Presented at Workshop for Decision Makers on Geothermal Projects in Central America, organized by UNU-GTP and LaGeo in San Salvador, El Salvador, 26 November to 2 December 2006.

COSTA RICAN GEOTHERMAL ENERGY DEVELOPMENT 1994-2006

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ABSTRACT

The exploration and development of geothermal energy and its contribution to the electricity needs of Costa Rica are reviewed. A national reconnaissance resource study, carried out during 1989 and 1991, indicated that the possible total geothermal potential of the country was about 900 MWe.

The first deep geothermal exploratory wells in Costa Rica were drilled at Miravalles in 1979-1980. Electricity began to be produced at that geothermal field in early 1994. Since then, the installed capacity has grown from 55 MWe to 163 MWe. The two undeveloped Costa Rican geothermal systems that have been studied the most are those associated with the Tenorio and Rincón de la Vieja volcanoes. In 2001, a deep exploratory drilling program was started at the Las Pailas geothermal zone on the southern slope of the Rincón de la Vieja volcano. At the same volcano, but in another geothermal zone called Borinquen, geothermal wells have been drilled starting in 2003 and 2004. Preliminary results of those drilling programs are presented.

The contributions of different energy sources to the electricity system of Costa Rica are discussed. At the end of 2004, geothermal energy contributed 1,204.4 GWh, representing more than 15% of the total electricity generated, even though it accounted for only 8.6 % of the country's installed capacity.

1. INTRODUCTION

Costa Rica is located in the southern part of the Central American isthmus, between Nicaragua and Panama. The country extends over an area of approximately 51,000 km^2 and has a population of about 4.3 million. In the early 1970s, Costa Rica satisfied its electricity needs using hydro (70%) and thermal (30%) energy sources. The continuous rise in oil prices, especially during the 1973 crisis, motivated the authorities of the national utility company, the Instituto Costarricense de Electricidad (ICE), to study the possibility of using other energy sources for generating electricity, including geothermal energy. The development and contribution of geothermal energy to Costa Rica's electricity system are described in the following sections.

2. COSTA RICAN GEOTHERMAL DEVELOPMENT

The first evaluations of the geothermal resources of Costa Rica were carried out in the mid-1960s. Preliminary exploratory studies of the geothermal areas in the Cordillera Volcánica de Guanacaste (Figure 1) were performed in 1975.

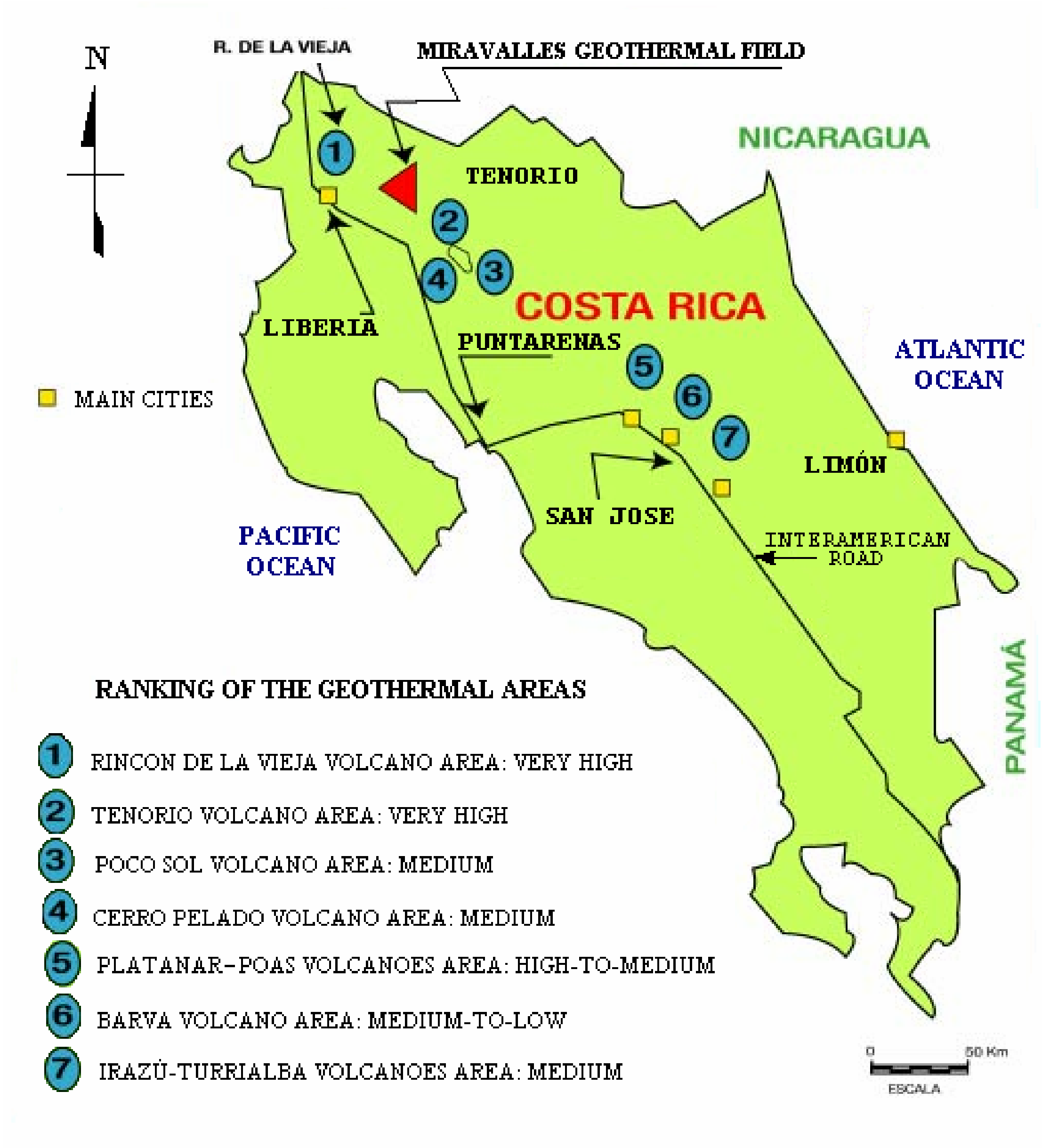

FIGURE 1: Location of geothermal areas in Costa Rica

One of the recommendations made was to investigate the areas on the slopes of the Rincón de la Vieja, Miravalles and Tenorio volcanoes in more detail. Thus, ICE began to collect geologic, hydrologic and geochemical data over a region of more than 500 km^2 between the volcanoes and the Interamerican Highway ("Carretera Interamericana"; Figure 1).

