Presented at "Short Course on Surface Exploration for Geothermal Resources",
organized by UNU-GTP and LaGeo, in Ahuachapan and Santa Tecla, El Salvador, 17-30 October, 2009.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

LaGeo S.A. de C.V.

THE CONTRIBUTION OF GEOTHERMAL EXPLOITATION AT THE MIRAVALLES GEOTHERMAL FIELD TOWARD THE REDUCTION OF GLOBAL WARMING*

[1]Paul Moya and [2]Emilia Rodríguez
[1]Instituto Costarricense de Electricidad, UEN Proyectos y Servicios Asociados
C. S. Recursos Geotérmicos, Apartado Postal 10032-1000
San José, COSTA RICA
pmoya@ice.go.cr

[2]P. O. Box 222-5000 Liberia
Guanacaste, COSTA RICA
emilia.liberia@gmail.com

ABSTRACT

Geothermal energy production in Costa Rica began in early 1994 with the first unit (Unit 1 - 55 MW) located at the Miravalles geothermal field in Guanacaste, Costa Rica. The Costa Rican Institute of Electricity (ICE), aware of the economic and environmental benefit that this type of energy represents, developed the Miravalles geothermal field in just one decade (1994-2004) to its present capacity of 163 MW. Additionally, ICE is expanding the installed capacity by 35 MW with the construction of a new geothermal project called Las Pailas, located on the south-southwest slope of the Rincón de la Vieja volcano.

Global Warming consists of an increase of the mean atmospheric temperature due to human activity (Gore, 2007). Fossil fuels and deforestation, to name two examples, increase the quantities of greenhouse gases in the atmosphere, which then retains more heat and the planet is re-heated. ICE began to change its initial energy model in 1994 (hydro energy + thermal energy), and has since been continuously modifying it to a new scheme (hydro energy + geothermal energy + wind energy + others). The present task is to increase the installed capacities of all these renewable energies and decrease or eliminate the thermal generation.

Geothermal energy is considered "green energy" because it emits very little sulphur and no oxides of nitrogen, both of which are responsible for acid rain. The geothermal fields live in harmony with the surrounding environment; in Costa Rica there are no reports of impacts on fauna and its habitat, or on the landscape of the zone, when utilizing mechanisms to camouflage installations and pipelines. The indigenous nature of the resource has reduced the country's dependence on foreign sources of energy as well as its dependence on oil. The high availability and reliability (i.e., production is not affected by dry periods) of the geothermal energy in Costa Rica has been demonstrated by the high load factors (between 82 and 87%) achieved during the last 8 years of electricity generation. Emissions of carbon dioxide from Costa Rica's geothermal plants have been between 15 and 100 kilograms per megawatt-hour (MWh), which makes geothermal generation one of the least contaminating energies in the world.

*This document has been submitted and accepted by the Technical Program Committee to be included in the Proceedings of the World Geothermal Congress 2010 in Bali, Indonesia.

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 4.5 million. In the early 1970's, 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 Costa Rican Institute of Electricity (ICE), to study the possibility of using other energy sources for generating electricity, including geothermal energy (Moya, 2006).

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 wellhead plants came on line as part of an agreement between ICE and the Comisión Federal de Electricidad de Mexico (CFE). The two temporary units were disassembled in April 1998 and April 1999 (Table 1) and returned to CFE. Unit 2, the second 55 MW plant, started delivering electricity to the national grid by August 1998. Within just 6 years, ICE, convinced to modify its energy model (to rely not only on hydro and thermal energy sources), increased the installed geothermal capacity to 144 MW. This led to a reduction in the cost of energy, satisfaction of summer energy demand, and avoidance of the contamination that would have been produced had thermal energy been used instead of geotherrmal. Finally, in January 2004, Unit 5, a 19 MW binary plant, increased the total installed capacity at Miravalles to 163 MW (Table 1).

