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Preface

Many areas of the developing world harbor opportunities for small geothermal projects. In this report, we examine ways to meet the special challenges that small geothermal projects must overcome in order to provide energy to remote and rural areas.

The Center for Research Program Management and Program Analysis, in support of the National Renewable Energy Laboratory's (NREL's) Geothermal Energy Conversion Project, prepared this report for the U.S. Department of Energy's (DOE's) Office of Geothermal Technologies. This report is intended to help DOE and U.S. industry evaluate the potential for small-scale geothermal systems.

We gratefully acknowledge our DOE sponsor, Ray Fortuna, of the Office of Geothermal Technologies. We deeply appreciate the assistance of others in that office: Ray LaSala, Marshall Reed, and Paul Grabowski.

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Approved for the
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Charles Kutscher
NREL Project Leader

Executive Summary

Opportunities for small geothermal projects exist in many areas of the developing world, including Latin America, the Caribbean, and the Philippines. For this study, we define small geothermal power projects as those with less than 5 megawatts (MW) of capacity. Geothermal power plants with less than 5 MW of capacity could supply electricity in remote areas. However, such plants would serve these markets almost exclusively in countries where strong government or regional policies promote this application. Such government intervention is needed for small geothermal projects because they face special financial and operational challenges associated with their small size. One such challenge is the relatively high transaction costs of obtaining project finance and the difficulty in establishing and supporting an operation and maintenance infrastructure for small plants in remote areas. These difficulties may be mitigated by bundling small projects together, as could occur within a national program. The widespread use of small geothermal units demonstrates the technological feasibility of small systems, but does not demonstrate operational or economic feasibility for remote applications.

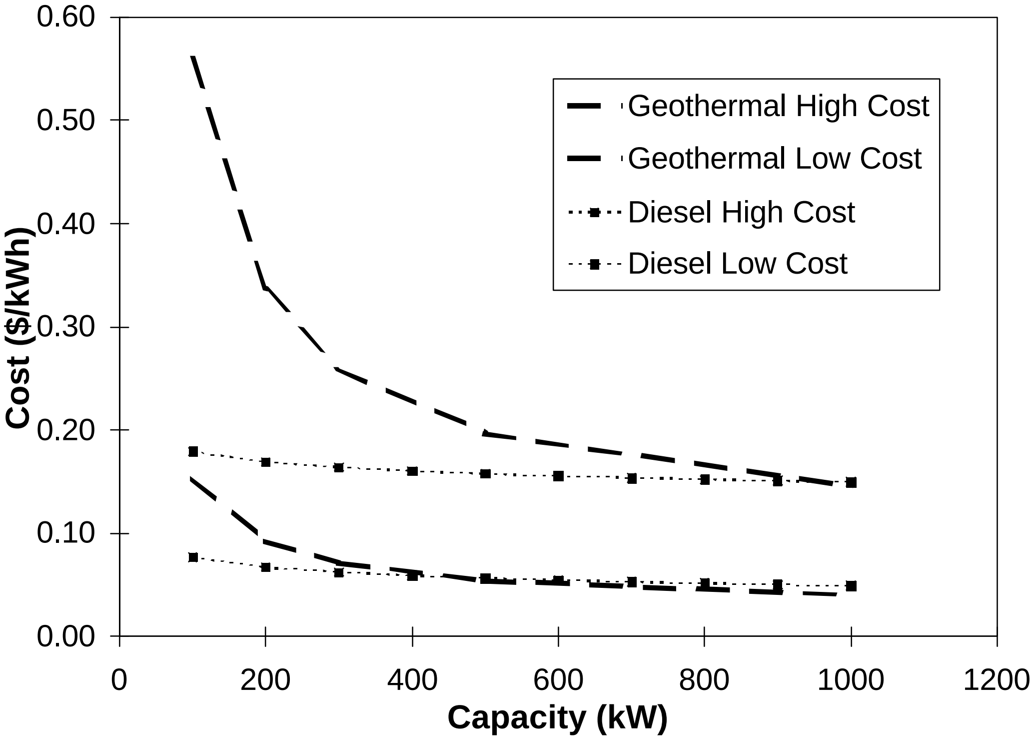
Technologies for Small Geothermal Projects

Small geothermal power plants, either binary or flash steam, can be manufactured and can be operated in remote areas, but each type of technology enjoys different advantages and faces different challenges in this application. For example, binary plants can typically operate with lower-temperature resources that are more common, and this could help a small project hold down drilling costs; however, greater system complexity can complicate operation and maintenance. The flash steam plant's simpler and less expensive design is especially welcome in a small system. However, flash steam plants are typically used with higher temperature resources that could be more expensive to obtain than lower-temperature ones. Using a flash steam plant with a lower-temperature resource might not be cost effective because of reduced efficiency. Finally, the complexity of managing scale deposition is likely to impose greater costs in flash steam plants than in binary plants.

The credibility of small geothermal projects must be strengthened with lenders. Both private- and public-sector investors require extensive documentation of technology performance, operation and maintenance requirements, and other project justification materials. This information could be developed into model documents that would help project developers obtain capitol investment. Developing such model documents could help identify technology or data issues that need to be addressed.

The costs of small geothermal projects depend significantly on power plant costs, drilling costs, resource quality, and costs of financing. Costs of small geothermal generation are in the same range as competitor technologies for rural electricity markets. Figure E-1 shows one estimate, in which the cost of small-scale geothermal generation substantially overlaps that of diesel. (The basis of this cost estimate for small geothermal plants is described in Box A in Section 2-3.)

Figure E-1. Cost of Diesel Generation and Geothermal Generation vs. Capacity



Finding Geothermal Resources for Small Projects

An effective, economical exploration program is essential for successful small geothermal projects. When characterizing resources for small geothermal projects, the developer must inexpensively identify resources of sufficient quality, in terms of temperature with depth and chemistry, to permit a group of economically viable projects. An exploration plan for small geothermal plant sites should pool exploration risks across many small projects and identify a group of projects that will be logistically viable when bundled. Small projects cannot afford high drilling costs, such as the $1–3 million per well spent during exploration for large projects. Drilling slim holes for exploration and production or using smaller, more portable drill rigs are promising methods to reduce costs. (Sample references for slim holes for exploration and production are provided.) The Latin American, Caribbean, and Philippines regions contain geothermal resources that have been characterized at various levels of detail. One can use existing data to help small geothermal projects achieve low exploration costs, but it should be understood that exploration goals for large projects are different from goals for small projects. In some cases, existing wells could be considered. (Data for existing wells in the Philippines are given in Box B in Section 3-5, and geothermal resources data for Latin America, the Caribbean, and the Philippines are provided in Appendix A.)

Markets for Small Geothermal Projects

Access to better energy technology could improve rural people's lives, and small geothermal plants could be one of those technologies. Rural electricity services can be improved by installing individual systems, national grids, and mini-grids. Individual systems are generally too small to be cost-effective applications of geothermal technology. However, a region where individual systems would be appropriate could be even better served with small geothermal plants, if extensive economic development changed the market conditions. For small geothermal projects to be used under these circumstances, a region would need to be far from any existing grid and undergo long-term, intensive, economic development that would greatly increase the region’s load density and the demand for and ability to pay for electricity.

Service in remote parts of national grids could be improved, in some cases, with distributed power generation from small geothermal plants. Even so, connection of a prospective site to an existing grid would need to be inexpensive. If the part of the national grid receiving the distributed generation needs improvements in power quality, reliability, or capacity, then installing a small geothermal plant would be one solution, but should be compared to other potential solutions. (Appendix C summarizes average cost data for electricity from national grids in Latin America and the Caribbean.)

Perhaps most promising, existing mini-grids present opportunities for small geothermal power plants to supplement or displace diesel generation. To be appropriate, mini-grids must already have sufficient base load to support a small geothermal plant, or must receive additional base load in conjunction with the small geothermal project. For example, regional development could add a productive load. (Appendix B includes information on diesel generation in Latin America, the Caribbean, and the Philippines.)

Electric sector reform is transforming the potential owners and operators of small geothermal projects from public utilities to private power producers. Reform is intended to improve the overall economic efficiency of the electric sector and may open new opportunities for small geothermal projects in this more competitive market. On the other hand, reform may change the roles of public utilities and governments such that they do not provide as much vital support to geothermal projects as they have in the past. Private power producers are likely to make electric capacity investment decisions that favor technologies with a lower share of capital cost as a fraction of total cost, and lower financing costs than what small geothermal power plants require.

Small geothermal projects can benefit from lessons learned from other renewable energy technologies that have already begun to supply rural markets internationally. For small geothermal projects, as for other renewables, appropriate financial arrangements are critical to success. Attributes of successful financial arrangements include consideration of the ability and willingness of rural customers to pay for services, a suitable financing mechanism, and appropriate use of subsidies. Experience from other renewable energy technologies has shown that market infrastructure can be difficult to develop in remote areas because its services (marketing, distribution, installation, maintenance, and revenue collection) require a sufficiently large base to support the needed personnel. Performance safeguards are essential in rural areas, where reliability, ease of use, and maintenance must be ensured under harsh conditions. Small geothermal plants need standards and testing for rural applications to determine what, if any, improvements are needed. The role of governments and donors in facilitating other renewable energy technologies highlights their potential analogous role for small geothermal projects, especially in such areas as resource assessment and the establishment of a legal and regulatory structure for cost recovery for rural electricity supply.

Geothermal Industry Players in a Possible Small-Scale Geothermal Market

Companies from the United States, Europe, Japan, Iceland, New Zealand, and developing countries will compete for profitable small geothermal projects in remote areas. If this market develops, the geothermal industry can provide the relevant technologies and experience for successful small projects. However, the industry could improve its products and equipment to enhance its service to the small-scale geothermal market. Serving this market would also require the industry to develop market infrastructure and innovative financing methods. National governments influence the relative competitive advantage of their own geothermal companies in international competition for geothermal projects by funding international geothermal exploration and development, supporting trade missions, and providing aid in exchange for contracts and equipment purchases.

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1.0 Introduction

Demand for electricity in developing countries is expected to grow rapidly in the coming years. Providing better electricity supplies to rural people will contribute to that growth. Small geothermal power projects, defined as less than 5 megawatts (MW) in size for this study, could compete in this market, but they face many hurdles. This report examines these hurdles. Because of their geothermal resources, dynamic electricity markets, and relatively low political risk, Latin America, the Caribbean, and the Philippines are the focus of this report. This overview of issues facing small geothermal projects is intended especially for those who are not already familiar with small geothermal opportunities. We also hope that readers who are already familiar with small geothermal projects will find this document useful as a summary of issues and opportunities and as a starting point in determining next steps to develop this market.

To describe opportunities to serve remote electricity markets with small geothermal power plants, we examine small geothermal systems (Section 2), geothermal resource characterization (Section 3), international rural electricity markets (Section 4), and the geothermal industry players that could compete in these markets (Section 5). Sections 6 and 7 provide conclusions and recommendations.

In Section 2, we establish the technological focus by defining small geothermal power plants and describing their current applications, technologies, and costs. We examine small geothermal power plants—less than 5 MW in size—because plants larger than this are less likely to be useful for remote applications; a lower maximum yields a size range of projects that is even harder to finance. Many small geothermal power plants exist, but most are part of larger geothermal developments and are connected to the national grid, not used for remote electricity supply. Small power plant technologies, including flash steam and binary systems, are compared. Cost estimates for small geothermal projects depend heavily on plant costs, drilling costs, resource quality, grid connection costs, and financing.

In Section 3, we describe resource characterization, including a description of geothermal resources, the exploration process, exploration cost-reduction opportunities, and the status of resource characterization in Latin America, the Caribbean, and the Philippines. Resources that are useful for electricity generation are hydrothermal resources with higher than normal temperature gradients. The resource characterization process culminates in a conceptual model of the underlying geology, which is critical to any geothermal project. Exploratory well drilling is needed to completely characterize the resource. The high fixed cost of wells relative to the total costs of small geothermal projects presents a greater economic risk during exploratory well drilling, compared to the risk for large projects at that stage. Improved exploration methods, reductions in costs of exploratory drilling, systematic exploration programs, and public access to existing data are some measures that can be taken to reduce the exploration challenge. The countries of Latin America, the Caribbean, and the Philippines contain many geothermal resources that are already developed and others that are promising. However, they vary in the level of existing resource data. We assess the implications of the exploration process for small geothermal power plants, and identify the extent of resource characterization within the region of interest.

In Section 4, we assess rural electricity opportunities by identifying rural energy needs, technological alternatives, customers, and lessons learned about rural electricity services. To develop economically, rural people need modern energy technologies for households, agriculture, and industry. Electricity can aid these activities, and its use in developing countries is expected to grow more rapidly than elsewhere during the next 20 years. We describe three approaches for supplying electricity: individual systems, national grids, and mini-grids. Within each of these approaches, geothermal would compete with different technologies to supply electricity, from batteries and photovoltaics for individual systems to diesel generators, natural gas turbines, mini-hydro, wind, and biomass for mini-grids. Alternatives in approach and technology define the opportunities for small geothermal power plants to compete for rural electricity market share. Small geothermal plants could serve existing mini-grids, provide distributed generation, or play a role in economic development. Small geothermal power costs at the busbar (the cost of electric power prior to distribution costs) are within the range of current rural supply systems and other possible competitors in locations throughout Latin America, the Caribbean, and the Philippines.

Public electric utilities are the traditional institutional customer for geothermal plants or their electricity, but these utilities can be radically altered under electric sector reform. Rapidly changing reformed electricity markets, financing challenges, and competitor technologies with lower capital costs are difficulties that small geothermal projects will face in rural electricity markets. Other renewable energy projects in these markets have already overcome significant challenges and may provide valuable lessons for small geothermal projects. We evaluate the significance of these market trends, competitors, and previous renewable energy experience.

In Section 5, we identify countries whose domestic geothermal firms are likely to compete in a market for small geothermal plants to supply rural electricity. Major capabilities of geothermal power plant manufacturers and project developers, and the impacts of government action on their competitive position are considered. Geothermal companies from the United States, Europe, Japan, New Zealand, Iceland, and the developing countries themselves will compete in this market. The geothermal industry has capabilities to develop small geothermal projects. Indeed, many small plants have already been built. However, this information should be assembled into model documents to justify small projects. Such documents would summarize the track record for small plants in remote settings, and preparing them would point to any gaps in that record. Documentation of appropriate operation and maintenance (O&M) infrastructure and financial basis would be part of this effort. Additional industry capabilities to reduce exploration risk and produce less expensive, smaller, simpler, more reliable, more versatile, and better-characterized power plants could improve chances for small geothermal projects. If competition for small geothermal markets occurs among firms from different countries, actions of respective governments will influence the relative competitive positions of these firms. National governments enhance the competitive position of their geothermal industries by funding exploration projects, supporting other collaborative efforts, such as trade missions, or providing aid that requires the recipient country to purchase goods or services from the donor country's businesses.

2.0 Small Geothermal Systems

Our technological focus defines small geothermal power plants, identifies their current applications, compares technologies for rural applications, and examines their costs.

2.1 What are Small Geothermal Projects?

In this report, we consider small geothermal projects to be less than 5 MW; other definitions are possible. Three methods of defining small geothermal projects are considered here: financing criteria, previous definitions, and rural electricity supply criteria. Small geothermal projects face financing challenges that larger projects do not. Project financing is unlikely to be available to small projects. Previous definitions of small geothermal projects provide another perspective. Entingh, Easwaran, and McLarty (1994a and b) refer to a range of 100–1000 kilowatts (kW). Recent work on using slim holes for small geothermal also defines "small" as 100–1000 kW (Pritchett 1998a).

Besides financing criteria and historical precedent, the size range of geothermal plants most useful for rural electricity supplies can be used to define "small." Efforts to provide electricity to unserved and under-served rural populations, often called "village power," emphasize systems far smaller than 1 MW, reflecting the more pressing need, larger number of possible sales, and higher cost of conventional energy sources as size decreases. With low per-capita electricity demands typical of rural people in developing countries, this market may be best served by many small generating units, rather than fewer, larger ones. For example, at 50 watts per household (for lighting) (Cabraal, Cosgrove-Davies, and Schaffer 1996), 1 MW could serve 20,000 households.

We will focus on rural markets for geothermal electricity systems smaller than 5 MW. This definition represents a compromise among financing, historical, and rural electrification criteria.

2.2 Current Applications of Small Geothermal Plants

Small geothermal power units are already common, though generally not in remote applications. Instead, they are used within larger geothermal developments, either because they are cost effective, because they fit with incremental development plans, or because they were installed early in a site's development. Current applications at large geothermal developments provide important experience with small plants, but remote applications would pose different challenges.