The first technical report (a set of pre-feasibility studies) on the possibility of exploiting geothermal resources for generating electricity within the area mentioned above was completed in 1976. The positive outcome of this work allowed ICE to continue its applications for loans from the

Interamerican Development Bank (IDB), which were needed to initiate the development of the Miravalles geothermal field (Figure 1).

To finance the successive phases of geothermal activities, from exploration to exploitation, Costa Rica decided to use its own funds as well as loans from the IDB. Following this policy, ICE obtained its first IDB loan in 1977 to fund the drilling of the first three wells at Miravalles; this work was carried out between June 1979 and May 1980. Based on the steam produced by these three successful wells (sufficient to generate around 15 MWe), the existence of a commercial-size geothermal system was inferred. It was thought to extend over an area of about 15 km^2 on the southwestern slope of Miravalles volcano, north-northeast of the small town of La Fortuna (Figure 2).

Six more production and injection wells were drilled at Miravalles during 1984-86. Based on the data gathered, feasibility and environmental impact reports for the first geothermal unit in the country were prepared in 1986-87. In 1987, ICE obtained a new IDB loan to cover the cost of: (1) 20 additional wells, (2) consultant services to prepare the feasibility report for future units, (3) power plant equipment, (4) powerhouse construction, (5) pipelines to transport geothermal fluids at the surface, (6) substation equipment, and (7) an electrical transmission line from the field to the main national line at Liberia (approximately 50 km away).

Between 1989 and 1991, ICE, using its own funds and those of the Italian government, carried out a national geothermal reconnaissance study which was managed by the United Nations Development Program (UNDP). The final report, issued in November 1991 and entitled “Evaluación del Potencial Geotérmico de Costa Rica” (ICE, 1991), ranked the various areas of geothermal interest in the country (Figure 1), and indicated that the possible total geothermal potential of Costa Rica was about 900 MWe.

3. MIRAVALLES GEOTHERMAL FIELD

Miravalles, the most important Costa Rican geothermal area, is located on the southwestern slope of the Miravalles volcano. The present field extends over an area of more than 21 km^2; about 16 km^2 are dedicated to production and 5 km^2 to injection. The temperature of the water-dominated geothermal reservoir is about 240^oC. Fifty-three geothermal wells have been drilled to date (Figure 2). They include observation, production and injection wells, with depths ranging from 900 to 3,000 meters. Individual wells produce enough steam to generate between 3 and 12 MWe; injection wells accept between 70 and 450 kg/s of separated geothermal fluids each.