ICE, aware of the economic and environmental benefit that this type of energy represents, has developed the Miravalles geothermal field in just one decade, and plans to increase the installed geothermal capacity by 35 MW by developing a new geothermal field called Las Pailas, located on the slopes of the Rincón de la Vieja volcano.

TABLE 1: Power units at the Miravalles geothermal field;
Abbreviations stand for: ICE (Instituto Costarricense de Electricidad); CFE (Comisión Federal de Electricidad, Mexico); WHU (Wellhead Unit); and BOT (build-operate-transfer)

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	

2. GLOBAL WARMING

The weather has always changed and suffered modifications; this is not new. The current problem related to global warming is that the rate of these variations has accelerated in an anomalous way, affecting life on our planet.

Global Warming consists of an increase of the mean atmospheric temperature due to human activity (Gore, 2007). The United Nations Convention on Global Warming was approved in New York in 1992, and it is directly related to the Kyoto Protocol of 1998. This Convention states that the activities related to the control of greenhouse-gas emissions are, among others: the energy sector, burning fuels, solid fuels, oil and deforestation. They increase the quantities of greenhouse gases in the atmosphere, which then retains more heat and the planet is re-heated. The consequences of global warming are

believed to include: extinction of a huge quantity of animal species due to changes in their ecosystems; an increase in the intensity and frequency of rain, hurricanes and storms; decreases in the levels of the rivers and lakes due to evaporation caused by high temperatures; creation of nutrient-poor desert soils; food shortages caused by soil deterioration and high temperatures; and increasing illness due to mosquitoes, tropical plagues and dehydration caused by heat (Semana, 2007).

It is within this framework that the current energy model of many countries should be examined. The current model is based mainly on burning fuels for electricity generation. Today, two factors raise questions about the continued viability of this model: exhaustion of fossil fuels, and the global warming associated with the greenhouse-gas effect. In this regard, Mr. Klaus Toepfer, Executive Director of PNUMA (United Nations Program for the Environment) indicates that "energy generation should depend less on coal. The renewable energies such as wind, solar, geothermal and biomass are all feasible and reachable, and they should be developed and implemented widely. The change in energy sources also constitutes an economic necessity due to the increasing energy demand and fast growing of some economies such as those in Asia".

It is because of these considerations that human beings should use renewable energy sources, which are abundant, secure and less harmful to the environment. Renewable energy sources include the sun (solar), rivers (hydro), wind (aeolian), biomass, ocean waves, ocean tides, and, also, the internal heat of the earth (geothermal - "geo" meaning earth and "thermal" referring to its heat). The contribution of geothermal energy to the reduction of global warming is addressed in the following sections.

As mentioned before, ICE began to change its initial energy model (hydro energy + thermal energy) in 1994, and has since been continuously modifying it to a new scheme (hydro energy + geothermal energy + wind energy + others). The present task is to increase the installed capacities from all these renewable energy sources and decrease or eliminate the thermal generation. This is why the utilization of geothermal energy as an energy source, replacing other conventional energy sources, represents a strong option to be considered, since it reduces significantly the emission of greenhouse gases and the use of oil.

Several activities to promote geothermal energy and its benefits were carried out in Madrid, Spain in October, 2008. The First Congress of Geothermal Energy in the Edification and Industry (Geo Ener) provided an opportunity for scientists, technicians, universities, politicians and industries interested in this type of energy to analyze the means of its implementation as well as its legal framework.

3. GEOTHERMAL ENERGY

The Earth's internal heat is an energy source that can be considered inexhaustible and renewable, because millions of years remain before the Earth's interior becomes substantially cold, which is why this type of energy is considered one of the energy resources of the future (Memoria del Foro Chileno Alemán, 2004). Geothermal energy has several advantages over various other energy sources, making it one of the energy resources of great benefit for human beings: (1) It is considered to be a "green energy" because it emits little sulphur and no oxides of nitrogen, both of which are responsible for acid rain. (2) In Costa Rica geothermal produces emissions of only 15 to 100 kilograms of carbon dioxide per megawatt-hour (MWh) of generated electricity, which makes this type of energy one of the sources that produces the least contaminants in the world (Figure 1).