Examining size distributions of geothermal units throughout the world shows that small geothermal power units are numerous, that the number of units increases at smaller sizes, and that many units are smaller than 5 MW (Based on small geothermal units listed as "Operating" in the Geothermal Resources Council (GRC) geothermal project database, as of June, 1998). Although this might indicate that small, remote geothermal projects are common and easily completed, further examination of the GRC (1998) database shows that this is not the case, because most of the operating geothermal units 5 MW or smaller are installed at a site where the total generation is much larger. The sites where less than 5 MW of capacity has been developed are generally not remote; many are at sites very near larger developments, at sites where there were plans for additional development to a much larger size (Huttrer 1995), or are not actually operational (Smith 1998a). (See Table 1.)

Small geothermal units are used at larger developments for several reasons. First, a modular approach can be less expensive overall because of shipping and handling costs. Second, small modules increase reliability and improve flexibility when adapting to changing well and system performance. Third, a small, remote well is sometimes located so far from other wells that a power plant sized to the remote well costs less than transport pipes for the fluid. Well spacing must take reservoir characteristics into consideration, and so can not be optimized for power plant size alone.

Table 1. Small Geothermal Plants

Power Plant Name	Country	Site	Geothermal Field	MW at Site	Status
Amedee Geo.	U.S.A.	California	Amedee H.S.	2	Operating
Dieng Monoblock	INDONESIA	Central Java		2	Operational at different site (Sibayak)
Fang GT Demo Plant	THAILAND	Fang	Fang	<1	Expansion expected
Bouillante	FRANCE	Guadeloupe		4	Operating
Bjarnarfalg, Gufustoo	ICELAND	Namafjall		3	Expansion expected
Copahue Power Station	ARGENTINA	Neuquen Province	Copahue	1	Not operating
Empire Geo. Project	USA	Nevada	San Emidio KGRA	5	Expansion expected
Nagqu	CHINA	Tibet		1	Operating
Pico Vermelho	PORTUGAL	Pico Vermelho		3	Expansion expected
Kirishima Hotel	JAPAN	S Kyushu		<1	Near larger site
Wabuska	USA	Nevada		2	Operating

Source: GRC 1998; "Status" from World Geothermal Congress 1995; Smith 1998a; Wabuska and Nagqu from Ormat 1998

Small units are also found at larger sites when they were used during early phases of site development. Similarly, many of the geothermal fields initially have only a small geothermal unit but are slated for additional development (e.g. Dieng, Fang); (Ramingwong and Lertsrimongkol 1995). Placing a small plant at the site of a larger anticipated development supplies electricity during development of the field. If wells for resource confirmation are used for this small plant, no additional drilling cost occurs.

A plant installed early in development may remain alone at the site for many years when there are problems with the resource, when the demand for geothermal electricity is low, or when development lags for some other reason. For example, additional development at the Fang site in Thailand is difficult because the reservoir is small and expensive to locate using deep exploratory drilling (Ramingwong and Lertsrimongkol 1995).

Table 1 shows four examples of operating small geothermal plants that are at remote locations, not at larger sites. The Ormat plant at Nagqu, Tibet, China, may be the only example of a small, operating, remote geothermal plant in a developing country. This 1-MW binary plant was constructed as a United Nations Development Program project (Ormat 1998).

A critical distinction between the application of small geothermal plants within a larger site and application in a remote area is the load-following ability of small geothermal systems. Although geothermal plants can follow loads, this ability is limited and the cost of a reduced-load factor is high because much of the cost of the geothermal power plant is capital cost. Remote areas and small grids generally have low base loads, so the contrast between achievable capacity factors (and thus costs per kilowatt-hour [kWh]) for large versus small grid applications is striking.

Generally, the development of a large geothermal field has been the primary reason for installing small geothermal plants. The large number of small geothermal units installed shows that there is useful experience with small plants, at least in the 1–5-MW size range. Although similar technologies could be used for small, remote geothermal systems, this current application should be distinguished from the small, remote geothermal niche. Small systems at large sites have advantages over remote ones in that the financing is secured for the entire project. The resource is confirmed for that project, O&M infrastructures are readily available, a grid either exists or is constructed for the large project, and sufficient base load is available.

The existing small projects show that small geothermal plants are technically sound, and these projects could be used to gather installation, operation and maintenance data relevant to remote geothermal sites. However, the success of small systems at large project sites is insufficient to demonstrate their viability in remote locations.

2.3 Geothermal Technologies for Small Systems

The most likely technology choices for small geothermal power plants are flash steam and binary cycles. Dry steam systems are unlikely to be used in small geothermal plants because dry steam resources are thought to be rare.

Flash steam systems use steam produced from the geothermal fluid to drive a turbine, using backpressure or condensing designs. The simplest flash plants are backpressure units, in which the turbine exhausts to the atmosphere. Alternatively, in condensing units, the turbine exhausts to a condenser at sub-atmospheric pressure.

BOX A. Modeling Small Geothermal Plants: GT-SMALL

Entingh, Easwaran, and McLarty (1994a and b) summarized an economic evaluation of small geothermal electric systems for remote, off-grid locations. Binary systems, 100–1000 kW in size, reservoir temperatures of 100°–140°C, production well depth of 200–1000 meters, and injection well depth of 200–500 meters, were considered. The figures below show cost variation with each of these independent variables. Technical costs at the busbar from this evaluation range from $0.47–0.346/kWh. An example “modal” system costs $0.105/kWh.

Figure A.1. Electricity Cost vs.Plant Size for Small Geothermal Systems

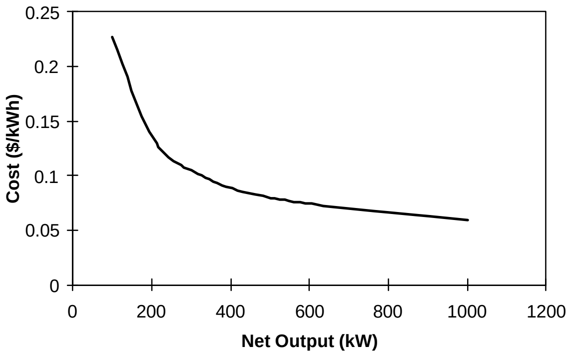


Figure A.2. Electricity Cost vs. Resource Temperature for Small Geothermal

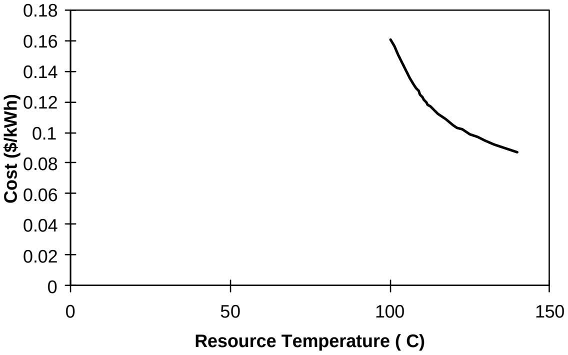


Figure A.3. Electricity Cost vs. Well Depth for Small Geothermal Systems

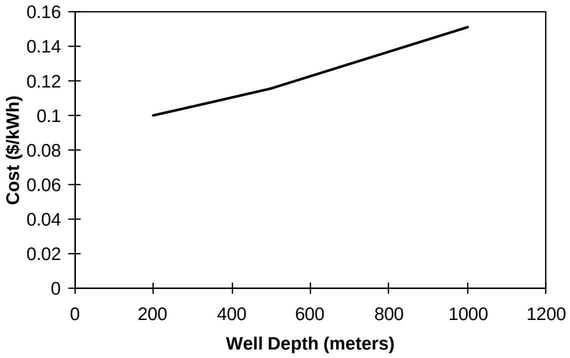
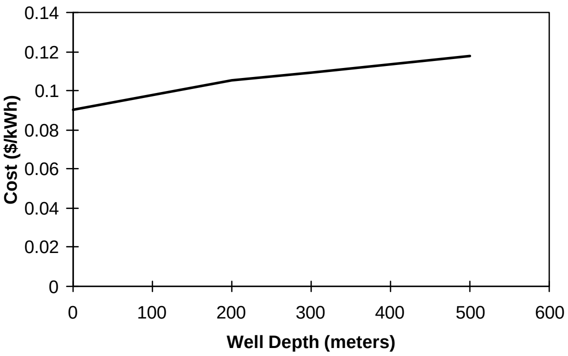


Figure A.4. Electricity Cost vs. Injection Well Depth for Small Geothermal Systems



Major Characteristics of Example System ("modal" system in the original papers)

COST: US $0.105/kWh	**Item**	**Units**	**Value**
Technical	Resource Temperature	°C	120
	System Net Capacity	kW	300
	Number of Wells		2
	Capacity Factor		0.8
Capital Costs	Exploration	$1000	200
	Wells	$1000	325
	Field	$1000	94
	Power Plant	$1000	659
O&M Costs	Field	$1000	32
	Plant	$1000	26
	Backup System	$1000	5

The advantages of flash steam systems in small applications include the relative simplicity and low cost of the plant. In contrast to binary plants, they require no secondary working fluid. However, when the geothermal fluid is flashed to steam, the solids that precipitate can foul equipment and pose health, safety, and disposal problems. If steam contains hydrogen sulfide or other contaminants, it poses an air quality problem when released directly to the atmosphere. Treating non-condensable gases in the condensing design adds complexity, maintenance, and disposal requirements (Forsha and Nichols 1997). Flash systems are most often used where higher resource temperatures (above 150ºC [300ºF]) are available, although a low-pressure turbine design for lower-temperature flash plants (110ºC [230ºF]) has been proposed (Forsha 1994) and feasibility of lower-temperature flash plants has been studied (Pritchett 1998b).

Binary plants use the geothermal fluid to heat a secondary working fluid, which then drives a turbine. An advantage of binary technology is that, in small-size ranges, modular binary units are readily available. Because the geothermal fluid can be contained in a separate loop, precipitation and environmental effects of the geothermal fluid can be controlled. Conversely, secondary working fluids may be hazardous and difficult to supply. Other disadvantages of binary designs are the higher capital costs and greater complexity of plants (Forsha and Nichols 1997).

The choice between flash steam and binary designs for small geothermal plants will be site specific, and will depend on resource temperature, chemical composition of the geothermal fluid, and maintenance preferences. The site-specific characteristics of geothermal resources, the small number of small, remote, geothermal plants, and the limited amount of published data comparing operation and maintenance costs complicate the comparison between flash steam and binary designs.

2.4 Costs of Small Geothermal Plants

Ultimately, the costs of small geothermal plants will determine their potential market. The two types of cost evidence here are reported costs from small geothermal plants at large geothermal developments and modeled cost estimates. Assumptions underlying the modeled cost estimates are examined. Binary and flash steam plant costs are compared.

Reported costs from small geothermal plants are rare. Few small units in the GRC database list initial power prices. Those that do are located at large fields and are in the \$0.05–\$0.07/kWh range, for units in the 1–5 MW range (GRC 1998).

Entingh, Easwaran, and McLarty (1994a and b) developed a model called GT-SMALL for small, binary geothermal systems in the 100–1000-kW size range (See Box A in Section 2-3). The accuracy of GT-SMALL is difficult to evaluate given the scarcity of remote applications of small systems. The \$0.05–\$0.07/kWh prices reported in the GRC database are comparable to the modeled cost estimates at the 1-MW size.

Assumptions about the exploration costs, resource quality, and financing costs determine the modeled cost results. In their modeling study, Entingh, Easwaran, and McLarty (1994a and b) describe an example system that serves as a reference point. The characteristics of the example system are shown in Box A in Section 2-3. The example system represents neither the exceptionally good conditions that should be developed first, nor the average conditions. Only with extensive resource characterization could the probability of the example conditions be determined.

For a small geothermal plant, Entingh, Easwaran, and McLarty (1994a and b) assume exploration costs of $200,000 (averaged over many projects), and production well cost of $195,000 (1993$). Thus, the exploration cost could pay for drilling slightly more than one production-sized well to confirm the resource. This suggests that, assuming drilling costs dominate exploration costs, a group of sites would have an average of only two to three unsuccessful wells per site (if one became the injection well), or one to two unsuccessful wells per site (if a separate injection well were drilled). Two to three unsuccessful wells per small project is comparable to the success rate of 25%–40% cited elsewhere (Finger 1998). It is unclear whether an exploration program for small geothermal projects would achieve this rate. Actual estimates of exploration costs would need to be adjusted to reflect site-specific estimates of drilling costs and the risk of unproductive exploratory wells.

Another critical input to GT-SMALL is the resource temperature and depth. The 120ºC (248ºF) temperature of the resource at 300 meters in the example system is comparable to well data for the western United States (NREL 1994). A lower rate of temperature increase with depth at the proposed site, or greater uncertainty, would raise costs compared to the example system results.

GT-SMALL's financing assumptions are critical, given small systems' financing challenges. The cost of capital (a fixed charge rate of 12%) in the example system is moderate, to reflect rates available with government participation. Government guarantees are critical because small projects would face higher costs with private finance. For example, one geothermal developer suggested that private financiers seek 30% rates of return on investment. The *Geothermal Financing Workbook* lists rates of return in the 15%–30% range (Battocletti 1998). Although the assumption of a $200,000 charge for exploration represents an exploration risk pooled among many projects, other risks are not explicitly accounted for, and including these might increase financing charges (Entingh, Easwaran, and McLarty 1994a and b).

Although GT-SMALL did not include flash steam plants, these could be an alternative for small systems. Compared to the example system, flash steam plant capital costs would probably be lower. For example, estimated capital costs for binary plants in the United States were 1.2–3.1 times flash steam plants' costs (Petty, Entingh, and Livesay 1988). Cost comparisons between flash steam and binary plants are site specific, because operation and maintenance costs depend heavily on geothermal fluid quality.

The distribution of cost among major components of geothermal electricity in small projects in remote areas is not known. A rough approximation of the major technical cost components may be inferred from results of the IM-GEO model (see Table 2), which is intended to determine the effect of technology improvements on estimated life-cycle costs of electricity from large geothermal plants. However, IM-GEO results vary depending on resource and plant type, and do not include other cost components that are also important.

Table 2. Geothermal Electricity Cost Components for Large Plants

Item	Percent of Cost
Identify Reservoir	3%
Confirm Reservoir	5%
Production/Injection Wells	20%
Downhole Pumps	2%
Gathering Equipment	5%
Make-Up Wells	8%
Power Plant (Core)	47%
Brine TDS Effects	6%
Gas Handling	2%
Reservoir Insurance	3%

Source: Entingh 1991

Overall, capital costs represent about 55%–80% of the cost of electricity generation, and operation and maintenance costs represent about 30%–45% (Entingh 1991).

2.5 Summary

We have defined and characterized small geothermal projects for rural applications as summarized below.

- For the discussion in this report, we define small geothermal systems as 5 MW or less, based on financing, previous definitions, and rural applications.

- The current applications of small geothermal plants are primarily within larger geothermal developments, which provide valuable technical data. However, remote applications face different obstacles and more economic and logistical data is needed on them.

- Both binary and flash steam geothermal technologies could be used in small geothermal projects. The resource characteristics and feasibility of meeting their respective requirements for operation and maintenance help determine which technology to use at a given site.

- The cost of energy from small geothermal systems depends on power plant costs, drilling costs, resource quality, and costs of financing. The actual and modeled costs suggest that small rural geothermal electricity projects have the *potential* to achieve competitive *technology* costs, as low as $0.05/kWh (busbar).

3.0 Resource Characterization

A developer of small geothermal projects seeks useable geothermal resources that can be identified with relatively inexpensive exploration. After considering exploration cost issues, we review the status of exploration in Latin America, the Caribbean, and the Philippines.

3.1 Useable Geothermal Resources

Useable geothermal energy resources exist where geologic features produce temperatures sufficient for heating, cooling, and electricity production. In general, temperature increases with depth from the Earth's surface at an average rate of 25º–30ºC/km (124º–138ºF/mile) (Fridleifsson and Freeston 1994). Economically competitive use of the geothermal resource for electricity generation requires a higher than average temperature gradient. The natural presence of water (a hydrothermal resource), and permeable or fractured rock that allows replenishment of that water are critical resource characteristics for electricity generation; without them, small geothermal power plants would be too expensive.

