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GEOTHERMAL ACTIVITY STATUS IN THE VOLCANIC CARIBBEAN ISLANDS

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Key Words: Caribbean, exploration, development, indicated work requirements

ABSTRACT

The Atlantic Crustal Plate is subducting westward beneath the Caribbean Plate resulting in formation of volcanic island chains that comprise: 1) an eastern, eastward-convex arc of older, extinct volcanoes and 2) a western arc of younger, dormant to active volcanoes. The two arcs join at Martinique and from there trend southwestward into the Paria Peninsula of Venezuela.

Geothermal indicia including warm to hot springs, fumaroles, solfataras and mud pots exist, to varying extents, on Saba, St. Eustatius (Statia), St. Christopher (St. Kitts), Nevis, Montserrat, Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent and Grenada. Volcanic eruptions and associated geothermal phenomena have been documented on Montserrat, Guadeloupe, Dominica, Martinique, St. Vincent, Grenada and Kick-em-Jenny (a highly active seamount north of Grenada).

Geothermal resource surface temperatures in the Lesser Antilles islands range from tepid to above boiling (superheated). Subsurface temperatures high enough to support utilization of a double flash energy conversion system have been recorded in the wells drilled for the 4.2 MW La Bouillante power plant on Guadeloupe while temperatures up to 214°C were measured in wells drilled near Soufrière, St. Lucia.

Prior to 1995, geothermally oriented geologic, geochemical and geophysical studies were conducted on Guadeloupe, Dominica, Montserrat, St. Lucia and Grenada. Ten 500 meter deep wells were drilled at Watten Waven in Dominica; large diameter wells were drilled on Guadeloupe in 1982-1984 and two deep exploration wells were drilled in St. Lucia in 1984-1987.

Between 1995 and 1999, Caribbean geothermal activity was confined to prefeasibility and feasibility studies conducted on St. Vincent, Saba, Statia, St. Kitts and Nevis. The work included geologic, geochemical and some geophysical studies plus the acquisition of much non-resource related information. Though the signing of Power Purchase Agreements between utility companies, local governments and private developers has been reported on St. Vincent, Dominica and Grenada, to date no wells have been drilled.

Low temperature geothermal waters are informally used for bathing on several islands and bath houses have been built on St. Lucia and Nevis. Otherwise, geothermal fluids are not being used.

1. INTRODUCTION

The northern islands of the Lesser Antilles are all potential sites of geothermal resources because virtually all of the islands are underlain by active or dormant (but not extinct) volcanoes. The 11 islands falling into this category are, from north to south, Saba, St. Eustatius (Statia), St. Christopher (St. Kitts), Nevis, Montserrat, Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent and Grenada (Figure 1).

The islands comprise two eastward convex arcs. South of Montserrat, these arcs merge to form a single curvilinear island chain that intersects the South American continent at the Peninsula de Paria of Venezuela. The western island arc and its southern extension are of relatively recent volcanic origin. The northern and eastern islands, though once loci of volcanism, are now mantled by thick sedimentary deposits.

The reason for the active volcanism is that the Caribbean islands occupy a crustal plate that forms a “tongue” or buttress along the sides of which the North and South American Plates move westward and beneath which the Atlantic Plate is subducting westward (Figure 2). The Atlantic Plate subduction has created volcanic arcs typical of plate boundaries and, in the Caribbean, each volcano or group of volcanoes has formed the foundation of a discrete island.

2. GEOTHERMAL POWER GENERATION OPPORTUNITIES

The potential for construction of small to medium sized (5-25 MW) geothermal power generation facilities and/or significant direct-use projects is excellent in many Caribbean islands. The countries are still developing, their transmission and distribution grids are extensive and their power and thermal energy requirements are growing. Excluding the French islands, the largest electrical loads are on St. Vincent, St. Lucia and Dominica where 10-20 MW is or will soon be needed. Next in size is Grenada where 8-12 MW could be used and finally come all the rest of the islands whose current needs range from 2 to 5 MW.