For each watt-hour of fossil energy that is replaced by one watt-hour of geothermal energy, the effect of greenhouse gases is reduced by about 95%. (3) The extracted geothermal fluid does not produce residues because the fluids are reinjected into the reservoir, rather than being dumped into rivers or lakes, avoiding pollution of hydro sources. (4) Geothermal fields live in harmony with the surrounding environment. In Costa Rica there are no reported impacts on fauna and its habitat, nor on the landscape of the zone, when mechanisms to camouflage installations and pipelines are used. (5) It is

not affected by factors such as sun, rain or wind, or the fluctuations of the international oil price (as in 1973 and 2007), which in turn gives security in the energy supply. (6) The indigenous nature of the resource has reduced the country's dependence on foreign sources of energy as well as its dependence on oil. (7) Typical geothermal projects do not require huge areas for development; the areas required to install a geothermal plant are rather small. (8) Geothermal units do not emit smoke, but rather water vapour (steam). (9) In Costa Rica, geothermal energy represents the best complement energy to hydro power, which is not able to supply the demand of the country during the dry season (summer). (10) Geothermal energy has wide applicability, as it can be utilized for bathing resorts, heating, hot water, and electricity generation as well as industrial, mining and agricultural processes.

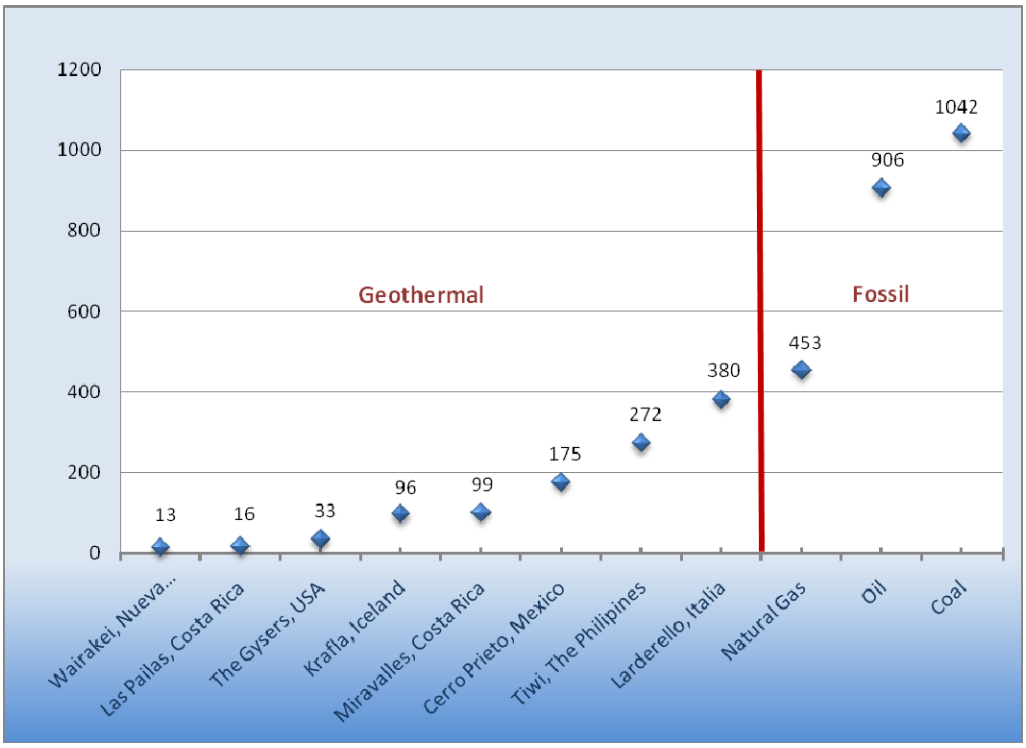

FIGURE 1: CO_2 emissions for a number of electricity generators
(after Barbier, 1997, e.g. Brown and Webster-Brown (2005), modified in 2009)

3.1 Miravalles geothermal field

The first technical report (a set of pre-feasibility studies) on the possibility of exploiting geothermal resources for generating electricity in the Miravalles geothermal field 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 field (Figure 2).