3.2 The Resource Characterization Process

Geothermal resource characterization for exploration of prospective sites for geothermal electricity production proceeds from the initial steps of identifying geothermal areas to the ultimate goal of understanding the hydrologic, geologic, and thermal characteristics of a site. Wright (1991) describes the exploration process and the techniques it uses. Although exploration strategies are case specific, Wright outlines a generic exploration strategy consisting of several stages: reconnaissance, prospect selection, and detailed exploration and drilling. The resource data are derived from geological, hydrological, geochemical, and geophysical studies. The literature on geothermal resource characterization techniques is extensive, and Wright (1991) provides an overview.

Reconnaissance, prospect selection, and detailed exploration and drilling would need to be performed for a small geothermal power project, though at a less-detailed level than for a larger one. Reconnaissance is undertaken in regions where geothermal resources are likely: along tectonic boundaries and where surface manifestations, such as hot springs and geysers, suggest the presence of a resource. In addition to surface manifestations, other geological data, as well as ownership and regulatory status, may be available in the literature to guide the selection of areas for reconnaissance. Once an area for reconnaissance has been selected, the goal is to develop a conceptual model of the underlying geologic features that is sufficiently detailed to support the selection of prospects, or to determine that further exploration should not be done. If exploration continues into the prospect selection stage, additional data is gathered at each prospective site to develop and refine the model of the geologic features until likely drilling sites can be selected. Exploratory well drilling is an essential step in characterizing the resource.

3.3 Exploration Cost Reduction for Small Geothermal Projects

Most exploration programs have been designed for large expected capacities, with budgets much too large for a small geothermal project. A lower-cost exploration approach would be required to improve opportunities for small geothermal plants. For the success of this small-scale exploration program, its uncertainties must be understood, and exploratory drilling costs must be low. The distribution of exploration costs between government and private industry, and among geothermal projects, also influences the viability of small geothermal projects. Using existing data during exploration is an important cost-reduction strategy for small projects.

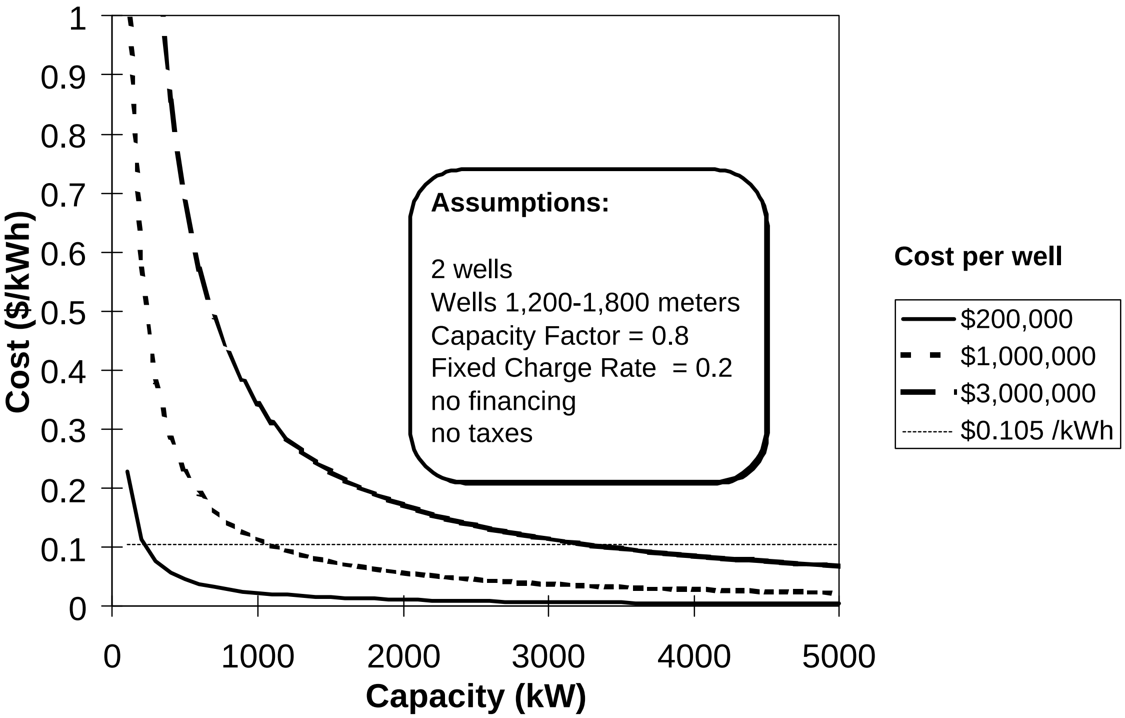
To control costs, exploration efforts for small projects would follow a simpler approach than a conventional exploration program for large ones. This approach would identify several project sites, would almost certainly require government involvement, would use less detailed testing and drilling, and might proceed as follows. A goal of five small projects in a region might be selected. Geothermal and electrification experts would select perhaps ten to fifteen prospective sites based on existing geothermal data and electricity needs. Each site would be subject to brief reconnaissance studies and limited testing. A maximum of two shallow exploratory wells would be drilled at the most likely sites. Each well would be drilled with the goal of using it as a production well.

Understanding and improving the effectiveness of this type of exploration program is critical to demonstrating the viability of small geothermal projects to obtain financing. Because greater certainty is required as greater investment is made, understanding the uncertainty associated with a small-scale exploration program would help determine the appropriate level of detail for exploration. However, the site-specific nature of geothermal exploration and the introduction and refinement of new techniques complicate efforts to compare the effectiveness of different exploration approaches. Few comparative studies of the effectiveness of different exploration programs have been completed.

The cost of drilling exploratory wells is the largest expense in exploration, and small geothermal requires exploratory well-drilling costs that are much lower than in a conventional exploratory well drilling program. Exploratory drilling for large geothermal prospects would entail drilling at least three production-sized wells at each likely geothermal site (OLADE 1994). At $1–$3 million per well and a 25%–40% success rate (Finger 1998), exploratory well drilling costs could easily preclude competitive small geothermal systems. To illustrate this, Figure 1 shows an estimate of the levelized cost of energy associated with well costs alone at different costs per well, based on the assumptions indicated in Figure 1. This estimate shows that a project of at least 3 MW would be needed to bring the cost of two $3-million wells down to $0.105/kWh.

Small geothermal plants could be considered where low costs per well can be achieved because of greater temperature gradients and easier drilling conditions than the $3-million well represents, and where low numbers of wells can be used because of good success rates and use of exploratory wells for production. Because of the expense of conventional drilling of production-sized exploratory wells, much research has focussed on opportunities to reduce these costs. Two of these approaches to cost reduction would include optimizing drilling processes (Huttrer 1997; Pierce and Livesay 1994) and drilling holes with smaller diameters. One study that is particularly relevant to geothermal development in remote regions is Sandia National Laboratories' Hydrothermal Drilling Cost Study (Glowka, Finger, and Pierce 1998), which characterizes cost reduction opportunities using compact drilling rigs.

Figure 1. Well Drilling Cost per kWh vs. Capacity



The use of small-diameter ("slim") holes for geothermal exploration and production has also been studied. Sample references on this topic appear at the end of the References section. Conventional production wells have a minimum production zone diameter of 8.5 inches (216 mm), with a 7-inch slotted liner in the production zone if needed (Pierce and Livesay 1994). Slim holes have a production zone diameter of 6 inches (152 mm) or less. Ongoing research is evaluating whether data gathered from slim holes can characterize reservoirs as accurately as production-sized exploratory wells, and comparing costs of exploration based on the two alternative approaches (Finger 1998). Research suggests that 40%–60% exploration cost reductions can be achieved using slim holes (Finger 1998).

Current research efforts are also evaluating the use of slim holes for production (Pritchett 1998a). Slim holes are theoretically capable of producing sufficient geothermal fluid to support as much as several megawatts of capacity (Combs, Garg, and Prichett 1997). Whether or not a slim hole supports artesian flow is an important factor in its economic viability for production, and in evaluating the alternatives of flash steam plants or binary plants. If a slim hole does not naturally have sufficient pressure, a downhole pump might be needed to produce geothermal fluid, or (especially in binary plants) to maintain pressure to keep the fluid in a liquid state. If a downhole pump were needed, a higher resource temperature would be required for the project to achieve favorable economics, and manufacturing of smaller downhole pumps would be needed. The engineering economic evaluation of slim holes with downhole pumps depends on site-specific evaluation that includes the parasitic load of the pump, its capital cost, and the generating capability of the slim hole with and without the pump (Pritchett 1997).

The distribution of the costs of exploration programs is an important consideration in determining the economic viability of small geothermal electricity generation. Publicly funded exploration subsidizes geothermal projects by distributing costs broadly. However, accounting for exploration costs is important to ensure appropriate priorities for public spending, even if the costs are not recovered through the project (Bradbury 1970). This is because the government incurs an opportunity cost equal to the value of activities that could have been funded instead of geothermal exploration. Another possible cost distribution would spread costs of regional or national exploration evenly among a large number of geothermal projects in the area, and so reduce the risk of excessive exploration costs on a single project. For example, Entingh, Easwaran, and McLarty assume "...an organized regional approach to exploration and test drilling, so that each stand-alone system does not bear all of the risk of exploration failure at any particular site" (1994b, p. 42).

Throughout exploration, availability of previously collected data would facilitate each step, and systematic organization and publication of any such data could be especially important for small geothermal projects. Opportunities to use existing data depend on the regional resource characterization status, which is outlined in the next section.

3.4. Resource Characterization Status

The status of geothermal resource characterization, including what data exists and who supported its development, will be considered here to identify opportunities for small geothermal projects to use existing data. Some of the existing data that characterizes geothermal resources may be useful to reduce exploration costs of small geothermal projects. The funding sources that supported the development of this existing data are important to consider, both because they may have proprietary claims on the more specific, useful data, and because they may be likely sources of funding for future exploration efforts.

Existing geothermal data ranges in detail from general locations of active geothermal regions to specific data about existing wells and conceptual models of geothermal resources. A global survey of thermal waters in the classic work by Waring (1965), “Thermal Springs of the United States and Other Countries of the World” provides basic data on geothermal surface waters for many countries. This information includes name and location, temperature, flow, total dissolved solids, principal chemical constituents, associated rocks, and descriptive notes.

More extensive characterization of specific geothermal fields has been completed in those countries with more advanced geothermal development status. Appendix A provides information and maps showing the status and expected potential of geothermal resources in Latin America, the Caribbean, and the Philippines. Resource characterization in fields that are already developed is much more advanced than in unexplored areas.

Although many known geothermal fields are likely to be developed with large generating capability, these resources are important to small-scale geothermal development for several reasons. First, known geothermal fields can be used to test small power plants. Second, if individual wells or entire known geothermal areas can not support a large system, a small one may be appropriate. In this case, the small system would benefit from data that had already been gathered. For example, the reduction in the total estimate of geothermal potential in the Philippines was based in part on the discovery that many high temperature prospects have low permeabilities (IGA 1998). If permeability were sufficient to support the lower flow rate of a small plant, these resources might be suitable for small projects. Third, countries with active geothermal development programs at large geothermal fields are much more promising for small-scale geothermal project development because of their in-country expertise and institutional commitment to geothermal energy. While this is not a resource issue, the extent of resource characterization is one indicator of these important personnel and infrastructure considerations.

In addition to using data from exploration of known large geothermal fields, earlier stages of exploration continue throughout the regions of interest. Examples of reconnaissance studies in Argentina, Mexico, El Salvador, Colombia, Guatemala, Peru, Chile, Bolivia, and the Caribbean are noted by Donovan (1985), World Geothermal Congress (1995), Smith (1998a), and Huttrer (1998). The results of some of these studies are recorded in a geographic information system that permits analysis with other important data, such as locations of roads and grids (Smith 1998a).

For the more specific, useful data, proprietary concerns may arise, depending on data ownership. Existing wells that were drilled for water, oil and gas, or large geothermal exploration may help geothermal exploration for small projects. In some cases, a national government or international development effort may have funded exploration costs. For example, the Philippines National Oil Company has conducted extensive drilling programs throughout the Philippines. Opportunities to use sites that this drilling program has identified for small geothermal plants are being investigated (Delfin 1998) (See Box B in Section 3-5). Some existing wells may be useable for production with a small geothermal plant. Exploration in developing countries has often been funded through international aid. For example, the United Nations Technical Assistance Programme funded initial geothermal exploration in some developing countries (Bradbury 1970), and subsequent United Nations funding has also been used (Donovan 1985). More recently, the U.S. Department of Energy is funding reconnaissance studies in South America (Smith 1998a). Similarly, the European Union and Italy have recently funded reconnaissance and feasibility studies in Latin America and the Caribbean (Ducci 1995).

While information may be available from the exploration and development of large fields and ongoing exploration, assessing overall potential for small systems based on this information would require that it be publicly available and assembled in a systematic manner. In addition, exploration has targeted large geothermal sites, possibly at the expense of exploring areas that might reveal opportunities for smaller projects. Thus, development of small geothermal power projects could be improved with better access to existing information and additional exploration.

3.5 Summary

An effective resource characterization program for small geothermal projects must contain costs more stringently than one for large projects, and some considerations important in accomplishing this can be summarized as follows:

- Small geothermal projects require appropriate hydrothermal resources.

- Exploration programs for small projects must accomplish the exploration process (reconnaissance, prospect selection, and detailed exploration and drilling) at low cost.

- Understanding the uncertainties of small-scale exploration programs will help with financing.

- Drilling slim holes for exploration and production or using smaller, more portable drill rigs are promising methods to reduce costs.

- Exploration risk should be pooled through an organized, regional exploration program designed to site multiple small projects.

- Exploration in Latin America, the Caribbean, and the Philippines (as well as many other regions of the world) has generated data that could be useful for small geothermal projects.

- Existing wells may help geothermal exploration for small projects.

- When interpreting existing data, it is important to consider that small geothermal projects may be feasible where permeability is sufficient for a small plant, but not a large one.

BOX B. Geothermal Exploration in the Philippines

The Philippine National Oil Company (PNOC) engages in exploration for geothermal resources. U.S.G.I.C. has investigated the possibility of using existing geothermal wells from that exploration for small geothermal systems, and determined that the wells listed below are possibilities (Lovekin 1998). Note that Bacman is a large geothermal field with existing capacity. PNOC reports poor permeability at Daklan (Delfin 1998).

Table B.1. Existing Wells in the Philippines

	Location	Total Depth (m)	Max. T(°C)	Well-head Pressure (MPag)	Mass Flow (kg/s)	Enthalpy (kJ/kg)
Alto Peak	AP1D	2013	309	0.60	23.7	2044
Alto Peak	AP5D	2427	259	1.05	9	990
Biliran	BN2	2434	211	0.56	37.9	894
Daklan	DK1A	2692	293	0.55	7	1150
Daklan	DK4	2747	291	--	--	--
Bacman	MO-2	1092	217	0.55	56.7	930

Source: Lovekin 1998; Delfin 1998

4.0 International Markets for Small Geothermal Projects

There are many opportunities for small geothermal projects to provide electricity for rural energy needs in Latin America, the Caribbean, the Philippines, and other developing regions. These needs can be met with several technological alternatives under three rural electricity improvement approaches. We describe the criteria for decisions among these alternatives, and the customers who will select small-scale geothermal power. We will also consider lessons learned about rural electricity services that could apply to small geothermal projects.

4.1 Rural Energy Needs

Understanding current rural energy needs clarifies the role that electricity from small geothermal plants could play in improving those energy services. Rural energy uses, the status of rural electrification, and different approaches to rural electrification are described below.

Rural people in developing countries frequently lack access to modern energy technologies. The World Bank (1996) estimates that there are roughly two billion people without advanced energy sources. These people use traditional energy forms, such as burning biomass and using human labor. The World Bank (1996) summarizes information on rural energy use as shown in Table 3.

Table 3. Rural Energy Use Patterns in Developing Countries by End Uses

End Use	**Household Income**		
	Low	**Medium**	**High**
Household			
Cooking	Wood, residues, & dung	Wood, residues, dung, kerosene & biogas	Wood, kerosene, biogas, LPG, & coal
Lighting	Candles & kerosene (sometimes none)	Candles, kerosene, & gasoline	Kerosene, electricity, & gasoline
Space heating	Wood, residues, & dung (often none)	Wood, residues, & dung	Wood, residues, dung, & coal
Other appliances	None	Electricity & storage cells	Electricity & storage cells
Agriculture			
Tilling	Hand	Animal	Animal, gasoline, diesel (tillers & tractors)
Irrigation	Hand	Animal	Diesel & electricity
Post-harvest processing	Hand	Animal	Diesel & electricity
Industry			
Milling & mechanical	Hand	Hand & animal	Hand, animal, diesel, & electricity
Process Heat	Wood & residues	Coal, charcoal, wood, & residues	Coal, charcoal, wood, kerosene, & residues

Source: Reproduced from World Bank 1996, p. 25

Geothermal energy, as electricity or in direct use applications, could improve energy services for many of these end uses. Lighting, appliances, irrigation, harvest processing, milling, and mechanical energy could be powered by electricity, and space heat, harvest processing, and process heat could be supplied through direct use. The focus of this report is on geothermal electricity generation, so this niche will be emphasized, not direct use. However, direct use could be an important source of energy for rural areas, either alone or in cascading uses that employ geothermal fluid after it exits a geothermal power plant.