In virtually all of the islands, generation (predominantly diesel-fueled, with some hydro), transmission and distribution costs (including all soft costs) range between $0.12 and $0.15 per kWh. It is important to note that while few of the utility companies have an accurate accounting of their real costs, it seems very likely that geothermally generated power could be provided for a lower cost than the utilities now pay in-house. In many countries, O&M-caused brownouts or power outages are all too common and are reportedly on the increase.

Careful, realistic calculations of planned geothermal project economics and of current true power costs must be made. Assuming that they confirm the economic viability of a planned project, they will be critically important in convincing governments and utility officials that geothermal power will be less expensive and more reliable than their traditional generating systems.

3. CARIBBEAN GEOTHERMAL POWER PROJECT PROS AND CONS

The conditions favoring small geothermal power developments in the Lesser Antilles include:

- Good to excellent chances for discovery of economically viable geothermal resources.
- A generally positive attitude by all of the national governments toward the exploitation of their indigenous resources.
- A growing realization that power generation by entities other than the government can be simultaneously beneficial to the host nation and to independent power producers.
- Increasing impatience on the part of citizens and government officials, on all the islands, towards long standing, excessive O&M problems with diesel generator sets.
- Power demand growth of 7-10% per year in most countries. This may actually accelerate because all of the nations are seeking to increase their revenues by attracting tourists. More tourists will require more hotels and more air conditioned hotels will require more power.
- The high cost of power generation on most islands that almost certainly could be decreased with the addition of geothermally generated electricity.
- The pressing need for fresh water on all the islands except Dominica and St. Lucia. If more economical electricity were to become available on the dry islands, large reverse osmosis installations could be built and operated to alleviate periodic water shortages, rationing and the need to depend on rainfall collection in cisterns.

Some negative aspects or obstacles regarding initiation of Caribbean small geothermal power project are:

- The difficulty in financing small (<$50 million) projects.
- The relatively low rate of return likely on small Caribbean geothermal power projects and the associated need to minimize exploration expenditures which unavoidably will increase the risk level perceived by potential investors.
- The speckled history of fiscal management on the part of the governments of several of these islands and their consequent low international credit ratings.
- The marginal solvency of many of the national utility companies and the inability or unwillingness of the national governments to guarantee payments by their utilities for power purchased.
- The common occurrence of destructive hurricanes in the region and the recent experiences with damage due to the volcanic eruptions on Montserrat.

4. EXPLORATION AND DEVELOPMENT STATUS SUMMARIES

Some prefeasibility and reconnaissance exploration has been conducted since 1995, but the only exploratory drilling and power plant construction in the region was done in prior years (1979-1986). The scope of these activities is summarized below.

4.1 Prefeasibility studies - The author, with assistance from Dr. D. E. Michels and J. Renner, conducted prefeasibility studies on St. Vincent, Saba, St. Eustatius (Statia), St. Christopher (Kitts) and Nevis since 1995. In all cases, the work included reviews of geothermally-relevant literature, acquisition and stereoscopic analysis of airphotos, reconnaissance (confirmatory) geologic mapping, petrographic studies of fresh and altered rock samples, geochemistry of thermal and non-thermal waters and collection of large amounts of non-resource related information. The latter included data regarding electric power, environmental topics, permitting, government philosophies about use of indigenous resources, locally available labor, facilities, supplies and costs and logistical/construction matters.

4.2 Reconnaissance - Second stage work is herein defined to include some or all of: detailed geologic mapping, comprehensive water and/or gas geochemistry, electrical surveys (resistivity, S-P, CSAMT, MT etc.), gravity or magnetic surveys, soil mercury, radioactivity or CO_2 and shallow (thermal gradient or slim-hole) drilling. It has been done, *prior to 1995*, on Dominica, Guadeloupe and Martinique by the French, on St. Lucia by the English, Los Alamos National Laboratories and Aquater of Italy and on Montserrat by British, Italian and US entities. On St. Vincent, in 1996 and 1997, a US company undertook some second stage studies including geochemistry, geology and electrical geophysical surveys. These studies have resulted in advanced characterization of the chemistry, temperature and depth of resources on St. Vincent and the signing of documents needed to allow geothermal drilling and development in the future

4.3 Deep Exploratory Drilling - Following reconnaissance studies performed in the 1970's and 1980's, this expensive work has been undertaken to date only on Guadeloupe by CFG and BRGM and on St. Lucia where 2 wells were drilled by a multilaterally-funded team led by Italian geothermists. The first St. Lucia well found heat but low permeability however second well, spudded in 1987, discovered what appeared to be an economically exploitable resource. Unfortunately, this well suffered mechanical failures and the produced steam was never harnessed to generate power. There has been no deep drilling in the Caribbean since the completion of this well in 1988.