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" (1991), showed the various areas of geothermal interest in the country (Figure 3), and indicated that the total geothermal potential of Costa Rica was about 865 MWe (single-flash) at that time. The Miravalles geothermal field was considered in this evaluation to have a potential of 164 MW (163 MW is the current installed capacity), and therefore, the predicted remaining geothermal potential is now about 700 MWe (single-flash).

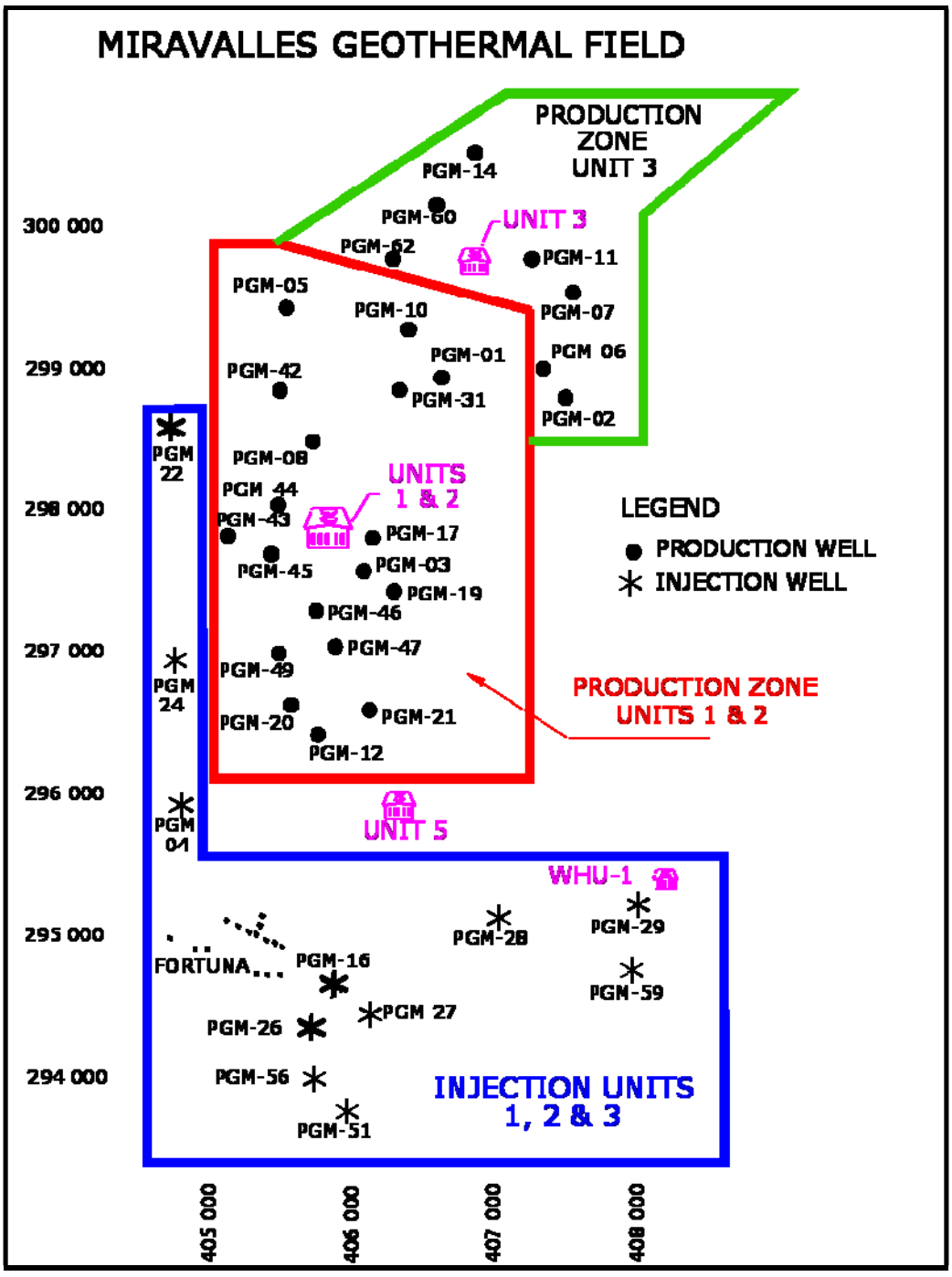

FIGURE 2: The Miravalles geothermal field

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°C. Fifty-three geothermal wells have been drilled to date. 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 (Moya and Yock, 2007).

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

FIGURE 3: Areas of geothermal interest in Costa Rica

installation of a 5 MW wellhead unit. This unit was located in the middle of the field for almost 12 years (1995-2006), but in early 2007 it was moved to a new location at the south-eastern part of the field.