Much of the population that lacks access to electricity is in rural areas of developing countries. Table 4 shows the difference in developing country electrification rates between rural and urban people in 1970 and 1990.

Table 4. Urban and Rural People Connected to Electricity in Developing Countries (percent)

Region	**Urban %**		**Rural %**	
	1970	1990	1970	1990
North Africa and Middle East	65	81	14	35
Latin America and Caribbean	67	82	15	40
Sub-Saharan Africa	28	38	4	8
South Asia	39	53	12	25
East Asia and Pacific	51	82	25	45
All Developing Countries	52	76	18	33
Total served (millions)	320	1100	340	820

Source: World Bank 1996

Electricity use is expected to triple in developing countries, from 3 trillion kilowatt hours in 1996 to over 9 trillion kilowatt hours in 2020, while use in industrialized countries almost doubles. Growth in Eastern Europe and the Former Soviet Union is stagnant over the same period of time. This IEA reference case forecast assumes annual economic growth of 4.3% in Central and South America and 6.2% in developing Asia between 1995 and 2020, and does not consider electricity prices. It also assumes electric sector reform (IEA 1998).

The rural energy needs, rural electrification rates, and projected growth in developing country electricity consumption show that providing electricity to rural areas supports development goals in growing markets. Overall, three approaches can improve rural electricity: extending or improving the national or regional grid; establishing, extending, or improving micro- or mini-grids; and establishing or improving individual systems. The decision among these different approaches should be based on cost, willingness and ability to pay, and future projections of each, so that the cost of the system will be recovered. The willingness and ability of rural households to pay for electricity services is an essential consideration in determining what type and level of service to offer. Level of service refers to the amount and hours of service of electricity available. Productive loads, such as industrial or commercial enterprises, enhance the ability to pay for electricity. Distance to the grid, number of households to be served, load density, and cost of generation determine the cost of grid service. Economic and population growth influence future ability to pay and the costs of infrastructure per household.

Table 5 shows the conditions under which each of the electrification approaches might be best. With the appropriate cost data, quantitative analysis could be performed to map the conditions under which each of the three rural electrification approaches in Table 5 would be economically justified.

Table 5. Approaches to Rural Electrification

Approach	**National or Regional Grid**	**Build or Extend Local Micro- or Mini-Grid**	**Install Individual Systems**
Conditions			
Distance from Local, National, or Regional Grid	Close to national or regional grid	Far from national or regional grid	Far from national or regional grid
Household Service Level	High	High	Low
Number of Households	High	High	Low
Load Density	High	High	Low
Size of Productive Load	High	High	Low
Rate of Growth	High	High	Low

Note: Site-specific data would be needed to quantify the decision analysis.
Source: Adapted from Cabraal, Cosgrove-Davies, and Schaeffer 1996; Galen 1997

Competitors of small-scale geothermal power production vary depending on which of the three electric service improvement approaches best applies. We consider the competing technologies next.

4.2 Technologies to Meet Rural Energy Needs

Technologies for individual home systems, national grids, and mini-grids compete with small geothermal systems in rural electricity markets. These technologies include batteries and photovoltaic home systems in the individual system market; coal, hydropower, and oil in centralized generation for national grids; and diesel generators, gas turbines, mini-hydro, wind, and biomass in micro- and mini-grids. For purposes of our discussion, national governments, utilities, or private firms that have concessions for supplying rural electricity are assumed to make the choice among individual systems, national grids, and mini-grids, and to select an electricity generation technology.

Current geothermal electricity generation technologies are not small enough to supply individual systems, which are generally only tens to hundreds of watts in size. However, individual systems may be less expensive than grid-based technologies, once grid construction costs are included. Thus a national government, utility, or concessionaire could select individual systems as the least expensive method of electrification for some rural people. These decision makers compare the following two sums:

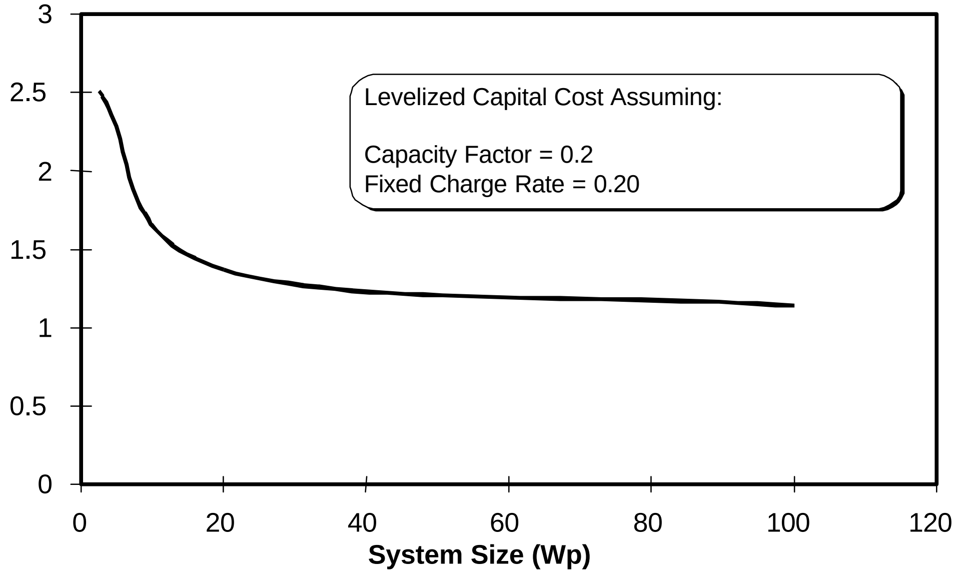
Generation .+ Transmission + Distribution + Operation + Maintenance = Cost of Grid Technology

Generation + Operation + Maintenance = Cost of Individual System.

Note that these institutional decision-makers face a very different set of alternatives from the individual rural households, which are usually considered the customers for individual systems. Individual households would compare the costs and levels of service of different electric and non-electric individual systems.

Of the technologies for individual systems, batteries are generally most expensive, with prices less than $1.40/kWh cited as a goal for some projects (Bergey 1997). Batteries are competitive for the smallest systems, such as 8-hour area lighting (Cabraal, Cosgrove-Davies, and Schaeffer 1996). Photovoltaic home systems are best for slightly larger individual systems, and have achieved large demand, mostly in developing countries. In 1996, there were an estimated 400,000 individual photovoltaic home systems installed. Figure 2 shows approximate levelized capital costs per kilowatt-hour (adapted from Cabraal, Cosgrove-Davies, and Schaeffer 1996).

Figure 2. Photovoltaic Home System Cost per kWh vs. Size

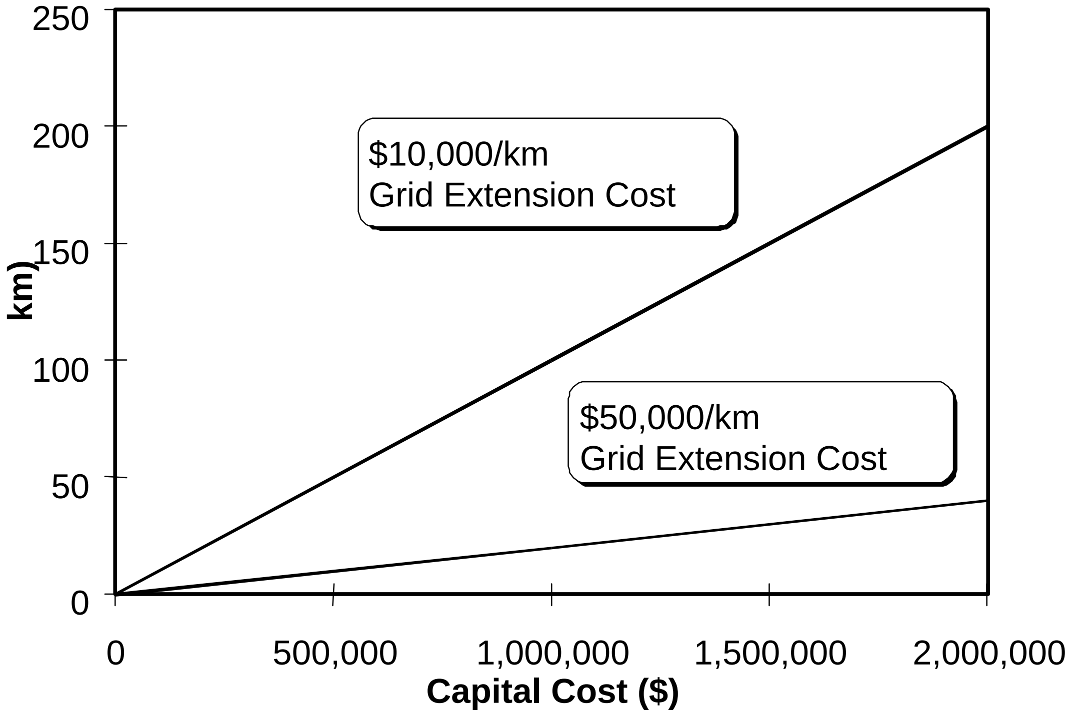


Source: Adapted from Cabraal, Cosgrove-Davies, and Schaeffer 1996

The service characteristics appropriate for an individual-system electrification approach are shown in Table 5. Although current commercial geothermal generation technology could not be used for individual electricity systems, regional economic development could change conditions from those appropriate for individual systems to the higher numbers, service level, load density, productive load, and growth rate appropriate to a local grid or national grid extension. Small-scale geothermal power generation could then be employed.

To justify building a small geothermal plant off the national grid, the distance from the national grid would have to be great enough that the capital cost of grid extension was, as a first approximation, the same as the capital cost of the plant. Figure 3 shows the distance from the national grid needed to justify different levels of capital investment. The grid extension costs are illustrative only, and depend on capacity needs and local conditions; they are roughly based on the range of estimated grid extension costs in Bolivia. There, a grid extension using a 3-phase, 34.5-kV line that can carry 2 MW of power up to 77 km with a 7% voltage drop would cost $11,000/km. A 69-kV line would cost about three times as much (Lilienthal 1998a).

Figure 3. Distance from Grid vs. Capital Cost



The impact of individual systems markets on the small-scale geothermal market are that the costs of individual systems help to establish a limit on the price that it is reasonable to pay for grid electricity, and that economic development could transform individual system markets into grid-based markets where small geothermal power plants could compete. Increasingly, individual systems are used to provide rural electricity, but traditionally this has been less common than national grid extension or improvement. The high cost of grid extension in unelectrified or under-served areas ($0.12–$0.55/kWh [World Bank 1996]) is prompting the shift.

Table 6. Installed Capacity in Latin America, the Caribbean, and the Philippines (MW)

Country	Hydro	Therm.Steam	Gas turbine	Diesel	Geothermal	Nuclear	Total
Argentina	6,454	6,932	1,897	1,415	1	1,018	17,717
	36%	39%	11%	8%		6%	
Bolivia	332	448	--	--	--	--	780
	43%	57%	--	--	--	--	
Brazil	48,600	5,578	616	575	--	657	56,026
	87%	10%	1%	1%	--	1%	
Chile	3,184	1,662	390	--	--	--	5,236
	61%	32%	7%	--	--	--	
Colombia	7,659	1,336	558	257	--	--	9,810
	78%	14%	6%	3%	--	--	
Costa Rica	754	14	188	53	--	--	1,009
	75%	1%	19%	5%	--	--	
Dominican Republic	371	2,079	--	--	--	--	2,450
	15%	85%	--	--	--	--	
Ecuador	1,471	824	--	--	--	--	2,295
	64%	36%	--	--		--	
El Salvador	404	64	21	187	105	--	781
	52%	8%	3%	24%	13%	--	
Guatemala	487	558	--	--	--	--	1,045
	47%	53%	--	--	--	--	
Haiti	62	155	--	--	--	--	217
	29%	71%	--	--	--	--	
Honduras	424	117	--	--	--	--	541
	78%	22%	--	--	--	--	
Jamaica	24	526	196	99	--	--	845
	3%	62%	23%	12%	--	--	
Mexico	8,172	19,632	1,754	147	735	675	31,115
	26%	63%	6%	--	2%	2%	
Nicaragua	103	259	15	8	70	--	455
	23%	57%	3%	2%	15%	--	
Panama	551	436	--	--	--	--	987
	56%	44%	--	--	--	--	
Paraguay	6,490	39	--	--	--	--	6,529
	99%	1%	--	--	--	--	
Peru	2,454	447	419	875	--	--	4,195
	58%	11%	10%	21%	--	--	
Uruguay	1,353	376	281	31	--	--	2,041
	66%	18%	14%	2%	--	--	
Venezuela	10,675	8,925	--	--	--	--	19,600
	54%	46%	--	--	--	--	
Philippines	2,333	1,460	--	5,349	1,414	--	10,556
	22%	14%	--	51%	13%	--	

Sources: Philippines: Philippines Department of Energy 1996; Other Countries: Dussan 1996

On the national grid, small geothermal plants would compete with a mix of fuels that varies within the geographic region, including hydropower, coal, oil, and natural gas. Table 6 quantifies types of electricity generation by country.

Within the national grid, small geothermal plants in remote locations could have distributed utility value, which is the value of having generation that is distributed throughout the grid, closer to loads. This value arises because distributed generation may improve reliability and power quality, including voltage support and line control, and avoids energy-wasting line losses. However, distributed generation must be evaluated in comparison to other approaches to these problems, some of which should be taken first, such as basic maintenance of the grid. The distributed utility value of small geothermal power plants will depend on whether the national grid has capacity problems, reliability problems, power quality problems, line-loss problems, or all of these, and on the options available to address them. If distributed generation were identified as the appropriate solution, installing a small geothermal plant could be the source of that distributed generation. To expand grid capacity, large geothermal is more likely to be competitive than small, but in remote regions of the distribution system, a small geothermal plant could make sense.

An example of the distributed utility application of a small geothermal project is the Copahue plant in a remote area of Argentina that is, nonetheless, connected to the national grid. Because of power needs for possible resort development plans in the area, bringing this plant back on line is under consideration (Smith 1998a).

In addition to individual systems and national grid extension, establishing, extending, or improving a micro- or mini-grid is a third electricity service improvement approach, and one that is considered the most likely niche for small geothermal projects. Here, small geothermal plants would compete with diesel, micro-hydro, wind, and biomass; diesel generators are the most widely used. The existing stock, sales, frequency distribution by size, and cost of electricity of small generators are important to determine opportunities for small geothermal projects to compete. The market for these generators is large and growing rapidly. World demand grew 4.5% to 386,000 in 1996, with most of the demand for sizes below 30 kW (AMPS 1997); India had 25% growth per year from 1992 to 1995, but growth in the very large category (500 kW–5 MW) was slow (Economic Times 1997). Several generators usually serve a load, so the total at a given site is larger than a single generator. Still, the diesel generator data shows that smaller-sized geothermal power plants would have more numerous opportunities.

In both the Philippines and Argentina, it appears that most diesel mini-grids are 100–500 kW, the small end of the small geothermal project size range. Argentina’s diesel generation sites are larger than the remote sites in the Philippines, but not all of them are mini-grids (See Appendix B).

The growth in demand for diesel generators shows that there is a promising market for small generation systems. The ability of small geothermal projects to compete in this growing market has not yet been demonstrated. Geothermal projects will have more difficulty as size decreases, which is where generator sales are most numerous and rapidly growing. However, capturing a small share of the generator market would represent dramatic market growth for small geothermal power plants.

To determine how many small geothermal plants could compete with existing diesel generation requires data on the relative cost of diesel and geothermal generation at each site, for the load profile at the site. Comprehensive data of this nature for Latin America, the Caribbean, and the Philippines are not available, and we based our estimates on data from Entingh, Easwaran, and McLarty (1994a and b), Lilienthal, Campbell, and Lambert (1998), and Abergas (1998). The cost of geothermal generation as a function of size was estimated using the GT-SMALL computer model (Entingh, Easwaran, and McLarty 1994a and b) (See Box A in Section 2-3). Capital, operation, and maintenance costs of diesel generation as a function of size was estimated (Lilienthal, Campbell, and Lambert 1998) (See Table 7).