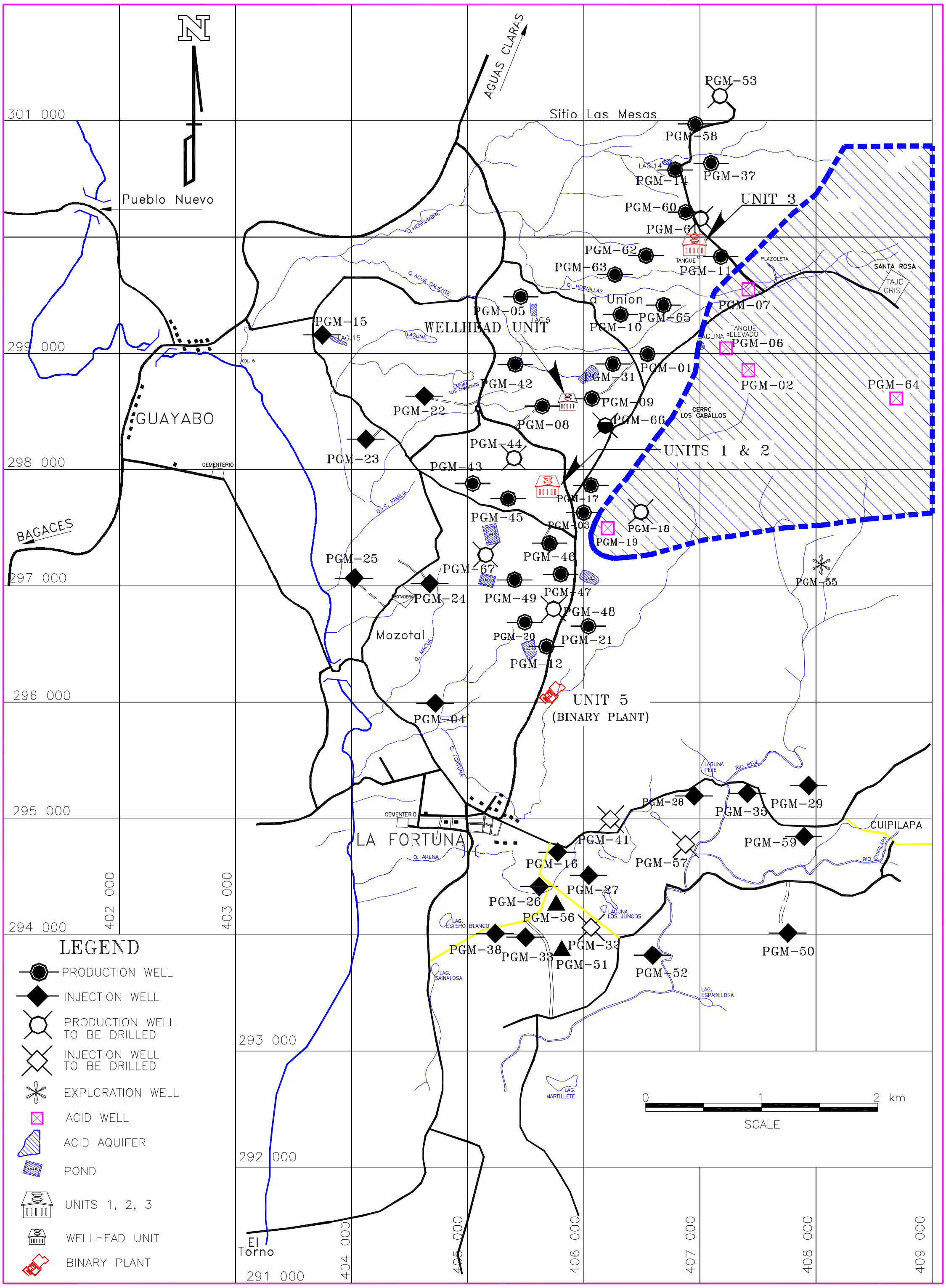

FIGURE 2: Map of the Miravalles geothermal field

Commercial production of electricity using geothermal steam began at Miravalles in early 1994, when Unit 1, a 55-MW single-flash plant, was commissioned. The following year, ICE completed the installation of a 5-MW wellhead unit. Then, two temporary 5-MW wellhead plants came on line as part of an agreement between ICE and the Comisión Federal de Electricidad de México (CFE). The two temporary units were disassembled in January and August 1998 and returned to CFE. Unit 2, the second 55-MW plant, started production in August 1998. In March 2000, Unit 3, a 29-MW single-flash private plant, started delivering electricity to the national grid, and finally Unit 5, a 19 MWe binary plant, increased the total installed capacity at Miravalles to 163 MWe (Table 1). The history of the growth of capacity at the field is shown in Figure 3. The location of the power plants is shown in Figure 2.

TABLE 1: Units at the Miravalles Geothermal Field

Plant Name	Power (MW)	Owner	Start-up Date	Shut-down Date
Unit 1	55	ICE	3/1994	
WHU-1	5	ICE	1/1995	
WHU-2	5	CFE	9/1996	4/1999
WHU-3	5	CFE	2/1997	4/1998
Unit 2	55	ICE	8/1998	
Unit 3	29	ICE (BOT)	3/2000	
Unit 5	19	ICE	1/2004	

In Table 1, the abbreviations stand for: ICE - Instituto Costarricense de Electricidad; CFE - Comisión Federal de Electricidad (México); WHU - Wellhead Unit; and BOT – build-operate-transfer.

Steam for Units 1-3 and the wellhead unit is separated from the produced hot water at seven separation stations. Generally, two or three production wells send their two-phase fluids to one of these stations. At present, separation stations 2, 3 and 4 supply steam mainly to Unit 1, stations 1, 5 and 6 feed Unit 2, and station 7 sends its steam to Unit 3. Figure 4 shows the amount of fluids handled by the seven separation stations since they began operation. Unit 5 extracts additional energy from the separated geothermal brine before it is injected back into the geothermal reservoir.