4.4 Development - The drilling of successful deep wells on Guadeloupe in 1969-1970 led to the building of a 4.2 MW double flash power plant in 1984. This plant has had intermittent problems caused by relatively high amounts of non-condensable gasses and associated H_2SO_4, but these seem to have been mitigated by CFG and the plant is now in operation. There is excellent potential for expansion of this development, and plans to have 20 MW on line by 2003 have been reported.

5. WORK NEEDED TO SITE DEEP WELLS

On more of the islands where strong geothermal indicia have been mapped via pre-feasibility studies, second stage reconnaissance work as defined above should be conducted. The extent and precise type of the geophysical work will be dictated by logistical considerations and the nature of the preliminary geothermal system model. Thermal gradient drilling should comprise no less than five 300 meter holes sited in accordance with the results of preceding surveys.

Once thermal gradient drilling results are available, decisions will have to be made whether to drill one or more slim holes or to drill a full scale exploratory well(s). A discussion of the factors to be considered when making these decisions is beyond the scope of this paper but it is estimated that pre-production well drilling costs will approximate $1.5 million.

6. GEOTHERMAL RESOURCE INDICIA AND STATUS SUMMARIES

Presented below, in descending order of development potential, are brief descriptions of geothermal indicia development status' on each of the 11 volcanic islands:

6.1 Guadeloupe - The volcano La Soufrière on Basseterre has large fumerolic areas and there are thermal springs on the mountain flanks. Plans are to expand the 4.2 MW currently generated at La Bouillante to 20 MW by 2003.

6.2 Saba - Saba is a small island comprising a central volcano with at least 15 andesitic domes on its flanks. There is a record of volcanic eruption(s) less than 1000 years ago and there are numerous hot springs along the shoreline and just off shore. The island is highly fractured, some hot springs temperatures have risen in the last 40 years. Though the potential power marked on-island is small, there may be potential for power export via sub-sea cable to Statia, St. Maartin and/or Antigua, Accordingly, second-stage work should be conducted.

6.3 St. Kitts - Though there are moderately large areas of steaming ground in the crater of Mt. Liamuiga and some small thermal springs along the western shoreline, the geothermal indicia are less well defined than on the previously described islands. Second stage studies will have to refine the currently rather nebulous geothermal targets. The work will be costly and may have lower priority than that on the above-listed islands.

6.4 Grenada - Prefeasibility studies have revealed one small solfatara on Mt. St. Katherine, several small thermal springs in ravines radial to the central volcano and numerous relatively young phreatic explosion craters. Additionally, the sub-sea volcano Kick-em-Jenny lies only 5 miles off Grenada's north coast suggesting that the zone between it and central northeastern Grenada may be geothermally prospective. Second stage work will have to cover large, rugged areas, but if successful, the market for geothermal power would be significant.

6.5 St. Lucia - Geothermal indicia on St. Lucia comprise a very large solfatara near the village of Soufrière, thermal springs nearby and very recent volcanic activity including both phreatic and pyroclastic eruptions. There is sporadic talk of resumption of the project undertaken in the 1980's, but nothing concrete has developed to date.

6.6 Dominica - The likely presence of geothermal resources beneath Dominica is suggested by a boiling lake, numerous boiling hot springs, several large solfataras and very recent (<500 YBP) volcanic activity. There are at least three geothermal centers. In 1995, an American company entered into agreements with the utility and the government to develop the resource at Soufriére but to date no action has resulted.

6.7 St. Vincent - La Soufrière volcano has erupted three times since 1902, there is a steaming resurgent dome in the crater and there are numerous hot springs in river valleys on the western side of the volcano. Following 1995 prefeasibility studies, an American firm conducted second stage work preliminary to drilling and signed geothermal project-related agreements with Vincentian entities. To date no further work has been done.