Table 7. Diesel Generator Costs

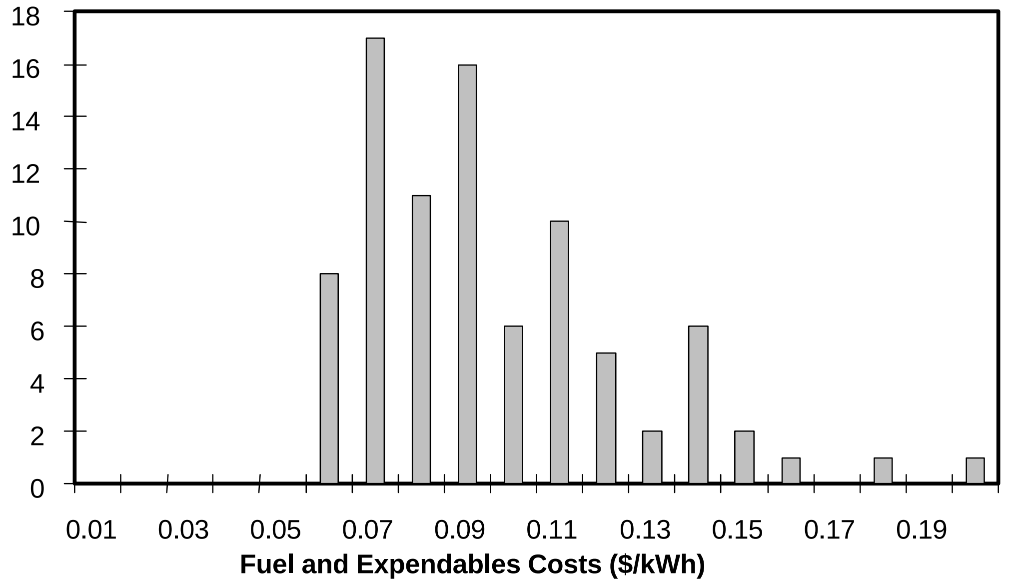
Item	**Units**	**Value**
Diesel Fixed Capital Cost	US$	9600
Diesel Incremental Capital Cost	$/kW rated	140
Diesel Fixed O&M Cost	$/hour	0.136
Diesel Incremental O&M Cost	$/hr/kW rated	0.014

Source: Lilienthal, Campbell, and Lambert 1998

If diesel generators achieve the lifetime intended in their design, diesel fuel cost accounts for most of the cost of diesel generation. However, diesel lifetimes, and the resultant capital costs of diesel generation, are very dependent on the duty cycle and quality of maintenance in specific applications. Fuel cost also varies greatly depending on the cost of transporting it to specific sites. Furthermore, each country has its own tax and subsidy systems, which are subject to rapid change during electric sector reform. Fuel cost data used here are from the Philippines' remote power utility, the Strategic Power Utilities Group (SPUG). The data represent fuel and expendables costs, without taxes, at small diesel systems, on small islands, away from the main grid, and a frequency distribution of these grids is shown in Figure 4. An exchange rate of 30 pesos per U.S. dollar was assumed (See also Appendix B for additional data on small grids).

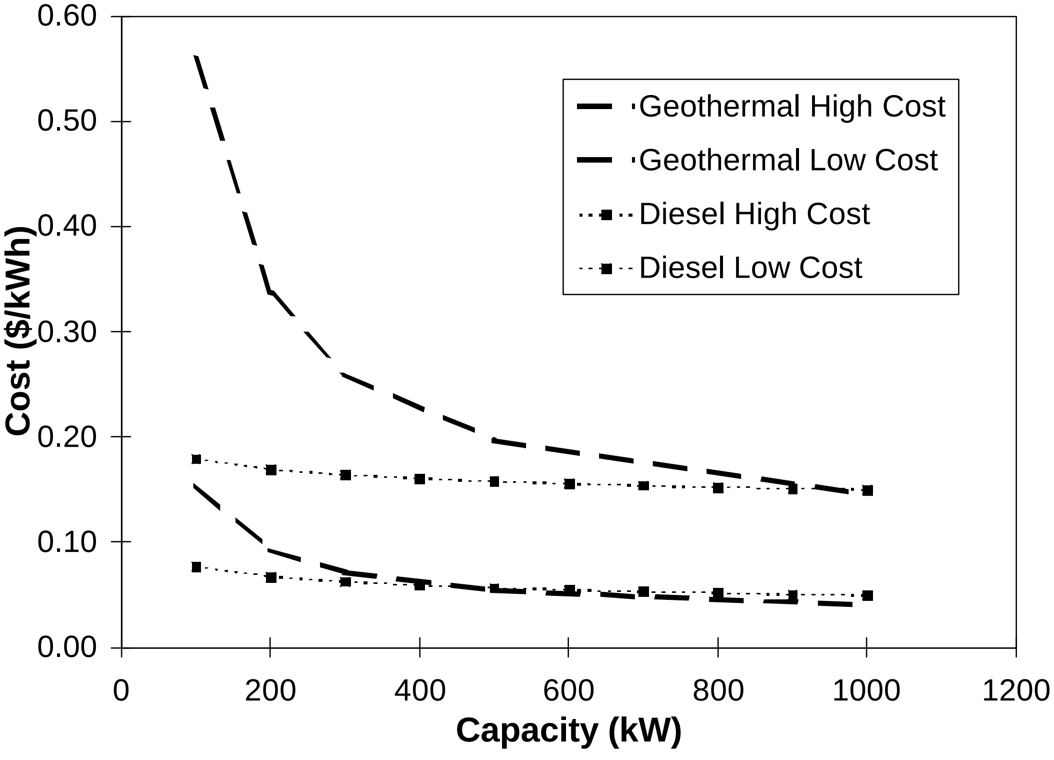
Combining these data yields the comparison of costs of geothermal and diesel as a function of size. As shown in Figure 5, the costs of electricity from small geothermal plants and diesel generators overlap in the 100–1000-kW size range. Overall, geothermal's chances improve at higher capacities. The example system that Entingh, Easwaran, and McLarty (1994a and b) describe is 300 kW in size. Capital, operation, and maintenance costs for diesel are derived from data used in the HOMER model (Lilienthal, Campbell, and Lambert 1998). A constant 80% capacity factor is assumed, although in practice this would generally decrease with decreasing size.

Figure 4. Frequency Distribution of Diesel Fuel Cost in the Philippines



Source: Adapted from Abergas 1998

Figure 5. Cost of Diesel Generation and Geothermal Generation vs. Capacity



Sources: Adapted from Entingh, Easwaran, and McLarty 1994a and b; Lilienthal, Campbell, and Lambert 1998; Abergas 1998

As noted earlier, the competitiveness of a geothermal system depends heavily on locating an appropriate resource. The range of geothermal costs from GT-SMALL represents only the range of conditions considered in that modeling effort. The probability of finding resources with certain characteristics is not shown. Thus, the geothermal lines in Figure 5 are not associated with a probability of finding the particular conditions that the line represents. The probability that a good geothermal resource is located close to an existing diesel mini-grid is not known, and improved estimates could be made with better geographic data.

Entingh, Easwaran, and McLarty (1994a and b) cite costs of diesel generation from \$0.46–\$1.03/kWh. These are considerably higher than the costs found in the Philippines data for mini-grids. Smith (1998b) estimates diesel generating costs in remote areas of Bolivia and Peru in the \$0.45/kWh range. Electricity prices in the Caribbean (where much generation is diesel) are estimated to reach a high of around \$0.50/kWh, but additional research is needed to determine the size of the systems where these high prices occur (Lillywhite 1998). Average electric rates in South America are generally lower, but average prices do not provide the cost data necessary to judge opportunities in rural areas (See Appendix C). In general, the occurrence of very high diesel prices (over \$0.50/kWh) is most likely found in small system sizes. The transportation costs that drive up the cost of diesel generation are also an indicator of challenging conditions for constructing and servicing a small geothermal power plant. The costs represented in GT-SMALL do not take into account these challenges. Thus, although there are certainly situations in which diesel costs will be higher than those shown in Figure 5, the Philippines diesel cost data are the most comprehensive available and are in a country with many favorable conditions for geothermal development. Higher diesel costs occur where conditions such as low load density and remoteness are likely to raise costs of small geothermal projects as well, yet the incremental cost of geothermal caused by remoteness may be smaller than the incremental cost of transporting fuel to these locations.

Diesel generator stock, sales, frequency distribution, and costs characterize the opportunity for small geothermal plants to compete. The cost implications of the load profile in the target service area are a critical part of this competition. The GT-SMALL model assumes an 80% capacity factor for its example system. However, remote loads are notorious for their low base loads. Geothermal plants, though they have some load-following ability, are most economic as base load. The low base load could make an 80% capacity factor extremely difficult to achieve, and a lower capacity factor would raise the cost of energy from a small geothermal plant. In contrast, the cost penalty for a diesel system operating at lower capacity factor is relatively small if its primary expense is fuel. The relative shares of diesel generator capital and fuel costs, in turn, depend on actual diesel generator lifetime.

Likely opportunities for small geothermal power plants in the Philippines occur on several islands with both sufficiently large average loads of 2–10 MW and geothermal resources: Romblon, Marinduque, Palawan, and Mindoro. This size of average load suggests a base load large enough to support a small geothermal plant (Abergas 1998) (See also Appendix B). Small geothermal plants in these island systems would need to be much smaller than the total capacity of their grid, and would need to be in a grid with peak load plants to achieve an 80%-capacity factor. Such hybrid systems would impose additional management costs.

Small geothermal power plants are one of many electricity generation technologies that could help meet rural energy needs. They could provide new grid electricity as part of economic development, improve electricity supply from remote parts of national grid, or enhance mini-grids, which are now mostly diesel fueled. To tap these potential markets, small geothermal projects will need institutional customers to buy the plants or the power they generate. These customers are considered next.

4.3 Customers for Small Geothermal Projects

Institutional customers will purchase the plant or the power that it generates, not the electricity consumer. We now examine the effects of this institutional customer on small geothermal projects through an overview of traditional electricity sector structure, independent power production, electric sector reform, and implications of reform for small geothermal projects.

The electricity sector has historically been government-owned or closely regulated throughout most of the world. Electricity has been viewed as a public service by electric utilities, which are the regulated, vertically integrated monopolies mandated to provide generation, dispatch, transmission, distribution, and customer service. Traditionally, many countries had a single major utility, with close utility-government relationships.

In national electric sectors dominated by utilities, independent power production is a common exception to the vertically integrated monopoly and can be a first step towards reform. Private companies may be allowed to build, own, and operate some generating facilities. The private company then sells its power to the utility under contracts that can take various forms. Countries within the regions of interest that allow private power projects include Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, the Dominican Republic, Guatemala, Honduras, Jamaica, Mexico, Panama, Peru, and the Philippines (Kozloff 1998). Table 8 shows several major types of contractual arrangements for private power projects.

Table 8. Ownership Arrangements for Independent Power Projects

Contract Type	**Name**	**Description**
BOO	Build-Own-Operate	The private contractor builds the plant, retains ownership, and operates it.
BOT	Build-Operate-Transfer	The private contractor builds the plant, operates it, and then transfers ownership.
BTO	Build-Transfer-Operate	The private contractor builds the plant, transfers it to the utility, and operates it under a contract.

Source: IEA 1997, p.55

Examples of contractual arrangements of recent private-power geothermal projects include Ormat's BTO contract at Mak-Ban in the Philippines (IEA 1997). California Energy Company has developed projects under BOT contracts at the Leyte field in the Philippines. In the Philippines and Costa Rica, Oxbow has developed projects under BOT contracts.

Although independent power production and sales are a common initial step towards private participation, electricity sector reform can extend far beyond this. Reform in the electricity sector is active throughout the world, including Latin America, the Caribbean, and the Philippines. Dussan (1996) summarizes the structure in the Latin American and Caribbean electric sector before reform, and Kozloff (1998) provides a similar overview for developing countries in general.

Electric sector reforms may be categorized into three major types: commercialization, privatization, and restructuring. Commercialization refers to the introduction of private-sector principles to the operation of a public electric utility. For example, commercialization would eliminate government subsidies to the utility. Privatization means that the private sector performs fundamental functions of the utility, such as power sales, capacity construction, and generation ownership. Independent power projects and independent power sales are examples of privatization. Restructuring separates different functions of the vertically integrated utility and allows competition in each of these markets (Kozloff 1998). Dussan (1996) identifies the major issues that reform in the Latin American and Caribbean region has sought to address and the important attributes of effective reforms.

Every country in Latin America except Mexico, Paraguay, and Uruguay has reformed its electric sector, and these remaining countries are initiating reform as well (Rudnick 1998). In the Philippines, although a final electricity sector restructuring law has not passed (IEA 1997; Weingart 1998), private power production and sales are allowed (IEA 1997), and privatization of the Philippines National Power Corporation's generating assets is planned.

The implications of electric sector reform for small geothermal projects are mixed, and include instability during regulatory transitions as well as changed competitive environments in the reformed market. Among these changes, mechanisms for rural electrification, governments' roles, and financing are especially important to small geothermal projects.

Until the new system has stabilized, reform means that the underlying institutional and economic conditions are uncertain, presenting project development risks. New electric reform laws are anticipated in Venezuela, Ecuador, and the Philippines. Electric sector reform laws have been passed in the past 2 years in Panama, El Salvador, Guatemala, Nicaragua, Costa Rica, Honduras, and Brazil. Electric sector reform laws in Chile, Argentina, Peru, Bolivia, and Colombia have had more time to take effect (Rudnick 1998). The effect of risk associated with reform on investment decisions in the electric sector of each of these countries depends on perceptions of the stability of electricity regulation, and expectations about smooth transitions to new regulations.

Although some uncertainty is inherent to electric sector reform, it can be implemented in ways that reduce the potential for political instability. For example, improving cost recovery is essential in countries that subsidize electricity. Although rate increases have sparked public protests (Goodwin 1994), the impact of rate increases on public welfare can be mitigated using lifeline rates or cash transfers to the poor, which ease the transition (Hope and Singh 1995; Freund and Wallich 1995). In addition, failing to increase rates to improve cost recovery is likely to result in poor maintenance and system failures, which also provoke public unrest (Caribbean Update 1997). Thus, effects of electric sector reform on political stability are country specific.

Table 9. Effects of Electricity Sector Reform on Small Geothermal Projects

Reform	Advantages for Small Geothermal Projects	Disadvantages for Small Geothermal Projects
Commercialization	• Removal of subsidies for competing technologies • Improved accounting for benefits of distributed generation • Improved opportunities for new technologies	• Removal of subsidies for small geothermal projects
Privatization	• Improved management and cost recovery in electric sector	• Private finance prefers lower share capital cost generation • Social objectives that may have justified geothermal are removed
Restructuring	• Consumer choice allows green marketing • Geothermal won't pay intermittency penalties for transmission access	• Environmental effects must be taken into account or consumers will just buy the least expensive • No entity realizes distributed generation benefits

Source: Kozloff 1998

Once reform occurs, small geothermal projects face a changed competitive environment. Likely advantages of electric sector reform to small geothermal projects include improved market function, removal of competing technology subsidies, and improved accounting for distributed benefits of remote generation. Likely disadvantages include diminished institutional commitments to coordinated national development of geothermal resources, removal of geothermal and electrification subsidies, and market biases against technologies with high capital-cost share (Kozloff 1998) (see Table 9). The reforms in each country determine whether these effects apply.

Of the changes arising from reform, treatment of electrification especially affects the remote markets considered in this report. No single method has emerged to improve rural electricity in a reformed market. Such methods must be established because utilities often subsidize electricity improvements (Kozloff 1998). Government contracts to private companies to serve rural areas are one mechanism. For example, Argentina grants concessions that designate an exclusive provider for a rural region. Rates are negotiated during bidding (Kozloff 1998). In contrast, the Philippines' reform proposal does not privatize electrification and rural services. Instead, the part of the Philippines National Power Corporation responsible for remote areas, the SPUG, will be a subsidized independent government agency with a public service mission (IEA 1997).

Changes in government roles under reform also affect small geothermal projects. Now, national governments secure international financing for specific geothermal projects that they have requested. Under reform, the private sector is expected to invest a greater share of funds in capacity expansion, although the government may still obtain public development funds. Reform could reduce the ability of national government to help small geothermal projects because it reduces governments' role in setting electrical capacity expansion policy and coordinating funding of energy projects and programs. Despite this reform trend, countries placing high priority on geothermal resource development may retain a government role. For example, Nicaragua has a national master plan for geothermal energy to facilitate granting concessions for geothermal exploration and development (Zuniga 1998). As an indigenous resource, geothermal energy can support government policy goals for energy self sufficiency and allocation of foreign exchange, and such goals would lend support to a continued government role despite reform.