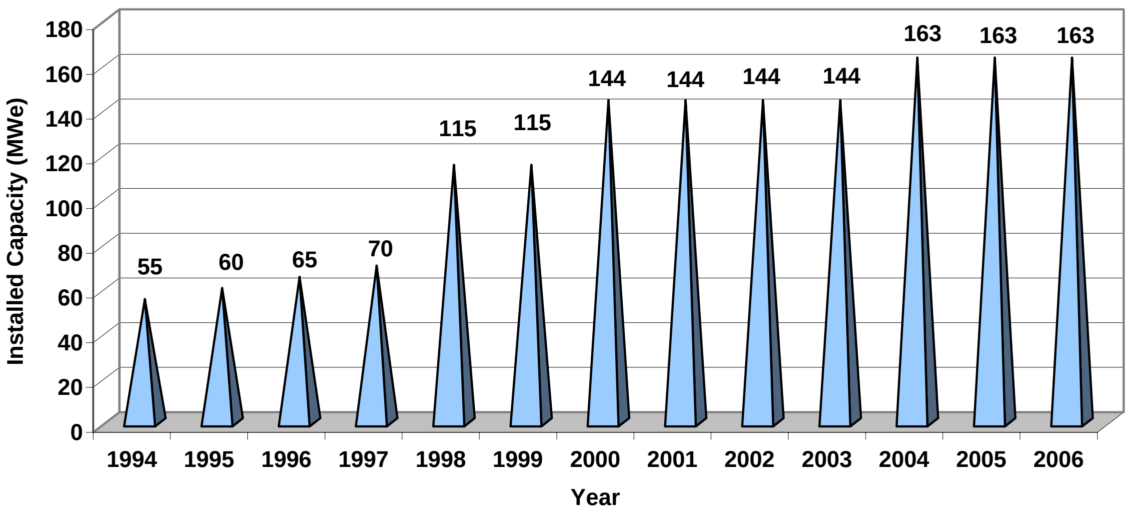

FIGURE 3: Costa Rica installed geothermal power capacity: 1994 - 2006

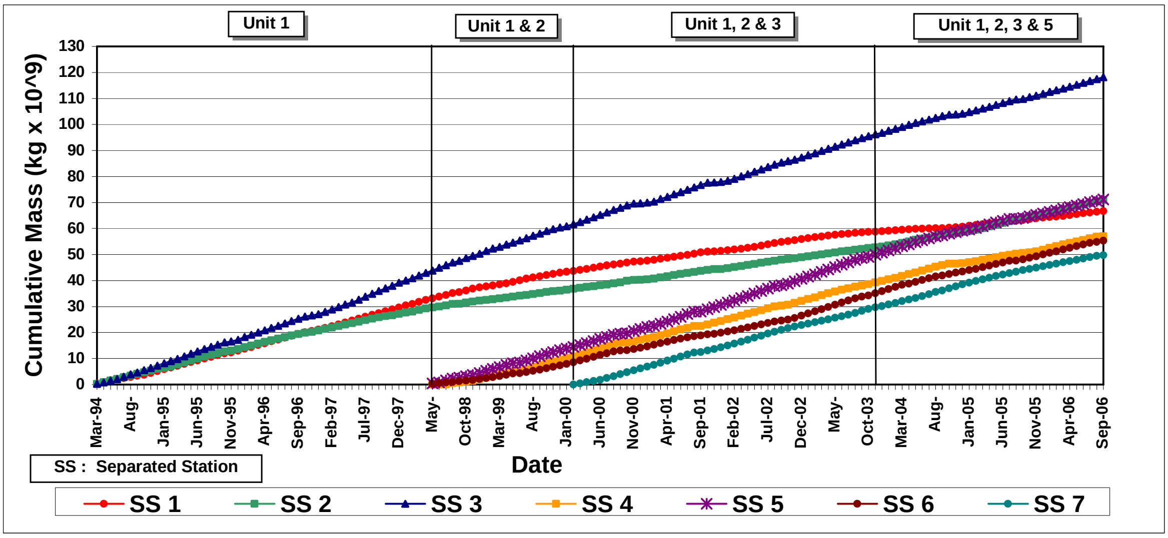

FIGURE 4: Cumulative fluid mass per separation station

Currently, the total steam delivered to the power plants is about 300 kg/s. The mass produced from the reservoir since 1994 is shown in Figure 5. Incremental production increases have accompanied each of the new units coming on line. Around 1,250 kg/s of residual (separated) geothermal water is sent to the injection wells, which are distributed in four areas of the field, i.e., the northern, southern, eastern and southwestern sectors (Figure 6).

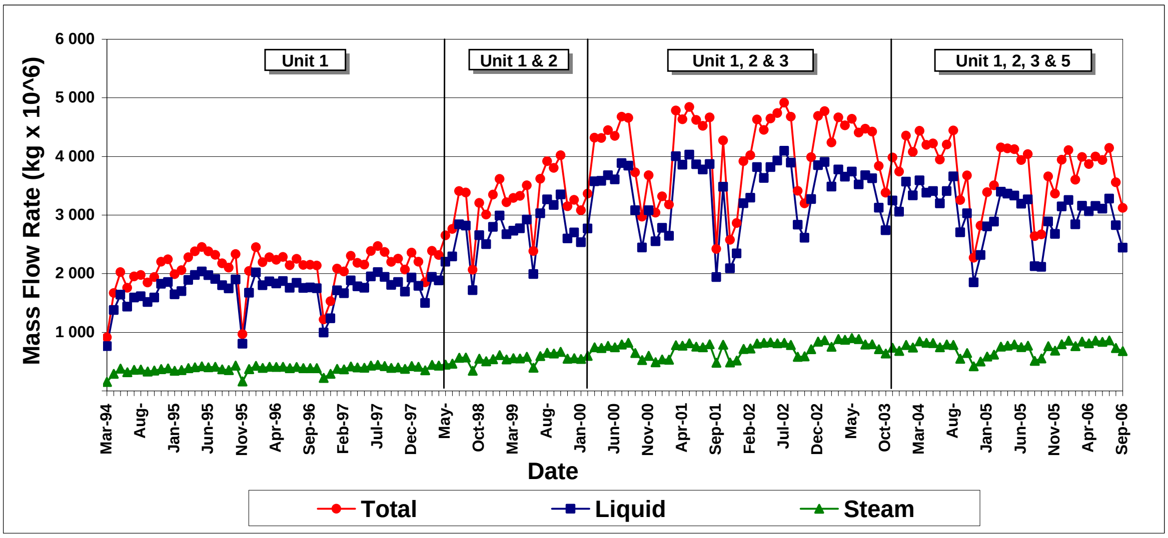

FIGURE 5: Mass produced from the Miravalles geothermal field

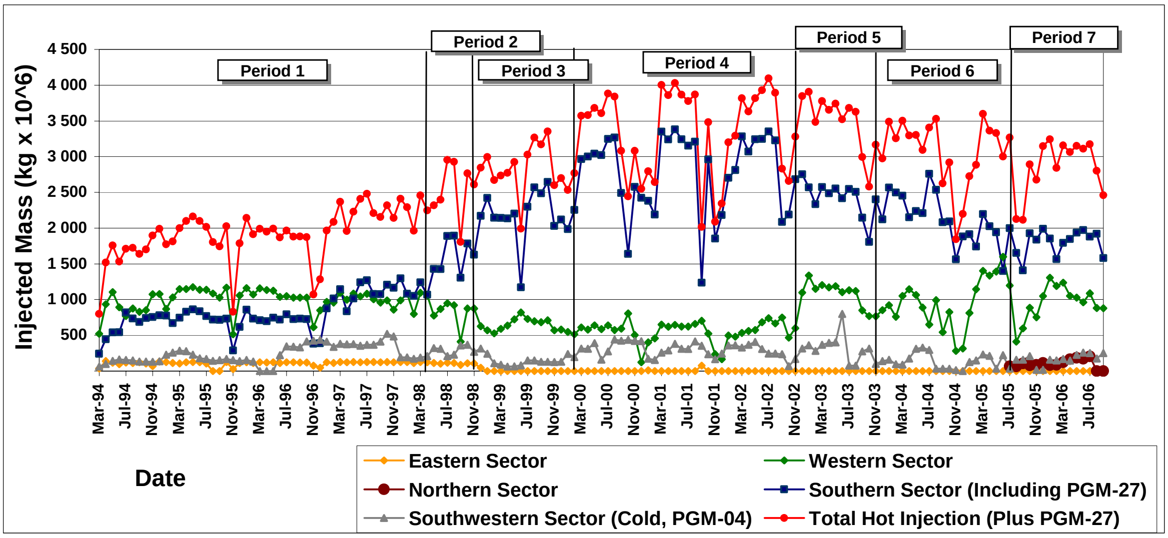

FIGURE 6: Mass injected into different sectors of the Miravalles geothermal field

The Miravalles reservoir fluids have been classified as sodium-chloride waters, with a pH around 5.7 and a silica content of 430 ppm (at reservoir conditions); they tend to deposit carbonate scales within the wellbores (Moya and Sanchés, 2002). Production wells at Miravalles showed a high potential for calcite scaling even before exploitation of the field began. For each production well the degree of calcite saturation (log Q/K) was calculated using the Watch computer program (Bjarnason, 1994). It was found that the pre-flashed, neutral-pH reservoir fluids are below saturation levels.

Arnórsson (1989) discussed two mechanisms by which calcium carbonate minerals can be formed from geothermal fluids, i.e., hydrolysis and boiling. At Miravalles the scaling in the production wells is caused by boiling; this is supported by the fact that calcite deposition occurs on the downhole capillary tubing near the flashing zone. As the hot brine ascends through the wellbore, the fluid pressure drops and flashing occurs. Thus, the brine becomes supersaturated with calcite and there is a high potential for calcite to be deposited (Moya and Yock, 2001).