6.8 Nevis - On Nevis' western and southern sides, there are two solfataras, numerous thermal wells and a large area of hydrothermal alteration. Also, strong earthquakes with hypocenters very near Nevis occurred in 1951 and 1961. There are encouraging geothermal indicia at 5 places on the island. The need for second stage work can be easily justified.

6.9 Martinique - The very active Mt. Pelé comprises an obvious locus for geothermal resources. There are solfataras, hot springs, earthquake epicenters nearby and well developed fracture systems. This island is controlled by France. If and when they decide to develop the undoubtedly great geothermal resource, they will do so. To date, they have not been inclined to invite participation by non-French entities.

6.10 Montserrat - Even before the 1995 eruptions, the southwestern flank of the Soufrière Hills volcano was the site of solfataric activity and of numerous thermal springs. There was also significant seismic activity and several well developed fracture systems transecting the volcano. Though the energy potential of the Soufriére Hills has been made abundantly obvious, there may be few financial or insurance firms willing to participate in a geothermal project on the flanks of a very active volcano.

6.11 Statia - While some heat probably remains beneath The Quill as evidenced by reported occurrences of thermal waters in two wells drilled for drinking water, there are no known hot springs or paleo-thermal areas on the island. This island has the lowest priority for follow-on exploratory work. Further studies will have to wait until more cost effective technology makes Statia an economical development prospect.

7. SUMMARY

There are 11 volcanic islands in the Lesser Antilles of the Caribbean Sea having modest to very significant geothermal resource potential. Prefeasibility and reconnaissance phase exploration and power generation have been accomplished to varying degrees on these islands with generally encouraging results.

Power demands range from 2 to 45 MW and the average annual power demand growth rate of 7-10% is anticipated to increase. Access to grids is not a problem on any island. Geothermal power could almost surely be sold to the utilities for less than the $0.12 to $0.15 per Kwh cost of generation now estimated by the various utility companies and the prospect of initiating significant savings is appealing to government officials as well as the citizens-on-the-streets.

Though financing of small projects may be difficult to obtain and greater returns on investment may be possible via other types of projects, these obstacles should be surmountable. The environmental and social benefits of geothermal resource use are very impressive and they virtually mandate that the developed nations make strong efforts towards its development in the Caribbean island nations.