Two temporary 5 MW wellhead plants came on line as part of an agreement between ICE and the Federal Commission of Electricity of Mexico (CFE) during 1996 and 1997. These two temporary units were disassembled in April 1998 and 1999 (Table 1) and returned to CFE.

Unit 2, the second 55 MW plant, started production in August 1998, and in March 2000 Unit 3, a 29 MW single-flash private plant, started delivering electricity to the national grid. Finally, Unit 5, a 19 MW binary plant, increased the total installed capacity at Miravalles to 163 MW (Table 1). The history of growth of capacity at the field is shown in Figure 4 and its corresponding generation is shown in Figure 5. The location of the power plants can be seen in Figure 2.

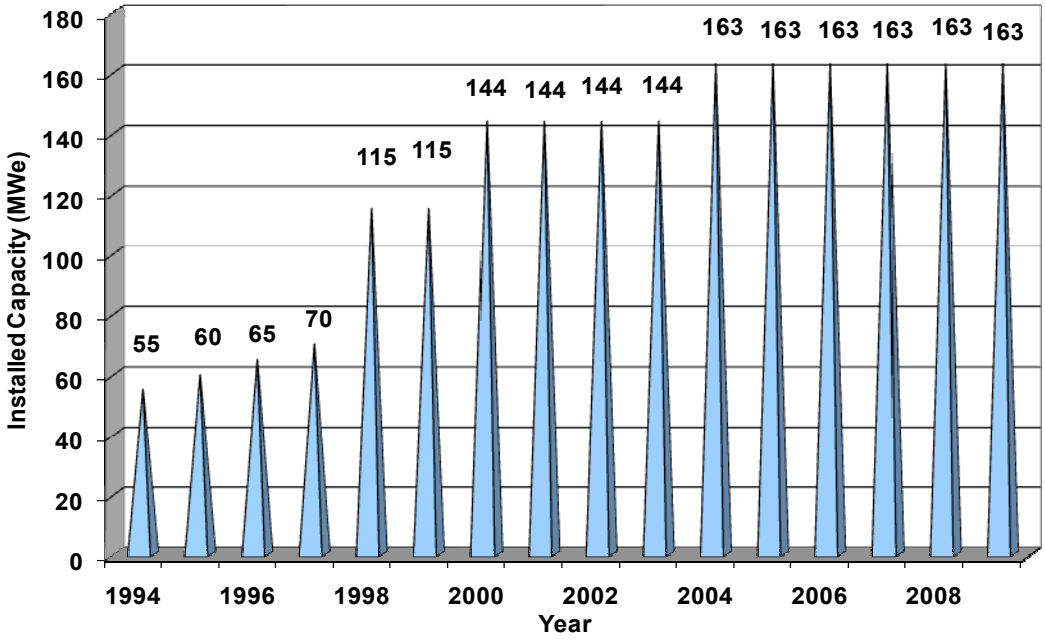

FIGURE 4: Geothermal installed capacity (1994 – 2009)

Steam for Units 1, 2, 3 and brine for Unit 5 are separated from two-phase fluids at seven principal 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 6 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. Currently, the total steam delivered to the power plants is about 330 kg/s.