In order to maintain fluid production (i.e., to avoid or significantly reduce scaling) each production well is equipped with a calcium carbonate scale inhibition system (Figure 7). At present (2006), there are 21 inhibition systems operating continuously at Miravalles.

Five of the 53 wells drilled to date (PGM-02, PGM-06, PGM-07, PGM-19 and PGM-64; Figure 2) have produced acid fluids (with a pH between 2.3 and 3.2). These wells are located in the northeastern part of the field, suggesting the possible presence of an acid reservoir of some extent in the vicinity of the Miravalles volcano. With the exception of PGM-64, the wells have been tested to determine whether they can be put on line after a neutralization system is installed in the boreholes. To date four acid wells, PGM-19 (since February 2000), PGM-07 (since October 2001) and PGM-02 and PGM-06 (since March 2006) have been placed in production utilizing such a system (Moya and Sanchés, 2002).

The neutralization process consists of adding a solution of sodium hydroxide (NaOH) to the geothermal fluid, which raises the pH of the acid brine. The injection of the hydroxide must be continuous, and it must be done at an adequate depth in the borehole, to protect the casings and all surface equipment against corrosion (Figure 8). The design of the fluid neutralization system is basically a modification of the calcium carbonate inhibition system used at Miravalles since 1994 (Moya and Sanchés, 2002; Sanchés 1995) and it is tailored to the chemical and production characteristics of individual wells.

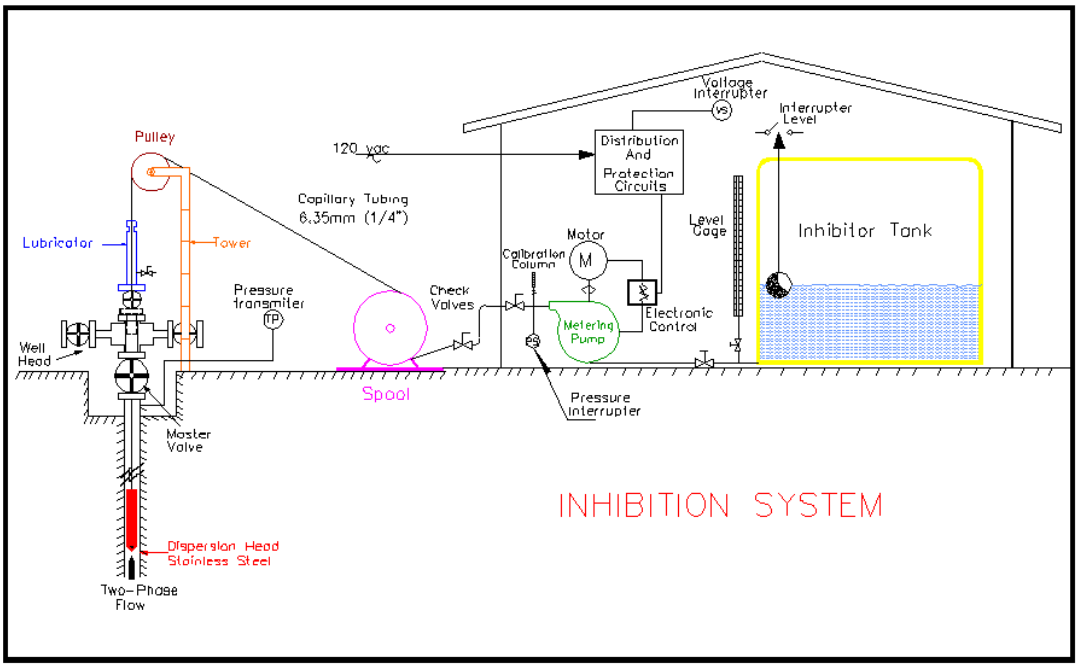

FIGURE 7: Calcium carbonate scale inhibition system at the Miravalles geothermal field

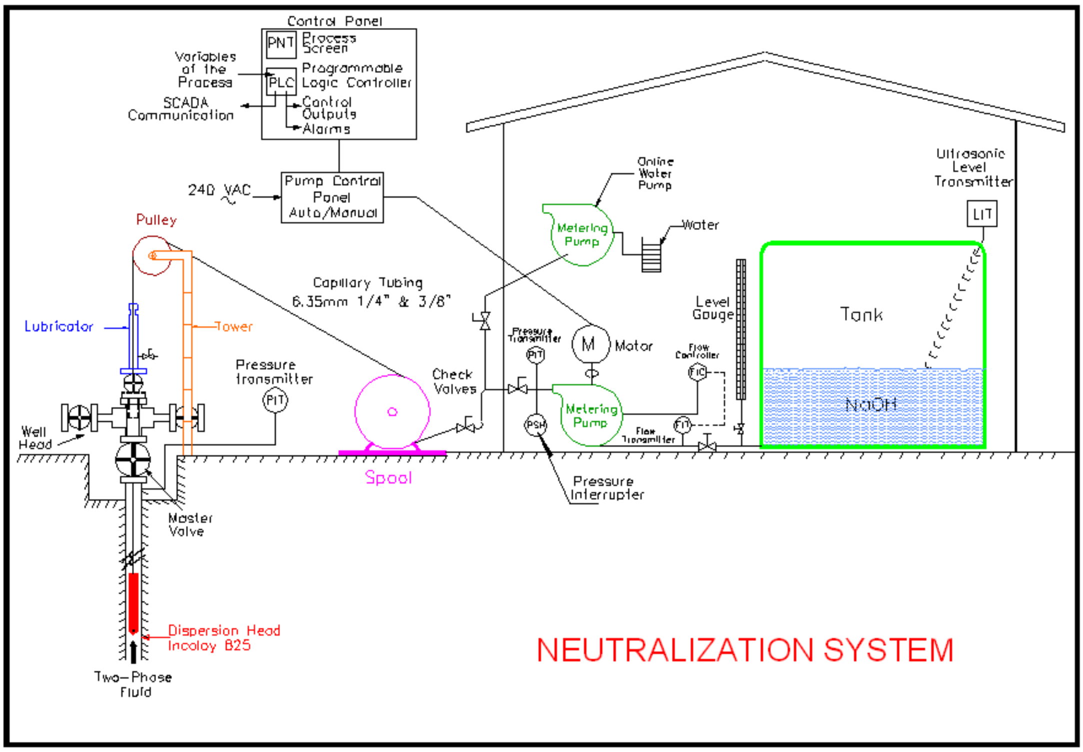

FIGURE 8: Neutralization system at the Miravalles geothermal field

Reservoir pressure decline has been monitored in several observation wells located in different parts of the field. The present rate of pressure decline (approximately 2 bar/year) agrees with the results of numerical modeling studies performed in 2001 (Figure 9) (Mainieri et al., 2002).