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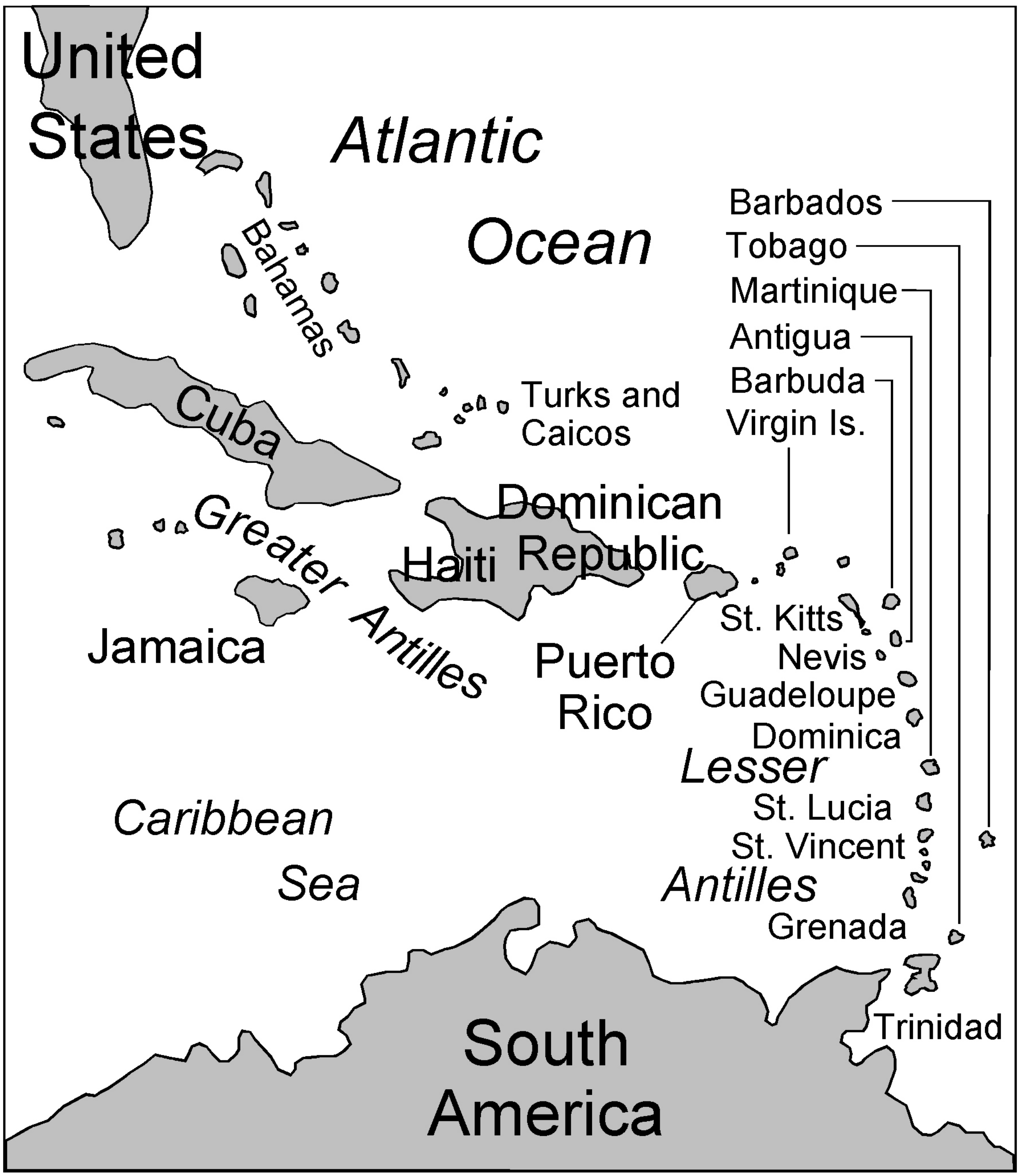