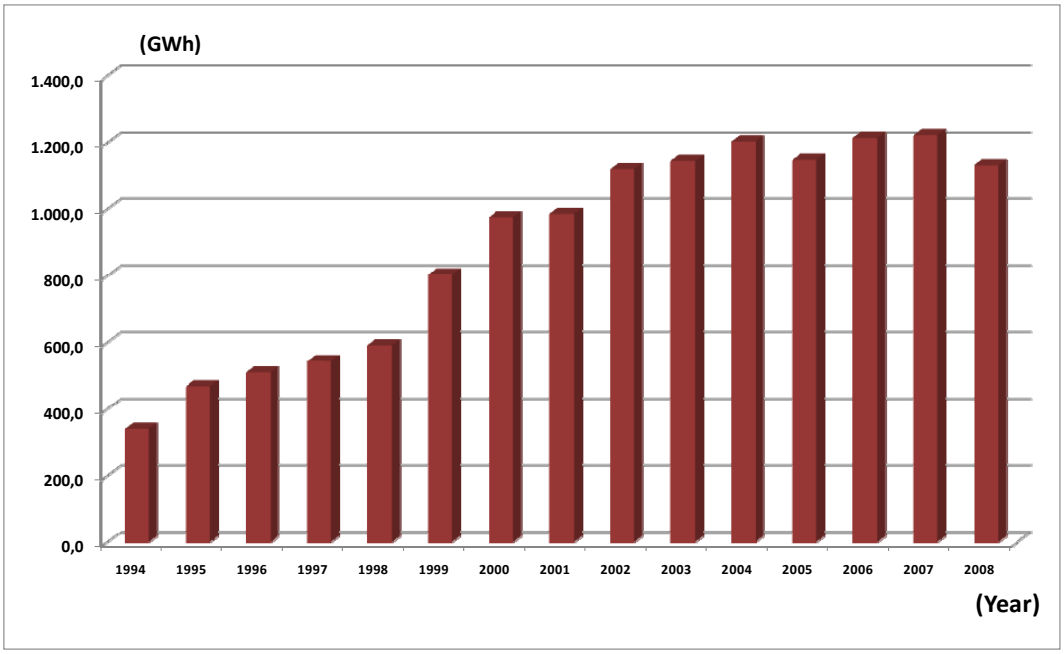

FIGURE 5: Geothermal generation in GWh (1994 – 2008)