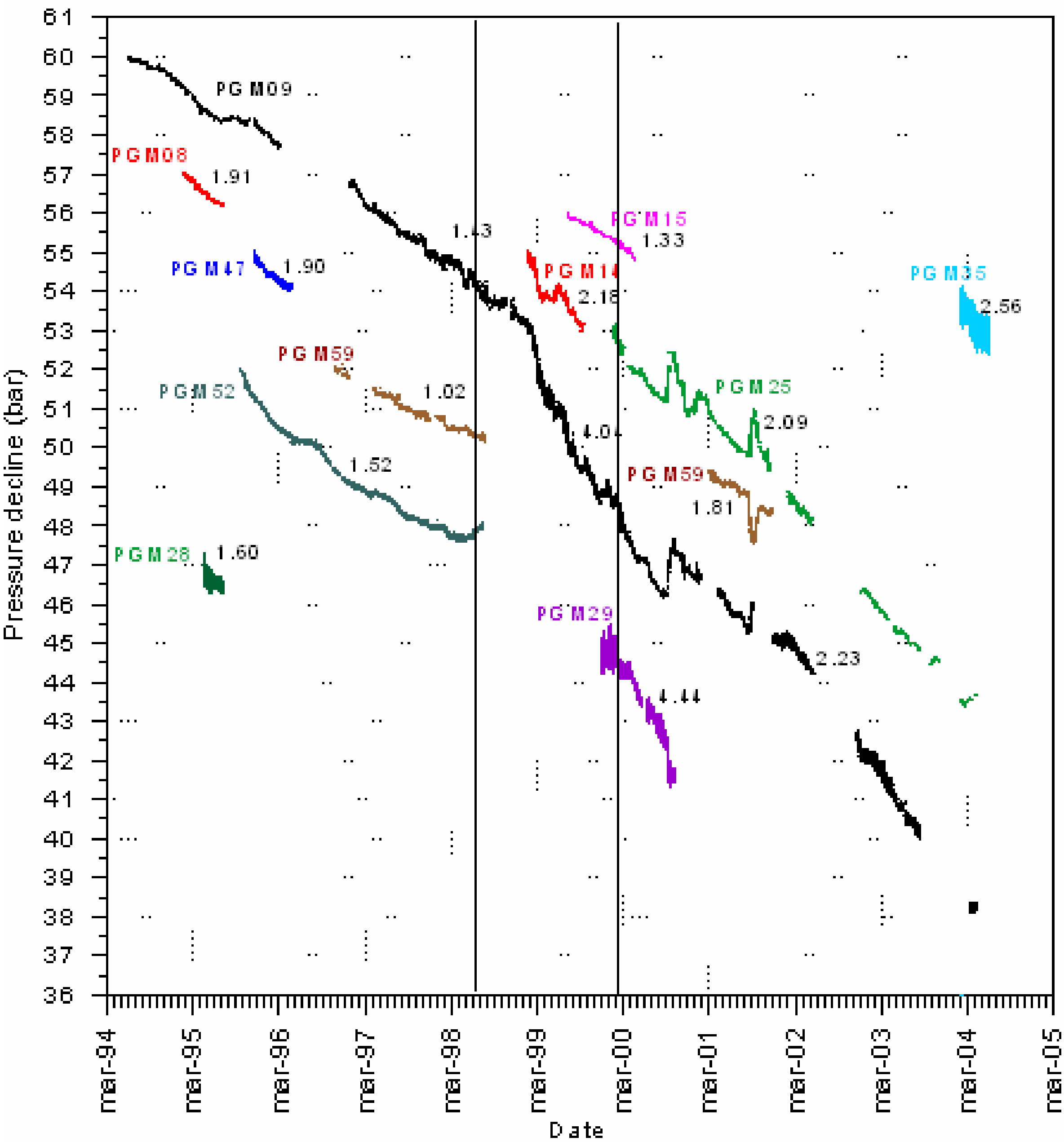

FIGURE 9: Pressure Decline in Observation Wells [7]

Unit 5 (a 19 MW binary plant) was commissioned during January 2004 and increased the installed geothermal capacity at Miravalles to 163 MW. Based on data and results from twelve years of commercial exploitation, as well as numerical modeling studies, ICE has decided to wait to build additional flash units in the known 21 km^2 geothermal area. A new exploratory well, located to the east of the principal production zone, was completed in February 2003 and will provide steam support to the main production zone. No increase in the installed geothermal capacity is foreseen in the next few years unless a new reservoir is found.

4. RECENT EXPLORATION ACTIVITIES

The most-studied undeveloped geothermal systems in the country are those associated with the Tenorio and Rincón de la Vieja volcanoes. Pre-feasibility studies have already been concluded for both areas. In 1999-2000, two exploratory wells were drilled at Tenorio (to 1,345 m and 2,472 m depth). The results were disappointing, as they only encountered zones of low temperatures (up to 160 ºC) and low injectivity (up to 0.5 l/s/bar).

In January 2001, as part of a feasibility project, a deep exploratory well program was begun at the Las Pailas geothermal zone on the southern slope of the Rincón de la Vieja volcano. A total of five wells were drilled during the first phase of this project. Downhole measurements indicate temperatures up to 240ºC. Some parameters of the wells are shown in Table 2. The Las Pailas feasibility study was completed during August 2003.