Reform also affects financing for geothermal projects. One goal of electric sector reform is to increase private investment, which could create opportunities for small geothermal projects to compete in more open markets. Thus, challenges of attracting private investment are all the more important to address under reform. Mid-sized transactions of \$1–\$10 million, typical for small geothermal projects, are particularly difficult to finance (Battocletti 1998). Too large for informal micro-finance mechanisms, small geothermal projects may also be too small for traditional development bank lending programs.

A reduced government role coupled with financing difficulties poses a challenge to small geothermal projects. National governments can improve financing prospects for small-scale geothermal developments, for example, by organizing exploration, bundling projects together for financing, or combining geothermal projects with economic development. However, unless government involvement is deliberately retained, electric sector reform may leave competing private firms to select new capacity types. Private firms favor technologies with lower capital costs as a fraction of total cost because of the lower initial financial risk. Although technologies with relatively high capital costs and relatively low variable costs, such as geothermal, reduce or eliminate the risk of fuel price increase, these risks are less immediate than paying a large fraction of the cost of energy as initial capital cost. However, capital costs of diesel generation may be underestimated if in-use lifetimes for the expected duty cycle and operating conditions are not taken into account. A deregulated market may allow consumers to express a preference for specific types of generation, such as geothermal, because of advantages such as low environmental emissions. Price is likely to be the primary consideration for consumers, however, especially in developing countries.

In sum, electric sector reform is shaping the customers for small geothermal plants. Geothermal projects must compete in electricity markets as they are commercialized, privatized, and restructured. Implications of reform for rural electricity supply, national governments' roles, and private finance present challenges and opportunities for small geothermal projects. Experiences in rural electrification using other renewable energy technologies could help small geothermal power plants succeed.

4.4 Best Practices for Rural Electrification: Lessons Learned

Lessons learned from implementing other renewable energy technologies may apply to geothermal in remote areas. One reason we select "best practices" and review "lessons learned" is to understand prerequisites for functioning markets for renewable energy in rural electrification. The types of best practices here include financial arrangements, market infrastructure, performance safeguards, and government and donor support (Cabraal, Cosgrove-Davies, and Schaeffer 1996). Lessons learned from village power activities are considered in Table 10.

Table 10. Lessons Learned in Renewable Energy for Rural Electrification

Topic	Lessons Learned
Financial Arrangements	• Initial cost barrier must be overcome for small consumers. • Innovative finance is needed. • Long-term subsidies must be selected cautiously. • Effects of politics on decisions should be examined.
Market Infrastructure	• Market infrastructure must include marketing, distribution, installation, maintenance, and revenue collection. • Existing local infrastructures can be used. • Local needs must be considered.
Performance Safeguards	• Rural conditions can be harsh. • Reliability, ease of use, and maintenance are key. • Quality control and managing user expectations are important.
Government and Donor Support	• Support should facilitate expansion of market size. • Governments and donors have a role in catalyzing private finance. • Coordination is essential to leverage donor and government resources.

Best practices in financial arrangements ensure financing of initial system costs and feasible payments without extensive subsidies. Consistent with electric sector commercialization, grants and subsidies should be used in a limited, temporary manner for specific goals, such as starting a market. Experience implementing renewable technologies shows that long-term subsidies that only support prices are not sustainable (Taylor 1998). Taxes and duty structures need to be changed if they distort markets (Cabraal, Cosgrove-Davies, and Schaeffer 1996; Stern 1997).

Credit for small, rural, renewable energy projects is limited, despite evidence that rural people are an excellent risk. Innovative financing and diversifying investors and investments are important priorities at institutions that finance or facilitate financing of development projects, including the World Bank (Stern 1997), U.S. AID (Pumfrey 1997), and renewable energy industry associations (Siegel 1997). Innovative financing is a pressing need for many rural renewable energy projects, including small geothermal projects.

Best practices in market infrastructure will establish a viable market based on local capabilities and personnel (Cabraal, Cosgrove-Davies, and Schaeffer 1996). Necessary infrastructure includes marketing, distribution, installation, maintenance, and revenue collection (Taylor 1998). Services should be tailored to the needs of specific areas, with local organizations used for marketing and retailing whenever possible. Initial and follow-up training of locally available repair technicians is considered a vital part of ensuring system performance and customer satisfaction (Cabraal, Cosgrove-Davies, and Schaeffer 1996). To improve sustainability, these functions are best accomplished by a private firm. Examples of subsidized efforts to establish market infrastructure include Winrock International's project, with U.S. AID and U.S. ECRE funding, to create Renewable Energy Project Support Offices in developing countries (Winrock 1997). The National Rural Electric Cooperative Association (NRECA), expert in rural electrification in South America, has provided training and management infrastructure for successful renewable energy projects (Waddle 1997). Using the same market infrastructure to serve several renewable technologies in remote areas is a hallmark of these programs. The technical complexity and relatively large size of geothermal projects poses special challenges for market infrastructure development in rural areas. At the 1997 Village Power Conference, Inter-American Development Bank representatives highlighted using development assistance to establish viable markets, with pilot projects to identify and remove barriers (Smyser and Millan 1997). A World Bank representative cited local participation and institutional development, and also noted that government can address market failures (Stern 1997). Existing infrastructure should be used to speed projects, obtain active, broad (especially local) support, and establish maintenance systems (Taylor 1998). This experience confirms the importance of in-country expertise in managing operation and maintenance, collections, new electric connections, and other aspects of electric markets, as well as geothermal expertise.

Performance safeguards ensure that electricity services accomplish their goals. Standards for performance of geothermal technologies for rural applications should be established and used in performance tests. Although standards and testing can be costly, they help avoid the higher cost of equipment failure, and the bad reputation that comes with poor performance of a technology. Experience with other technologies indicates that reliability and ease of maintenance are higher priorities for remote areas, in comparison to other factors such as efficiency and cost, because repairs that require site visits by outside experts are costly (Taylor 1998). Performance standards that already exist should be enforced, and other performance standards may be needed. Quality control on manufacturing, installation, and maintenance should be established.

Public education about the technology is also important to ensure that performance meets the consumers' expectations (Cabraal, Cosgrove-Davies, and Schaeffer 1996). NRECA highlights standards for construction and operation within its electrification efforts (Waddle 1997). Performance of small geothermal plants may need additional documentation and troubleshooting to improve their reliability in remote areas, and better comparative data on binary and flash steam geothermal plants is needed. Technical experts at the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories have provided some assistance with technical standards for bids for renewable energy projects. Bids for large numbers of small geothermal projects for rural applications would require similar technical review.

The role of donors and governments is the final area of "best practices" that the World Bank report identifies (Cabraal, Cosgrove-Davies, and Schaeffer 1996). In general, donor and government activities should remove barriers to increase market size. Many of these activities occur during the initial phases of establishing a market. For example, for small geothermal projects, resource exploration risk, and technology risk are significant initial barriers that donors and governments might appropriately address.

International donors include a variety of institutions that provide grants or loans for development aid. Stern (1997) views the predominant role of donors as identifying and supporting reform in policies and institutions, with a lesser role in supporting important innovations. Similarly, he characterizes the government's role as establishing conditions under which markets can work and improving their function by providing technical assistance, information, and support. Facilitating access to financing is a critical role for governments and donors in encouraging new technology markets. Coordination among different sources of support for projects is essential, so that each assumes a role to allow good market function (Cabraal, Cosgrove-Davies, and Schaeffer 1996; Stern 1997; Smyser and Millan 1997). In light of the strong role that governments and donors play in geothermal projects, and the changes that electric sector reform will impose on these roles, these perspectives have clear implications for the small geothermal project.

NREL has an international Village Power Program to implement renewable energy projects, and is active in Brazil, Argentina, Chile, Dominican Republic, Mexico, and the Philippines. Sandia National Laboratories collaborates on Village Power in Mexico. This activity develops and implements technically sound, economically competitive, operationally viable, and environmentally beneficial rural electricity applications of renewable energy technologies. Components of the Village Power Program include development of renewable energy applications in rural areas and pilot projects; computer modeling, systems analysis, technical assistance, and remotely accessible databases (Flowers 1997). Applications development is essential to target technologies to rural energy needs and conditions. For small geothermal plants, this might mean designing smaller modules that required less maintenance, even under harsher conditions.

In the Village Power Program, pilot projects serve as important tests for these applications and foster the necessary expertise within the country. For a small geothermal program, a pilot project would mean full-scale demonstration of the technology and its supply and maintenance infrastructure. As projects progress, retaining staff is critical to project success. Expanding upon the initial introduction of a technology in a country has proven to be a time-consuming process, estimated to take five years or more from initial introduction to widespread use. In the case of geothermal, again, the presence of in-country expertise, which exists in the Philippines and many countries of Latin America, could facilitate this process.

Computer modeling of small-scale geothermal applications could serve to identify appropriate locations and sizes of power plants. Computer models have been developed to analyze a rural village for optimal electrification approaches and combinations of renewables with other technologies (Lilienthal and Lambert 1998; Lilienthal, Flowers, and Rossman 1998). Efforts are now under way to develop a computer model that will aid in siting power plants and grids within a rural region (Lilienthal 1998b).

Village Power also features collaboration and possible hybridization among several renewable energy technologies. As mentioned above, market infrastructures can serve several renewable technologies synergistically. Similarly, the Village Power Program evaluates opportunities for different renewable energy technologies to contribute to a given project. For example, projects in Chile and the Philippines are evaluating opportunities for renewable technologies to complement each other in electrification projects. With adequate resource and technology cost and performance data, evaluation of small geothermal projects could be integrated with other renewable resource use.

Integrating renewable energy projects with economic development faces ongoing challenges. Electrification alone accomplishes much less than a broader rural economic development program (Taylor 1998). Electrification is not always well integrated with rural economic development, because different institutions and different funds support these activities. Better integration of energy projects with economic development would help geothermal energy because rural economic development plans that increase load and base load could be coordinated with plans for small geothermal projects. For example, such development plans could improve mini-grid load profiles by linking productive loads, such as agricultural water pumping, to mini-grids that now serve mostly residential loads.

4.5 Summary

Small, rural geothermal projects serve rural electricity markets, which are very different from the market for electricity generation from the national grid. The following list summarizes characteristics of this market that are important considerations when evaluating opportunities for small geothermal projects.

- Much of the population that lacks access to electricity is in rural areas of developing countries, and that population is growing rapidly. Geothermal energy, as electricity or in direct use applications, could meet many of the energy needs of this population.

- National grids, mini-grids, or individual systems can be used for rural electricity development. Decision-makers consider a variety of factors in determining how to improve rural electricity, such as willingness and ability of rural households to pay for electricity services, distance to grid, load density, and productive loads. Quantitative geographic data is needed to support decisions about rural electricity development.

- Higher diesel costs occur where conditions such as low load density and remoteness are likely to raise costs of small geothermal projects as well, so diesel and geothermal would need to be compared at specific sites.

- Reform in the electric sector can reduce the role of national governments, and small-scale geothermal projects are likely to rely on such government catalysis. Despite electric sector reform, a government role in facilitating small geothermal projects could be retained.

- Innovative financing is a pressing need for many rural renewable energy projects, including small geothermal projects.

- Market infrastructure must include marketing, distribution, installation, maintenance, and revenue collection, and should use existing local infrastructures whenever possible.

- Small geothermal projects may benefit from the experience of other technologies showing that reliability and ease of maintenance are higher priorities for remote areas, in comparison to other factors such as efficiency and cost, because repairs that require site visits by outside experts are costly.

- Donor and government activities should remove barriers to increase market size. For small geothermal projects, resource exploration risk and technology risk are significant initial barriers that donors and governments might appropriately address.

5.0 The International Geothermal Industry

We now focus on competitive opportunities for power plant manufacturers and developers within the geothermal industry, by describing the capabilities and limitations of the major companies, and examining how national governments may influence their competitive position in markets for small geothermal power plants.

5.1 Current Industry Capabilities

Geothermal companies span a broad range of expertise, including geothermal development; exploration; drilling; power plant design, equipment, and construction; specialized scientific instruments for testing, monitoring, control, and logging equipment; heat exchange; and many different types of consultants (GRC 1998; GEA 1998). All of these industry sectors could work on small geothermal power plant projects. However, this examination of international competition will focus on the development and power plant segments of the geothermal industry.

The geothermal industry has experience with all of the major technology alternatives that might be used in small geothermal power plants including dry steam, flash steam, binary, topping/bottoming cycles, hybrids, and combinations with direct use. As discussed previously, flash steam and binary cycles are the most probable choices for rural electricity. The United States, Europe, and Japan are the most common location of companies listed in the GEA (1998) and GRC (1998) databases as project developers and power plant suppliers. Similarly, representatives of U.S. companies named Japanese and European firms as their most likely competitors in telephone interviews. Industry interviews with companies outside the United States were not conducted. Although Fuji is the only Japanese turbine manufacturer listed in the GRC database, U.S. company representatives noted that others, especially Mitsubishi and Toshiba, are strong competitors for geothermal equipment supply, so they could also participate in this market.

5.2. Development of Industry Capabilities for Small Geothermal Projects

Although the geothermal industry can supply technologies for this market, information on the operation and maintenance of small geothermal plants could be improved or, if available, developed into model project justification documents. Additional technology development is needed to improve the geothermal industry's capabilities to serve this market. Available operation and maintenance information includes the description by Forsha and Nichols (1997) of the Wineagle plant in California, which is presented as a model of what could be achieved in remote areas of developing countries. Its availability is reported as 98% during 11 years of operation, with "infrequent" unscheduled maintenance, periodic inspections, and yearly scheduled outages for maintenance. The plant has automatic control systems and is monitored by remote control. Remote control of geothermal plants has also been used in Italy to improve overall availability of large geothermal power plants from about 91% to 96% (Bracaloni et al. 1995).

For all sizes of geothermal plants, plant availability data are available from the GRC database. These data are incomplete, but show an average availability of 85%. Systematic identification of causes of outages for existing plants could be essential in achieving adequate performance and designing appropriate maintenance systems for remote areas.

Small-sized equipment manufacturing capability is a limitation on the growth of the small-scale geothermal market in a few respects. First, mass producing small plants as a package has been achieved only to a limited extent. Ormat probably approaches the goals of mass production and packaging most closely, with its modular binary systems. Producing large numbers of pre-packaged small plants would reduce the cost of each plant if the small-scale market opportunities increased.

A second equipment availability limitation is the size range of units that are generally manufactured. Individual units are available in small sizes. Examples of small-sized units that are readily available include Geothermal Power Company's 500 kW steam units and Ormat's 300-kW binary turbines. Demonstration units have been prepared in even smaller sizes than this, but a significant shift in the economic size of geothermal power plants would be needed to increase manufacturing of smaller-sized units. In general, binary units have been manufactured in relatively small sizes, compared to steam systems.

A third equipment availability challenge for small plants is the limitations of other equipment and parts besides the power plant itself. For example, the highly portable, modern drilling rigs that Sandia National Laboratories examined to reduce drilling costs (Huttrer 1997) may be less available than older, less efficient ones. Pritchett (1998a) also notes that the lack of a downhole pump small enough for slim holes is a current limitation, although one that could be overcome. A full systems study of each phase of development of a small power plant would likely reveal other equipment barriers to optimal development of these projects.

If there were a growing market for small, remote geothermal projects, international competition would come from several geographic areas. U.S., European, and Japanese companies probably have the best chance to successfully compete because of their international experience with geothermal projects and their international development programs. Iceland and New Zealand, with strong domestic experience, international training schools, and some international geothermal projects also have capabilities to serve this market.

In addition, several developing countries, Mexico and the Philippines, for example, already have significant expertise with specific aspects of geothermal power projects. If this market grows, the geothermal industry in developing countries could grow and become even more effective in competing or partnering with other international companies. Mexico and the Philippines could increase their exports of geothermal services to neighboring countries. An effective indigenous industry serving the small-scale geothermal market would be particularly likely in countries that already have significant industrial capabilities. A developing country is likely to provide strong political support for its own government or private sector geothermal efforts. For example, PNOC's exploratory well data, and its status as a government corporation, could pose challenges for geothermal projects in the Philippines that did not have PNOC support.