Figure 1 – Location Map

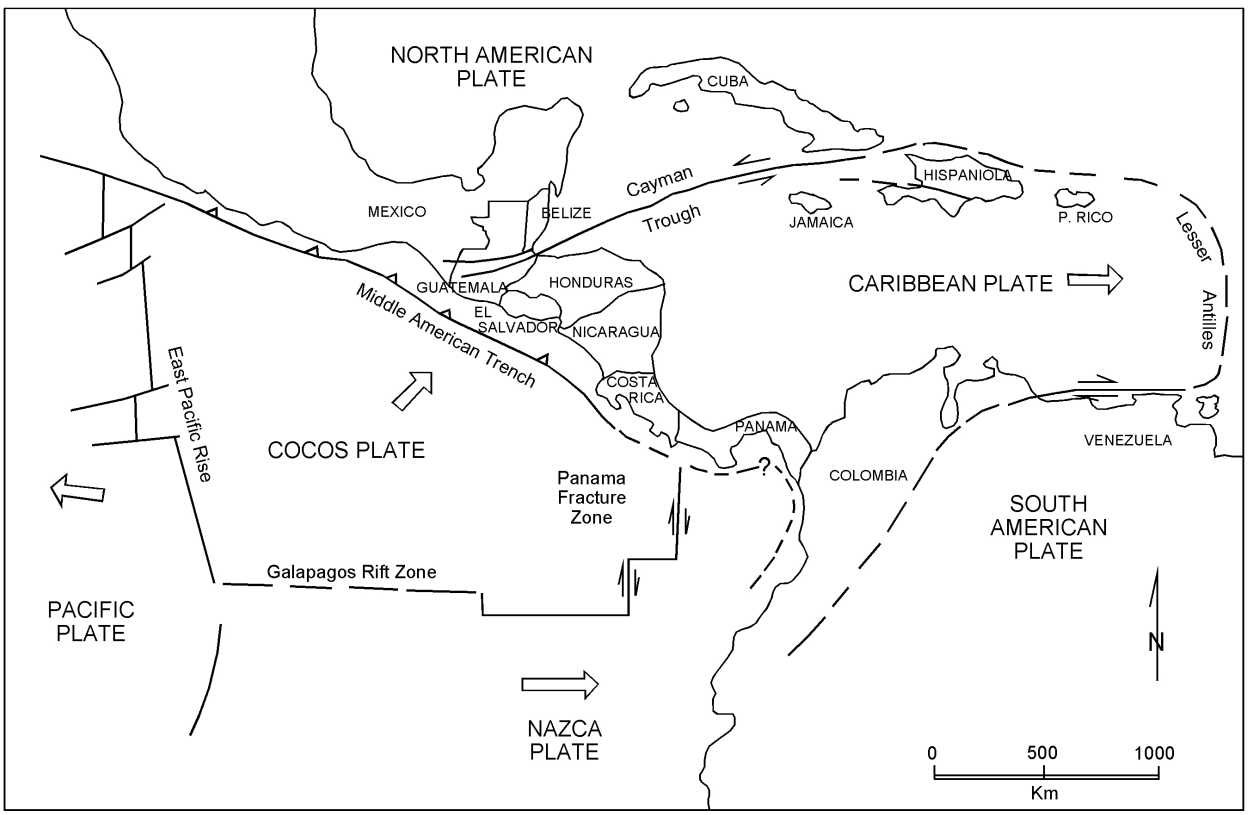

Figure 2 – Crustal Plates of the Caribean Region

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICTY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specifiy)		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in January 2000	4.2	27.594	107.295	430.397	9	64.259					120.495	522.249
Under construction in January 2000												
Funds committed, but not yet under construction in January 2000												
Total projected use by 2005	20	131.4	107.295	430.397	9	64.259					136.295	626.056

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 1999

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Data for 1999 if available, otherwise for 1998. Please specify which.

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1]	Type of Unit[2]	Unit Rating MWe	Total Installed Capacity MWe	Annual Energy Produced 1999[3] GWh/yr	Total under Constr. or Planned MWe
Guadeloupe	La Bouilliante - 1984		1		2F	4.2	4.2	27.594	20
Total			1				4.2	27.594	20

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 1999

[1] I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish and animal farming
S = Snow melting
H = Space heating & district heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

[2] Enthalpy information is given only if there is steam or two-phase flow

[3] Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[4] Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

[5] Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Locality		Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
			Flow Rate	Temperature (^{o}C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
			(kg/s)	Inlet	Outllet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Nevis	The Baths	B	4.594	43.9	41.5			0.046	3.063	0.969	0.66
TOTAL			4.594					0.046	3.063	0.969	0.66

Note: please report all numbers to three significant figures.

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF DECEMBER 1999

This table should report thermal energy used (i.e. energy removed from the ground or water) and not the heat rejected to the ground or water in the cooling mode.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps
2) Report type of installation as follows: V = vertical ground coupled
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)
3) Report the COP = (output thermal energy/input energy of compressor) for your climate
4) Report the equivalent full load operating hours per year, or = capacity factor x 8760
5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Locality	Ground or water temp. (^oC)[1)]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2)]	COP[3)]	Equivalent Full Load Hr/Year[4)]	Thermal Energy Used (TJ/yr = 10^{12}J/yr)[5)]
None							
TOTAL							

Note: please report all numbers to three significant figures

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 1999

[1] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalphy (kJ/kg)] x 0.001

[2] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

[3] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Space Heating[4]			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish and Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	0.046	0.969	0.66
Other Uses (specify)			
Subtotal	0.046	0.969	0.66
Geothermal Heat Pumps	0	0	0
TOTAL	0.046	0.969	0.66

[4] Includes district heating (if individual space heating is significant, please report separately)
[5] Includes drying or dehydration of grains, fruits and vegetables
[6] Excludes agricultural drying and dehydration
[7] Includes balneology

Note: please report all numbers to three significant figures.

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 1995 TO DECEMBER 31, 1999

[1] Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)					
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total		0	0	0	0	0

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TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with a University degress)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributied Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
1995	0.1				1.5	
1996						1
1997	0.1	0.1			1.5	0.5
1998	0.1				0.2	
1999						
Total	0.3	0.1			3.2	1.5

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (1999) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1985-1989	2					100
1990-1994	0.2					100
1995-1999	0.3				66	34