TABLE 2: Data on deep wells drilled at the Las Pailas geothermal area

Well No.	**Depth (m)**	**Max. T (°C)**	**Inj. Index (l/s/bar)**	**W.T. (m)**	**Enthalpy (kg/kJ)**	**Flow (kg/s)**	**Est. Output (MWe)**
PGP-01	1,418	240	8.3	380	1079	108.8	8.9
PGP-02	1,764	240	< 1.4	400	N. A.	N. A.	N. A.
PGP-03	1,767	243	4.7	440	1140	44.2	4.2
PGP-04	1,418	227	2.1	400	971	58	3.4
PGP-05	1,827	168	N. A.	260	N. A.	N. A.	N. A.

Notes:
W.T. = Depth of water table
N. A. = Not available

Borinquen is the name of another geothermal area at the Rincón de la Vieja volcano. In this area, the drilling of well PGB-01 was initiated in March 2003. The final depth of the well was 2,594.6 m, its maximum measured temperature was 276°C and its injectivity index was less than 1.43 l/s/bar (Table 3). In summary, the well PGB-01 is very deep and very hot, but it has low permeability.

A new well (PGB-03) was drilled in the Borinquen geothermal area. Its final depth was 2,082 m and its maximum measured temperature (not stabilized) was 203.8ºC (9/23/2005). Well PGB-03 so far demonstrates low temperature and low permeability.

TABLE 3: Data on deep wells drilled at Borinquen geothermal area

Well No.	**Depth (m)**	**Max. T (°C)**	**Inj. Index (l/s/bar)**	**W.T. (m)**	**Enthalpy (kg/kJ)**	**Flow (kg/s)**	**Est. Output (MWe)**
PGB-01	2,594.6	276	<1.43	370	1079	31.3	N. A.
PGB-03	2,082	203.8*	N. A.	300	N. A.	N. A.	N. A.

Notes:
* = Temperature is not stabilized yet.
W.T. = Depth of water table
N. A. = Not available

5. THE IMPORTANCE OF GEOTHERMAL ELECTRICITY GENERATION FOR COSTA RICA

Table 4 presents the contribution of different energy sources to the Costa Rican electricity system for the years 2000-2005. Most of the installed capacity corresponds to hydro and smaller amounts to fossil fuel (bunker and diesel), geothermal (all at Miravalles) and wind. Table 4 also shows the amount of electricity generated during these years.

TABLE 4: Costa Rica Electrical System: 2000-2005

Year: 2000

Source of Energy	*Installed Capacity (MW)	Installed Capacity (Percentage)	Generated Electricity (GWh)	Generated Electricity (Percentage)	Load Factor (Percentage)
Hydro	1,213.5	74.5	5,690.6	82.3	53.5
Thermal	229.0	14.0	64.4	0.9	3.2
Geothermal	142.0	8.7	976.5	14.1	78.5
Wind	46.2	2.8	182.7	2.7	45.1
Total	1,630.7	100.0	6,914.2	100.0	

Year: 2001

Source of Energy	*Installed Capacity (MW)	Installed Capacity (Percentage)	Generated Electricity (GWh)	Generated Electricity (Percentage)	Load Factor (Percentage)
Hydro	1,229.5	74.2	5,658.2	81.7	52.5
Thermal	240.0	14.5	100.0	1.4	4.8
Geothermal	141.4	8.5	986.3	14.2	79.6
Wind	46.2	2.8	185.5	2.7	45.8
Total	1,657.1	100.0	6,930.0	100.0	

Year: 2002

Source of Energy	*Installed Capacity (MW)	Installed Capacity (Percentage)	Generated Electricity (GWh)	Generated Electricity (Percentage)	Load Factor (Percentage)
Hydro	1,229.5	73.5	5,983.6	79.9	55.5
Thermal	240.0	14.3	127.6	1.7	6.0
Geothermal	141.2	8.5	1,120.7	15.0	90.6
Wind	62.2	3.7	258.4	3.4	47.4
Total	1,672.9	100.0	7,490.3	100.0	

Year: 2003

Source of Energy	*Installed Capacity (MW)	Installed Capacity (Percentage)	Generated Electricity (GWh)	Generated Electricity (Percentage)	Load Factor (Percentage)
Hydro	1,240.5	69.6	6,022	79.6	55.4
Thermal	334.0	18.7	169	2.2	5.8
Geothermal	141.2	7.9	1,144	15.1	92.6
Wind	68.6	3.8	230	3.1	38.2
Total	1,784.3	100.0	7,565	100.0	

Year: 2004

Source of Energy	*Installed Capacity (MW)	Installed Capacity (Percentage)	Generated Electricity (GWh)	Generated Electricity (Percentage)	Load Factor (Percentage)
Hydro	1,283	69.6	6,295.3	80.5	56.0
Thermal	334	18.1	66.5	0.8	2.3
Geothermal	159	8.6	1,205	15.4	86.5
Wind	68.9	3.7	257.2	3.3	42.6
Total	1,844.9	100.0	7,824	100.0	

Year: 2005

Source of Energy	*Installed Capacity (MW)	Installed Capacity (Percentage)	Generated Electricity (GWh)	Generated Electricity (Percentage)	Load Factor (Percentage)
Hydro	1,303.6	68.7	6,565.4	80.1	57.5
Thermal	365.6	19.2	283.4	3.5	8.8
Geothermal	159.0	8.5	1,147.7	14.0	82.4
Wind	68.6	3.6.	203.6	2.4	33.9
Total	1,896.8	100.0	8,201.0	100.0	

Note:

* Installed Capacity (MW) = Installed Capacity authorized by ICE (MW)

Concurrently with the growth in installed capacity at Miravalles (Figure 3), there was an even more important increase in the amount of electricity generated (Figure 10). Between 1994 and 2004 the installed capacity at the field grew from 55 to 163 MW (a 196% increase), while the generation grew from 341 to 1,204.4 GWh (a 253 % increase). The high availability of geothermal plants is illustrated by the numbers shown in Table 4. Even though the installed capacity at Miravalles is only 8.6 percent of the country's total (year 2004), it produced more than 15 percent of the electricity generated. For Miravalles the load factor was 86.5% (year 2004), the highest of all types of power plants installed in the country.

The cost of the electricity produced by ICE for three types of energy sources (hydro, geothermal and thermal) during 2000 and 2005 is shown in Figure 11. Hydro continues to be the cheapest source of energy for the generation of electricity in Costa Rica. The cost associated with geothermal is higher, but much lower than that for the thermal plants. The low load factor of the oil-burning plants – used only during a relatively few peak load periods – makes them very expensive to operate.

