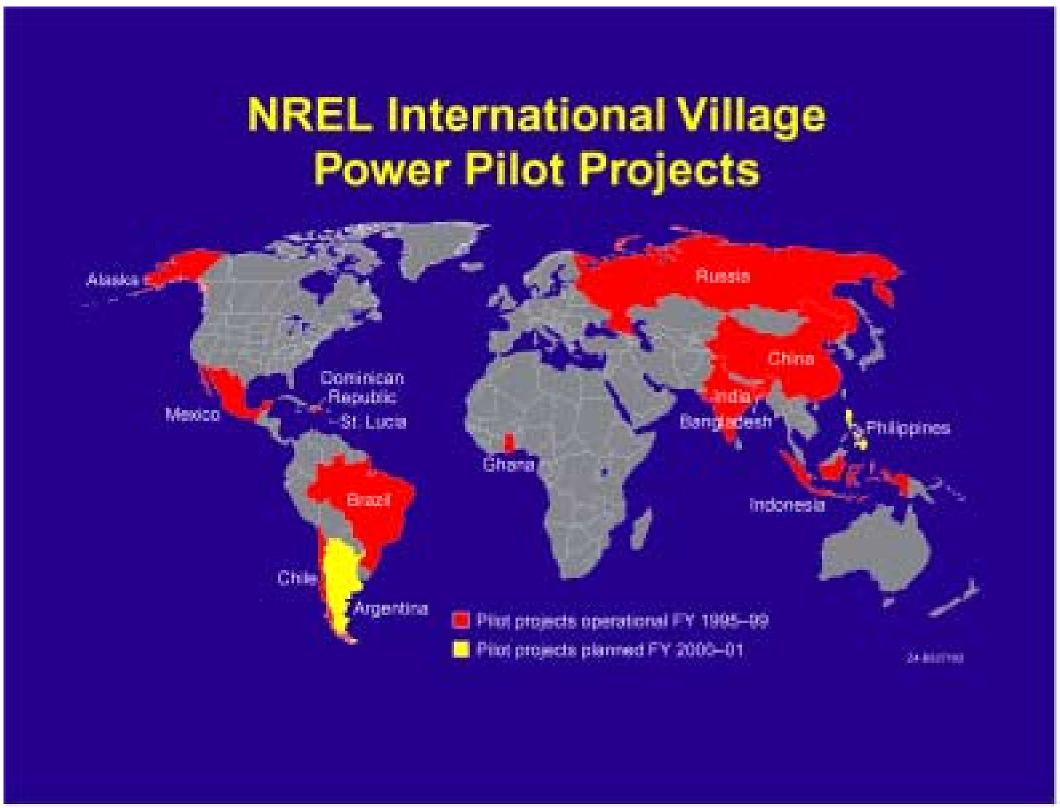

Figure 6. Map Showing Location of Pilot Projects

Chile

During REIA'94, Chile's Commission National de Energia (CNE) and the U.S. Department of Energy (DOE) entered into a cooperative agreement to explore the use of renewables in Chile's rural electrification program (see Baring-Gould, Flowers 1999 and Holz et al. 1997). While the original pilot projects were in Region IX, which had the largest unelectrified population, replication has focused on Regions X and XII. The primary reason for this switch in regional emphasis was the continuity and interest of our partners and organizations in those regions. Because of the excellent wind resource in southern Chile, the pilot projects were wind-fossil hybrids. The initial Region IX pilots served as a good learning platform to design the present pilots and replication programs. The pilots in Region X and XII are being watched closely by regional officials prior to large-scale replication, which will require serious operational and management attention by the regional utility.

Mexico

Figure 7. This Wind-Fossil Hybrid System Installed on the Island of Tac will Supply Full-Time Electricity to the 87 Families on the Island.

As a part of the United States Agency for International Development (USAID's) Mexico RE program for rural communities, a number of wind-based remote hybrid and water pumping pilots were installed. Good-to-excellent wind resources exist in a number of Mexican states, especially in coastal and mountainous areas. The earliest hybrid pilot project at Xcalak, QR, provided both technical and institutional lessons. The salt environment, lightning, system complexity, and the lack of local maintenance capability or funds created serious performance problems. Institutional issues of system ownership and management, metering, and tariffs design fundamentally undercut the system's sustainability. Currently, there is a collaborative effort to upgrade both the generation and distribution systems, as well as correct some of the institutional issues. Subsequent projects improved system design, corrosion resistance, and lightning protection, but suffered from other institutional system oversight and operational issues, including the overriding one of insufficient number of projects to support a service business.

The most recent wind-PV-diesel hybrid project is located in the fishing village of San Juanico, BS, and was developed collaboratively by CFE and the Arizona Public Service Company (APS). NREL provided design review, supporting analysis, performance monitoring, and a socioeconomic survey. While the remote monitoring has been somewhat problematic, the data was useful in diagnosing system performance through the development of a special protocol developed cooperatively with APS. The socioeconomic survey was designed to evaluate the effect of converting from part-time to 24-hour power. The initial results showed an increase in refrigeration and small appliance use in households and businesses; an increased sense of security resulting from public lighting; increased telecommunications; increased

Figure 8. Wind-PV-Diesel-Hybrid Project at San Juanico

educational environment (eliminated school generator); and interest in the local fishing coop in cold storage facility. However, some issues remain that should be addressed to improve user acceptance.