Japanese firms benefit in comparison to their international competitors because of the close cooperation between Japanese government and industry and the Japanese government's high profile as an international donor. Japan has used international development funds to support geothermal exploration. For example, the Japanese Overseas Economic Cooperation Fund provided the financing for feasibility studies for geothermal projects in Nicaragua, the Philippines, and Costa Rica (West JEC 1998). Japan provides "tied aid," in which development aid is packaged with contracts for Japanese businesses.

Similarly, the European Union, Italy, France, and Belgium have funded geothermal projects, from reconnaissance through construction, in Latin America and the Caribbean (Ducci 1995). The European Union funded the project, “Evaluation of the Capability for Managing Geothermal Resources in Latin America and the Caribbean.” This project furthers international goals of the United Nations Economic Commission for Latin America and the Caribbean (UN CEPAL), and benefits European industry. For example, the project description explains that benefits to the European Community include improved information about geothermal resource potential, investment opportunities, technological and personnel requirements, and legal and financial conditions (CEPAL 1998). As in Japan, close ties between government and industry are shown in France, where CFG is a commercial subsidiary of a public agency (CFG 1998).

Development aid from national governments clearly plays a role in facilitating geothermal development. The relationship to business development in the country that provided aid may be a direct one, as with "tied aid," or an indirect one based on networking and building relationships between representatives from the geothermal industry of the donor country and decision-makers in the recipient country.

5.3. Summary

The international geothermal industry has capabilities to develop small geothermal projects for rural electric markets, and these capabilities could be enhanced.

- The geothermal industry has experience with all of the major technology alternatives that might be used in small geothermal power plants, and is technically well positioned to serve this market. Both developed and developing countries have significant geothermal capabilities.

- Better knowledge, or better documentation, of infrastructure requirements of small plants in remote settings could enhance industry success in these markets.

- Mass production of small plants, manufacture of smaller-sized units, and improved availability of portable drill rigs, small diameter pumps, and other supporting equipment could help the geothermal industry with small projects.

- Government actions on the part of developed countries, such as development aid, can help the domestic geothermal industry of the developed country.

6.0 Conclusions

Small geothermal projects, less than 5 MW in size, could improve rural electricity supplies for the growing markets of Latin America, the Caribbean, and the Philippines. Small geothermal units could use either flash steam or binary technologies; these are technically proven and widely used in larger U.S. geothermal developments. However, their operational and economic feasibility in remote areas of developing countries is less well demonstrated. Investors in small geothermal projects will require documentation of performance in remote settings, including feasibility of plant designs and operation and maintenance plans. The choice between binary and flash will depend on site-specific characteristics. Small geothermal plants are potential competitors with diesel generators for rural electricity markets.

Exploration for small geothermal projects must be inexpensive so that the electricity from the project will be cost competitive. Understanding the effectiveness of small-scale exploration programs, and controlling drilling costs, present a significant challenge for small projects. Methods to reducing drilling costs include using slim holes for exploration and production, and advanced drilling systems. Geothermal resources have been characterized, to varying degrees, at many sites in Latin America, the Caribbean, and the Philippines. Using and adding to this knowledge base systematically could help small geothermal projects achieve low exploration costs. Existing wells may help geothermal exploration for small projects.

Rural people have pressing energy needs, and electricity from small geothermal plants could meet some of these needs. Individual systems, national grids, and mini-grids are used to provide rural electricity, and each type of system presents small geothermal projects with different competitors. Economic development could combine individual systems into a grid that small geothermal plants could serve. Small geothermal plants could provide distributed generation to remote parts of national grids. In mini-grids, a promising market for small geothermal plants, they would supplement or displace diesel generation. As electric sectors reform, private power producers become more likely customers for small geothermal power plants than public utilities. However, a continued public role may be important to catalyze small geothermal projects. Faced with competitive markets, small geothermal projects can benefit from lessons learned from other renewable technologies that supply rural markets: lessons about institutions to provide operation, maintenance, and other services; about innovative financing and technology performance; and about effects on market development of support from governments and financial institutions.

International firms from the United States, Europe, Japan, Iceland, New Zealand, and developing countries could develop small geothermal projects. These companies have the appropriate technologies for small projects, and have experience in international geothermal project development. The industry might respond to a growing small-scale geothermal market by tailoring power plants, drilling rigs, pumps, and other equipment to small applications. Better market infrastructure and innovative financing could improve industry success in these markets. National governments enhance the competitive position of their geothermal industries by funding international geothermal activities, supporting international trade, and requiring purchases in exchange for international aid.

7.0 Recommendations

Systematic, global exploration, including small and low temperature resources, should be continued. Existing wells and known resources should be considered for small geothermal projects. Geothermal resource data should be integrated with other geographic data such as grids, pipelines, roads, population, and projections of each; diesel generator locations, fuel costs, and operation should be included. This could be an expansion of current efforts, an international effort, or an effort from a government to develop small-scale geothermal opportunities.

All phases of small projects should be systematically evaluated to identify and reduce costs. Such efforts have been initiated in the drilling phase, with studies of portable drill rigs and slim holes. Evaluations should be performed on other topics specific to small, remote geothermal, such as appropriate secondary fluids for binary plants in remote areas, small pumps for slim holes, and operations and maintenance procedures. This could occur under the auspices of geothermal industry associations or under confidential agreements between private firms and researchers.

The small, remote geothermal concept should be proven to support financing of projects and planning of a service infrastructure. This proof could include establishing standards for small, remote systems to facilitate testing and improvements and developing data on operation and maintenance of small systems. Geothermal industry associations could establish self-enforced standards, or standards could be developed as specifications for government-funded projects.

Computer models should be used to determine the optimal size and location of geothermal plants and grids within a rural electrical system. To accomplish this, researchers could complete development of these models, and the private sector or governments could agree to apply them.

The problems for small projects associated with electric sector reform should be addressed. A strategy should be developed to interest private power producers in geothermal. Methods to determine the sale price of electricity from a small geothermal plant to the grid or mini-grid should be established. To smooth the transition to a reformed electric sector, a government could designate a small geothermal ombudsman, and international financial institutions could develop international standards for regulation and pricing. Industry, donor governments, recipient governments, and international financial institutions could partner to address these issues.

The credibility of small geothermal projects should be strengthened with lenders. This could involve exploring major issues for these projects with lender representatives. Financing approaches and processes may need to be standardized for small geothermal projects, and project bundling should be explored. Industry, donor and recipient country governments, and international financial institutions could collaborate to address this issue.

Private sector service models for small geothermal systems should be validated, by drawing on the expertise of existing geothermal personnel and other market development efforts. Other private industries' service logistics expertise could apply to small geothermal projects. Private industry could collaborate with public and financial players to design and validate these models.

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Appendix A – Geothermal Resources in Latin America, the Caribbean, and the Philippines

Note: The following maps, Figures A.1 through A.3, use data from these sources:

Geothermal Electrical Capacity: Fridleifsson 1997; Wright 1998.
Total Electrical Capacity: Pennwell 1996; DTI 1997
Geothermal Potential Electrical Capacity: Entingh, Easwaran, and McLarty 1994a and b

Figure A.1. Installed Geothermal Electrical Capacity

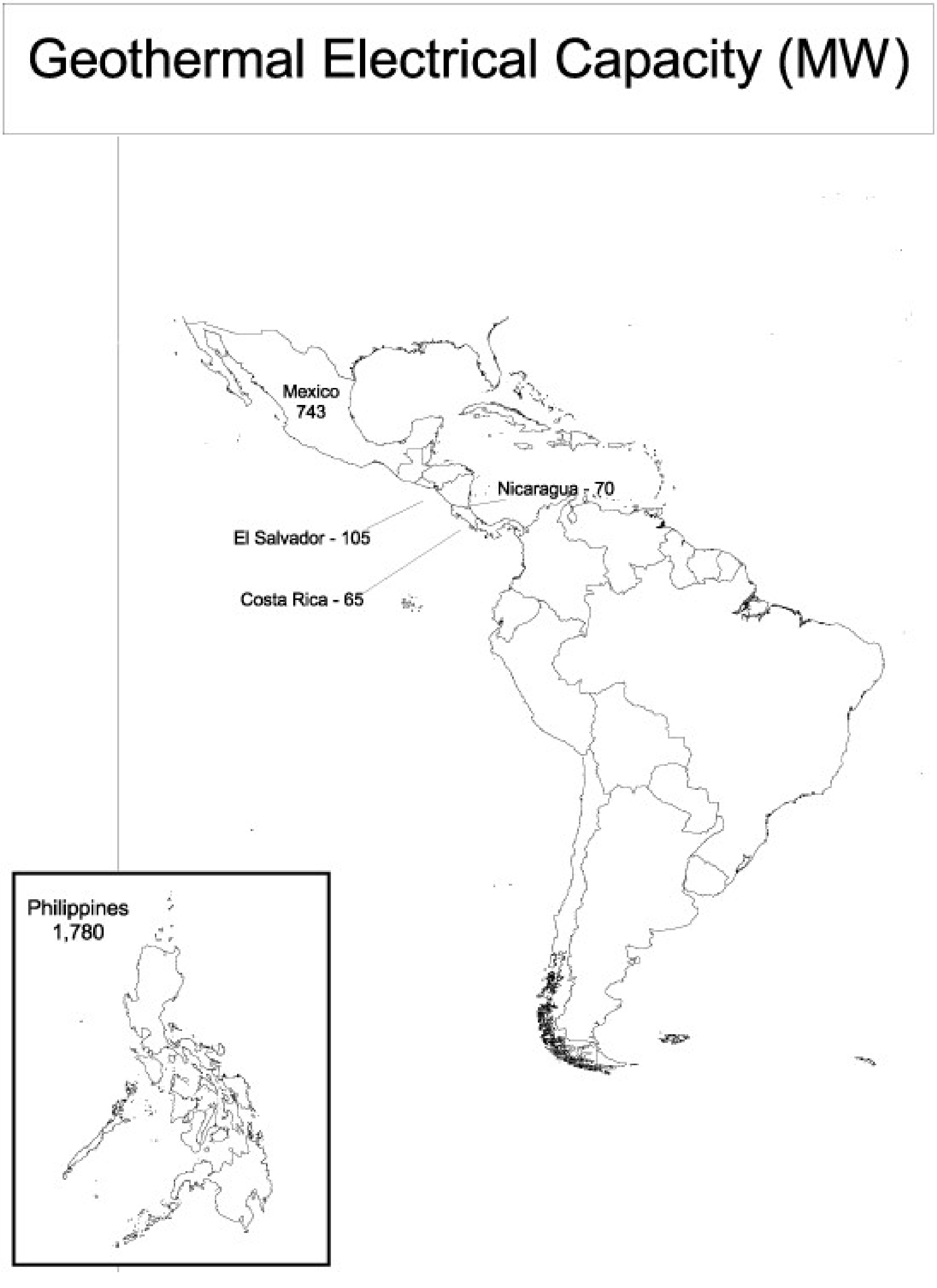


Figure A.2. Installed Electrical Capacity

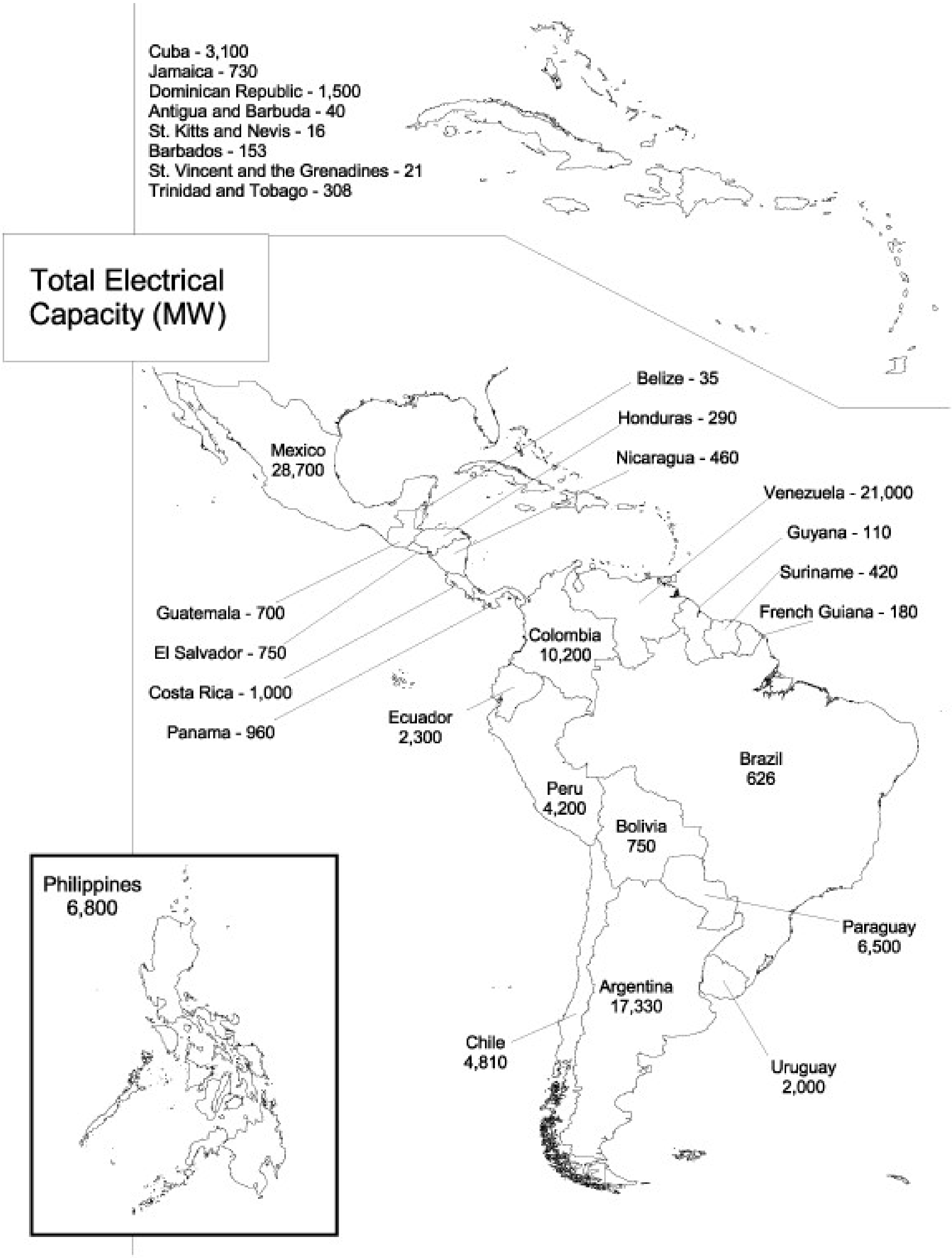


Figure A.3. Geothermal Potential Electrical Capacity

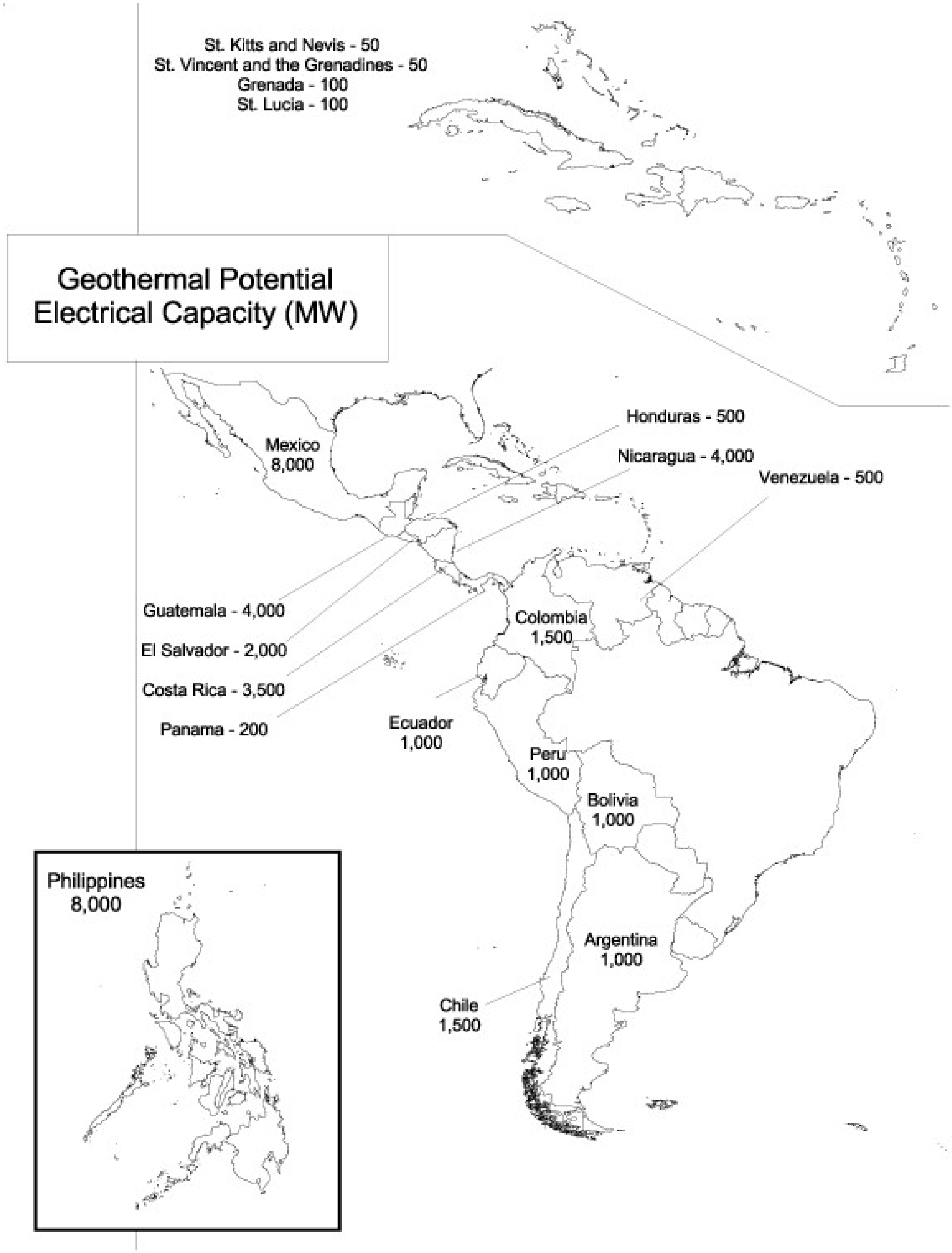


Table A.1. Major Geothermal Fields in Latin America, the Caribbean, and the Philippines.