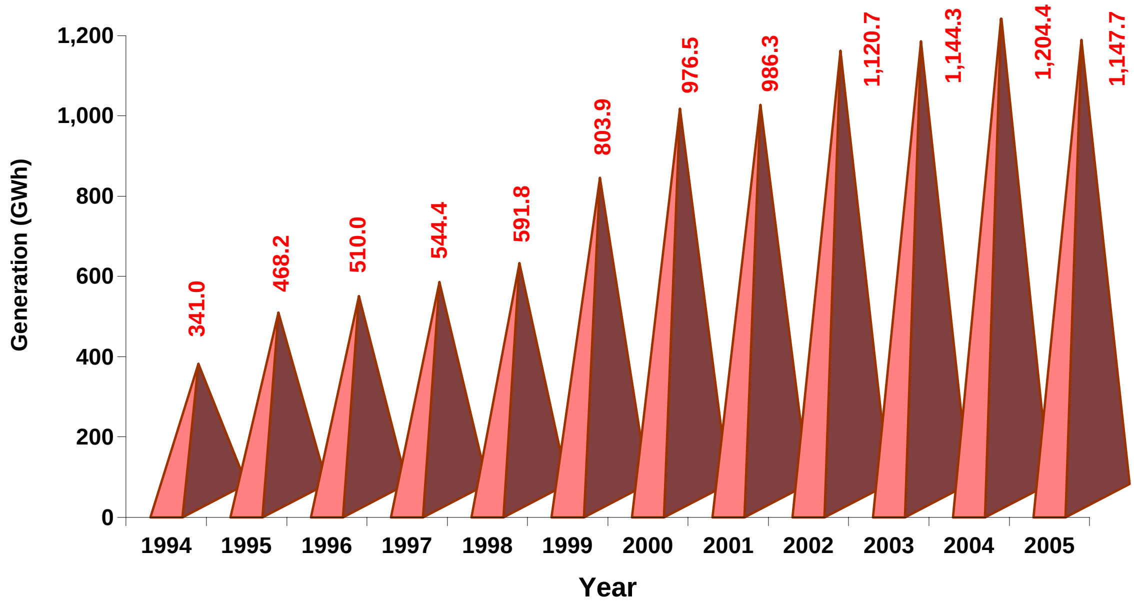

FIGURE 10: Geothermal energy generation in Costa Rica: 1994 - 2005

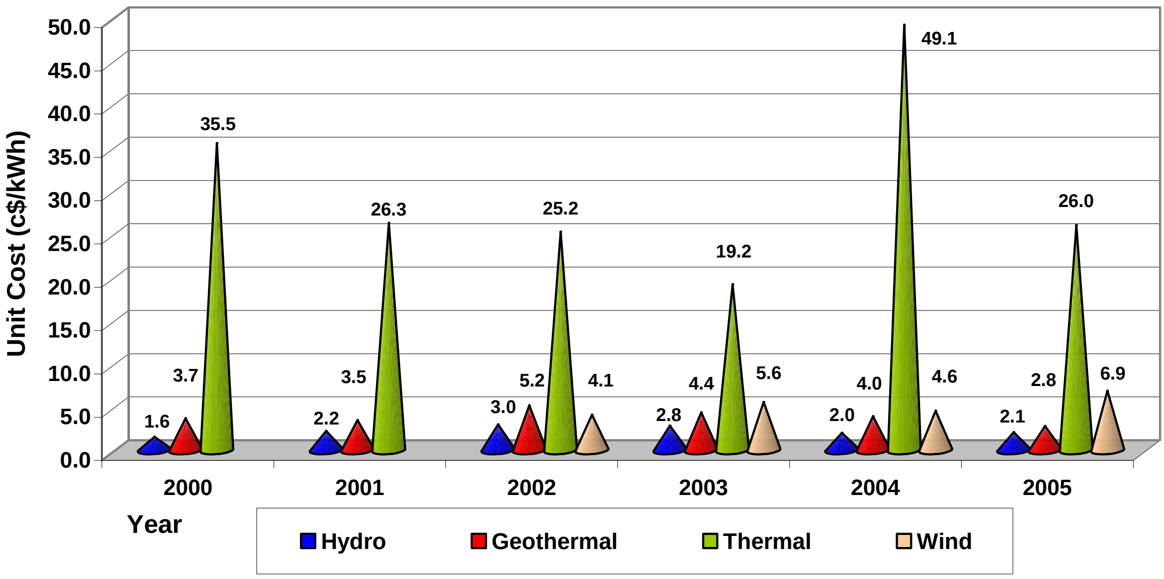

FIGURE 11: Electricity generation costs for different energy sources (2000-2005)

6. FINAL REMARKS

Exploration for geothermal resources in Costa Rica started in earnest in 1979-80 when the first deep wells were drilled on the western foothills of the Miravalles volcano. The success of these wells and the results of subsequent studies led to the installation to date of five power plants at the Miravalles field with a total capacity of 163 MWe. The first was commissioned in 1994 (Unit 1, 55 MWe). It was followed in 1995 by a 5 MWe wellhead unit, then came Unit 2 (55 MWe) in 1998, Unit 3 (29 MWe) in 2000 and Unit 5 (19 MWe) in 2004.

Based on the success at Miravalles, ICE has been exploring other geothermal zones of the country. Wells drilled in the Las Pailas area, near the Rincón de la Vieja volcano, have shown promising results.

Even though the installed electrical generating capacity at Miravalles is only about 8.6 percent of the country’s total, it produces approximately 15 percent of the electricity generated. The Miravalles geothermal plants have an average load factor of about 86.5 % (2004), the highest of all the energy sources used in the country.

The contribution of geothermal energy to the Costa Rican electrical system has been of great benefit to the country, not only because of the low cost of the electricity generated (significantly cheaper than thermal), but also due to its high availability and reliability (i.e., production is not affected by dry periods) and the indigenous nature of the resource (i.e., it has reduced the country’s dependence on foreign sources of energy). Therefore, ICE plans to continue working on the development of this clean and renewable energy source.

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