These issues include improved communications, tariff design, user education, and access to credit and appliances. It is too early to assess the long-term viability of this solution for remote coastal fishing communities.

Ghana

As part of the United Nations Development Programme (UNDP) and the Global Environmental Facility (GEF) efforts to promote clean energy technologies, NREL worked with the Ministry of Mines and Energy (MOME) in Ghana to develop a plan for rural electrification in the East Mamprusi District in the northeast corner of the country. Officially launched in February 1999, this $3 million project is known as the Renewable Energy Services Project (RESPRO). It was established initially as a special project unit of

Figure 9. Rural Electrification Project in East Mamprusi District, Ghana

MOME and will operate in close collaboration with the Volta River Authority/Northern Electricity Department (VRA/NED). It will be operated as a *for-profit enterprise,* to be "spun off" as a private sector company following the GEF project period. End-users will contract for the energy services they need (grain grinding, commercial refrigeration, vaccine refrigeration, community water pumping, household lighting, etc.) and the RESPRO will own, maintain, and repair the electricity supply equipment and, in some cases, may supply and own the end-use appliances. The electricity services will be provided from freestanding photovoltaic (PV) units and, for a few larger communities, from local 220-volt A/C mini-grids using PV/diesel hybrid power units. Service fees will reflect the revenue requirements for sustainability and growth of the enterprise. The RESPRO will establish the technical, financial, institutional, and socio-cultural requirements for sustainable provision of renewable energy-based electricity services in Ghana. The project is conceived as a *pre-investment project*, designed to lead the way for future investments by the private sector or in public-private partnerships, in rural energy, and infrastructure services companies.

Alaska

As part of the system development process, NREL is involved in exploring new concepts that may significantly lower the cost and/or improve the performance of village systems. One such concept is the "high-penetration" wind-diesel retrofit system. There are potential substantial diesel savings (>50%) associated with a control strategy and system architecture that allows shutting down the diesel genset when the wind is sufficient to carry the load, and uses short-term battery storage to reduce diesel start-ups during instantaneous lulls in the wind. In northern climates, an added feature is using both waste diesel thermal energy and wind "dump-load" to supply space heating to community buildings. The control strategy and software development was central to adapting the wind and storage subsystems to the diesel genset in an optimal, scalable, fail-safe manner. The control hardware, software, and storage subsystem were tested and debugged at the HPTB under simulated dynamic operating conditions prior to shipping to Wales, Alaska, for field experiments (see Drouilhet, S. M. July 1999). The system is currently being installed and commissioned, and will be monitored closely for several years. The performance of this system architecture/dispatch strategy will be compared to other, more conventional, wind-diesel systems currently deployed in Alaska, in anticipation of replication in other villages in Alaska and in the developing world.

Figure 10. The wind/diesel hybrid system in Wales, Alaska.

Lessons Learned

One of the most important contributions that the VP team can make is to pass along the explicit lessons we've learned in developing our pilot projects. While each pilot has specific lessons, we have looked across this experience and have summarized them into twelve primary lessons (not listed in order of priority). For a more detailed (and somewhat dated) list and explanation of NREL's RSVP lessons learned, please see "Lessons Learned-NREL VP Program", Windpower '98.

1. Systems need to be thoroughly tested prior to deployment in remote, harsh environments.
2. Systems should be robust and simple to operate; simplicity is often more important to effectiveness than lowest cost or highest possible efficiency.
3. Batteries are currently the weak link in rural RE systems, and often the most costly (life-cycle) component.
4. Energy meters and appropriate tariff design are critical to sustainable service.
5. Local training, including operating manuals in the local language, and regional O&M capability are critical for sustained operation.
6. Income generation activities, e.g., micro-enterprise/micro-finance development, are an important aspect of developing sustainable rural energy supply.
7. Singular isolated pilot projects, without a commitment to early replication, and regardless of technology and design rigor, fail due to lack of sustained support.
8. Rural electrification implementation processes discriminate against renewable solutions; there remains a critical need to level the analytical and subsidy playing field.
9. There is no universal best delivery model for rural energy services; the optimal approach requires matching the needs and capabilities of both the users and the service providers.
10. Integrating RE solutions into the country's rural electrification/poverty alleviation agenda/program is necessary for RE to become a mainstream rural solution.
11. A multi-year commitment (both in time and money) is required to achieve sustainable solutions.
12. An integrated approach that addresses the characterization of the rural situation, policy issues, financing, institutional delivery options, local/regional/national capacity building, characterization of renewable resources, and the comparative analysis of options, through the development of a sizeable, regional pilot is the key to developing a sustainable rural electrification program involving renewables.

The Village Power Initiative

This last lesson, the integrated approach, was developed in concept by a number of public and private organizations and firms that specialize in RE-based rural energy solutions. It was the group's consensus that the many well meaning efforts in the past and those currently underway to introduce or deploy renewables in rural areas around the world have fallen short of sustainability because one or more of these aforementioned elements was not adequately addressed in the pilot phase of the project/program. The pilot must be large enough in scope and funding, yet focused in a small enough region, to establish and sustain an operational "business unit" and a functional rural development approach, and thereby establish the institutional basis for wide scale replication. It is the group's intention to communicate and foster this integrated approach in the development of future RE rural programs through the application of large-scale, regionally focused pilot projects. As this concept emerges, we anticipate that the bilateral and multi-lateral development organizations, as well as their client countries, will embrace the integrated approach as the means to address their goals of rural electrification and poverty alleviation.

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