Country	Geothermal Field	Current Installed Capability (MW$_e$)	Planned or Projected Development (MW$_e$)
Argentina	Tuzgle	--	--
	Domuyo	--	--
	Copahue	1	--
	Valle del Cura	--	--
Bolivia	Laguna Colorado	--	50
Costa Rica	Miravalles	60	110
	Tenorio	--	120
	Rincon de la Vieja	--	140
El Salvador	Ahuachapan	95	150
	Berlin	10	15
	San Vicente	--	115
	Chinameca	--	--
	Coatepeque	--	--
	Santa Rosa Lima	--	--
	Obrajuelo Lempa	--	--
Nicaragua	Hoyo-Monte Galan	--	105
Mexico	Cerro Prieto	620	704
	Los Azufres	98	--
	Los Humeros	35	38
	Las Tres Virgenes	--	--
	El Ceboruco-San Pedro	--	--
	Araro	--	--
	Pathe	--	--
	Santa Rita	--	--
	Domos de Zitacuaro	--	--
	Bahia Concepcion	--	--
	La Primavera	--	70
Chile	El Tatio	--	100
	Puchuldiza	--	--
	Polloquere	--	--
	Jurase	--	--
	Chanchoco-Copahue	--	--
	Petrohue	--	--

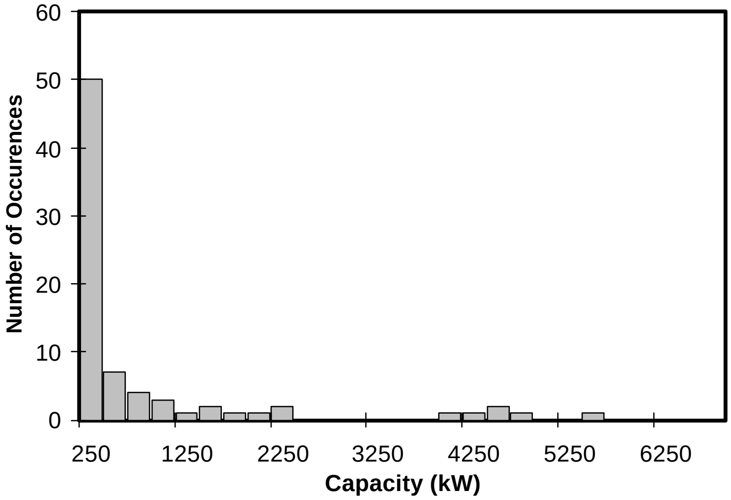
Country	**Geothermal Field**	**Current Installed Capability (MW_e)**	**Planned or Projected Development (MW_e)**
	Alitar	--	--
Guatemala	Zunil I	24	--
	Zunil II	--	50
	Amatitlan	--	30
	Tecuamburro	--	--
	San Marcos	--	--
Peru	Chivay	--	--
		--	--
Philippines	Mak-Ban	426*	11*
	Tiwi	330	--
	Tongonan	112	--
	Palimpinon	193*	--
	Bac-Man	130	20
	Sambaloran	--	30
	Upper Mahio	--	118
	Malitborg	--	77
	South Samaloran	--	154
	Mananagdong	--	180
	Alto Peak	--	77
	Palimpinon I	--	60
	Matangao	--	40
	Sandawa	--	40*
	Mt. Apo	--	47
Grenada	Castly Hill	--	--
	Hermitage-Peggy's Whim	--	--
	Clabony-Mount Hope	--	--
	Chambord	--	--
	Plaisance-Red River	--	--
	Adelphi - Saint Cyr	--	--

Sources: Huttrer 1995;
Nicaragua: Tsvi Meidav, Trans-Pacific Geothermal Corporation. Taken from IGA News #20 - January-March 1995.
Web site http://www.demon.co.uk/geosci/wrnicara.html, 7/4/98.
* IGA 1998

Appendix B – Diesel Generation in Latin America, the Caribbean, and the Philippines

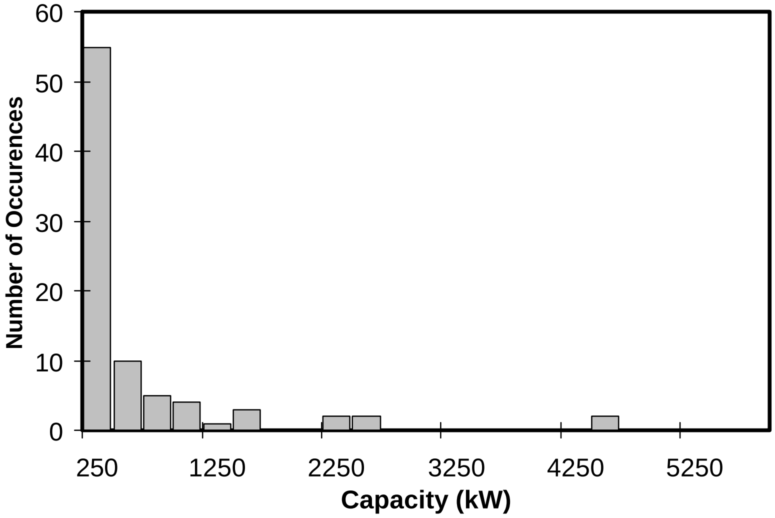
This appendix provides additional data on the size and cost of diesel generation in several countries in the region. The Philippines data below is for small, remote grids that are the responsibility of SPUG. In contrast, the Argentina data below is not remote grids alone. While the Philippines and Argentina data were obtained at a generator set level of disaggregation, and are displayed in the frequency distribution at the grid level of disaggregation, the Brazil data is aggregated at the state level.

Figure B.1. Frequency Distribution of Maximum System Demand for Small Grids



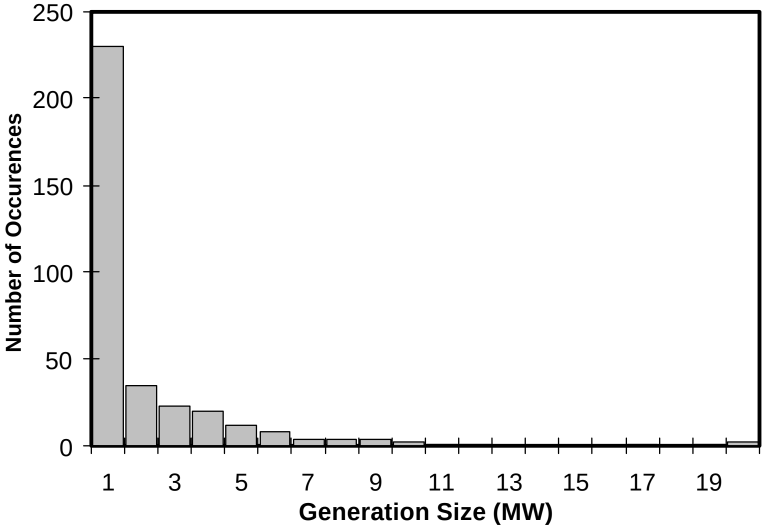
Source: Adapted from Abergas 1998

Figure B.2. Frequency Distribution of Diesel Generation in the Philippines



Source: Adapted from Abergas 1998

Figure B.3. Frequency Distribution of Diesel Generation in Argentina



Source: Adapted from Rieszer 1998

Table B.2. Isolated Grids in Brazil

Name	State	Hydro (MW)	Thermal (MW)	Total (MW)	Percent of National Capacity
MESA	AM	250	341.2	591.2	1.1
CEAM	AM	--	116	116	0.22
BVESA	RR	--	94	94	0.18
CER	RR	5	15	20	0.04
CEAM	AP	--	17	17	0.03
ELETRONORTE-Amapa	AP	40	54	94	0.18
ELETROACRE	AC	--	18	18	0.03
CERON	RO	8	110	118	0.22
CELPA-Isolados	PA	30	104	134	0.25
ELETRONORTE-Rondonia	RO	217	78.8	295.8	0.55
CELTINS-Isolados	TO	26.8	7	33.8	0.06
ELETRONORTE-Acre	AC	--	98.4	98.4	0.18
CEMAR-Isolados	MA	--	2	2	--
COPEL-Isolados	PR	--	1	1	--
CEEE-Isolados	RS	--	24	24	0.04
ENERSUL-Isolados	MS	--	3.5	3.5	0.01
CEMAT=Isolados	MT	10.2	49	59.2	0.11
TOTAL ISOLADOS		587	1132.9	1719.9	3.2

Source: Brazil 1998

General cost data is available for very small diesel generation in Guatemala. Note that these costs are higher than other diesel data reported elsewhere because of the much smaller size range here. In keeping with the smaller size, a 40%-capacity factor was selected, which also raises the cost compared to data elsewhere that uses an 80%-capacity factor for the cost calculation. This illustrates that size and load profile must be considered in comparing diesel generation to potential small geothermal projects.

Table B.3. Diesel/battery Generation Cost Assumptions for Guatemala.

Item	Cost
Generator (2 kW)	$1300 / kW
Fuel and lubricant	$0.1352 / kWh
Maintenance, inspection, and repair	$582 / year
Operation (to 25 homes)	$50 / month
Operation (26 to 50 homes)	$100 / month
Battery efficiency loss	15%

Source: Azurdia-Bravo 1998

These costs can be used to calculate the following costs per kilowatt-hour, assuming a 40% capacity factor and a 20% fixed charge rate.

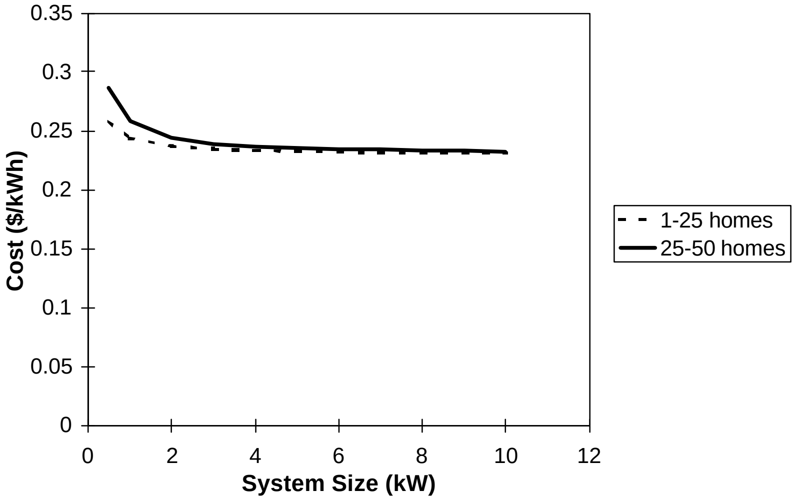


Figure B.4. Cost of Diesel Generation in Guatemala

Source: Adapted from Azurdia-Bravo 1998

Appendix C – Prices of Electricity in Latin America and the Caribbean

Table C.1. Estimated Caribbean Electric Power Production and Price.

Country	Total Capacity (MW)	Annual Production (1993) (GWh)	Electricity Price Range (cents/kWh)		Electricity Price (cents/kWh)			Reliability (Outages per year)		Percent Population on Grid
			Low	High	Residential	Commercial	Industrial	Low	High	
Anguilla			23	--	-	--	--	10	--	--
Antigua/ Barbuda	40	139	--	--	23	24	24	--	50	99
Aruba	--	--	11	16	--	--	--	10	--	--
Bahamas	--	--	16.5	20.5	--	--	--	2	20	--
Barbados	153	512	--	--	8.8	10.3	9.8	10	--	98
Belize	--	--	25	40	--	--	--	11	20	--
Bermuda	--	--	24.5	26.5	--	--	--	10	--	--
Bonaire	--	--	22.5	25	--	--	--	10	--	--
British V.I.	20	68	--	--	24	19	17	11	50	100
Cayman Islands	71	246	--	--	18.9	15	--	10	--	100
Cuba			11	16	--	--	--	26	50	--
Curacao	183	671			11.6	12.3	8.6	10	-	100
Dominica	15	49			20	22	--	-	50	95
Dominican Republic			27	38	--	--	--	-	50	--
Grenada			15	21	--	--	--	11	50	--

Country	Total Capacity (MW)	Annual Production (1993) (GWh)	Electricity Price Range (cents/kWh)		Electricity Price (cents/kWh)			Reliability (Outages per year)		Percent Population on Grid
Guadeloupe /Martinique	--	--	10	12	--	--	--	10	25	--
Guyana	118	239	--	--	25	40	30	50	-	65
Haiti			7	11						--
Jamaica	568	2140	--	--	11.8	10.8	9.1	10	50	64
Montserrat	4.6	19	--	--	18	20	17			--
Puerto Rico	4250	16743	--	--	8.15	10.9	8.5	11	25	98
St. Kitts/Nevis	16	60	--	--	11.8	12.6	12.6	10		--
St. Lucia	--	--	22	28	--	--	--	10	50	--
St. Maarten	--	--	17	20	--	--	--	-	50	--
St. Vincent/ Grenadines	21	57	--	--	22	25.2	20	11	25	95
Trinidad/ Tobago	308	3820	--	--	3.27	4	3.7	10	50	83
Turks and Caicos Islands	--	--	29	32	--	--	--	--	--	--
U.S. V.I.	240	--	--	--	12.5	12.5	12.5	11	50	99

Source: Capacity, generation, electricity price, and electrification data: DTI 1997. Table I.
Electricity Price Range data: DTI 1998. Reliability data: DTI 1997. Appendix H.

Table C.2. Latin America and the Caribbean: Average Electricity Rates (cents/kWh)

Note: These average tariffs are not intended to reflect the expected prices in remote areas, which are likely to be much higher than average.

Country	**Industry Rate - 1990**	**Residential Rate - 1990**
Argentina	6.8	7.3
Bolivia	5.5	5.3
Brazil	3.9	6
Chile	6.4	10.9
Colombia	5.6	2.7
Costa Rica	6.3	4.3
Dominican Republic	8.8	5.2
Ecuador	3.7	1.9
El Salvador	3.4	3.4
Guatemala	5.6	4.1
Haiti	9.6	12.7
Honduras	5.3	5.9
Jamaica	9.2	14.3
Mexico	4.8	4.4
Nicaragua	5.8	4.3
Panama	11.1	12.8
Paraguay	3.4	4.6
Peru	6.3	1.9
Trinidad	1.6	3.9
Uruguay	6.6	8.2
Venezuela	1.9	1.8

Source: Dussan 1996

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The objective of this report is to provide information on small geothermal project (less than 5 MW) opportunities in Latin America, the Caribbean, and the Philippines. This overview of issues facing small geothermal projects is intended especially for those who are not already familiar with small geothermal opportunities. This is a summary of issues and opportunities and serves as a starting point in determining next steps to develop this market.

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