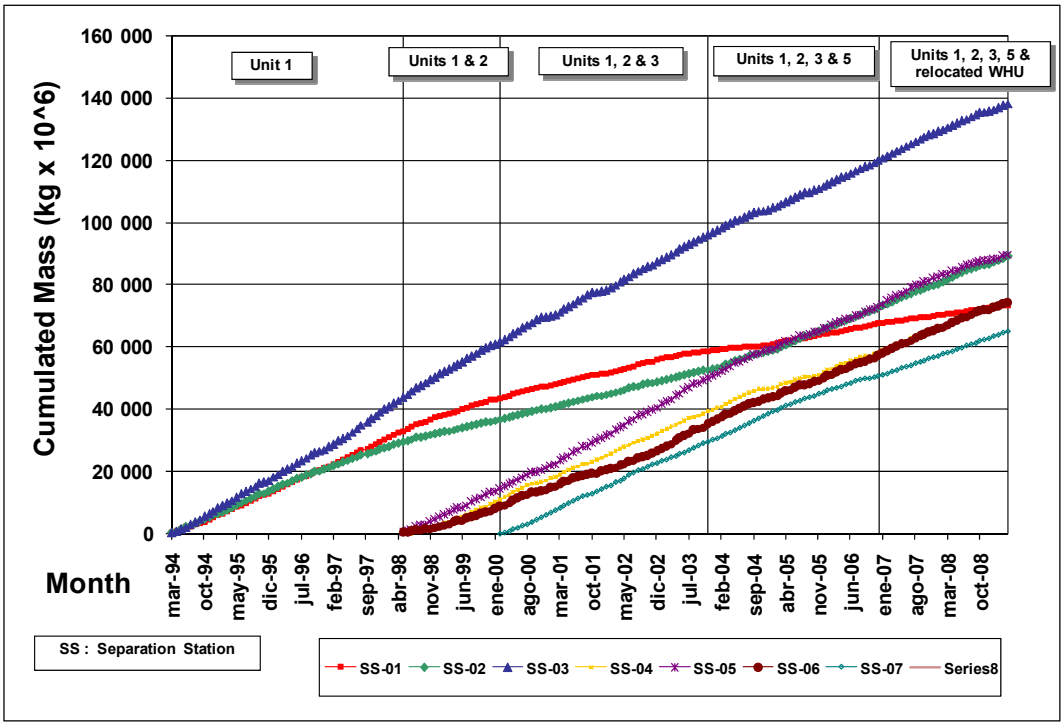

FIGURE 6: Cumulative mass from separation stations

The mass produced from the reservoir since 1994 is shown in Figure 7. Incremental production increases have accompanied each of the new units coming on line.

Around 1,235 kg/s of residual (separated) geothermal water is sent to injection wells, which are distributed in four areas of the field, i.e., the northern, southern, eastern and south-western sectors (Figure 8).

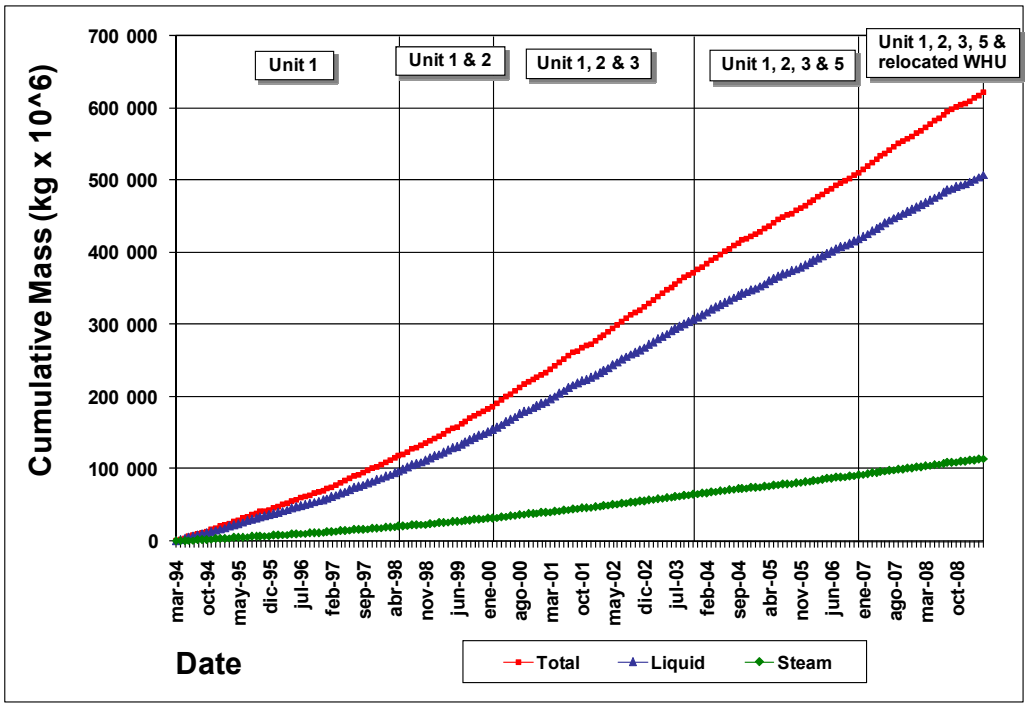

FIGURE 7: Cumulative mass at the Miravalles geothermal field

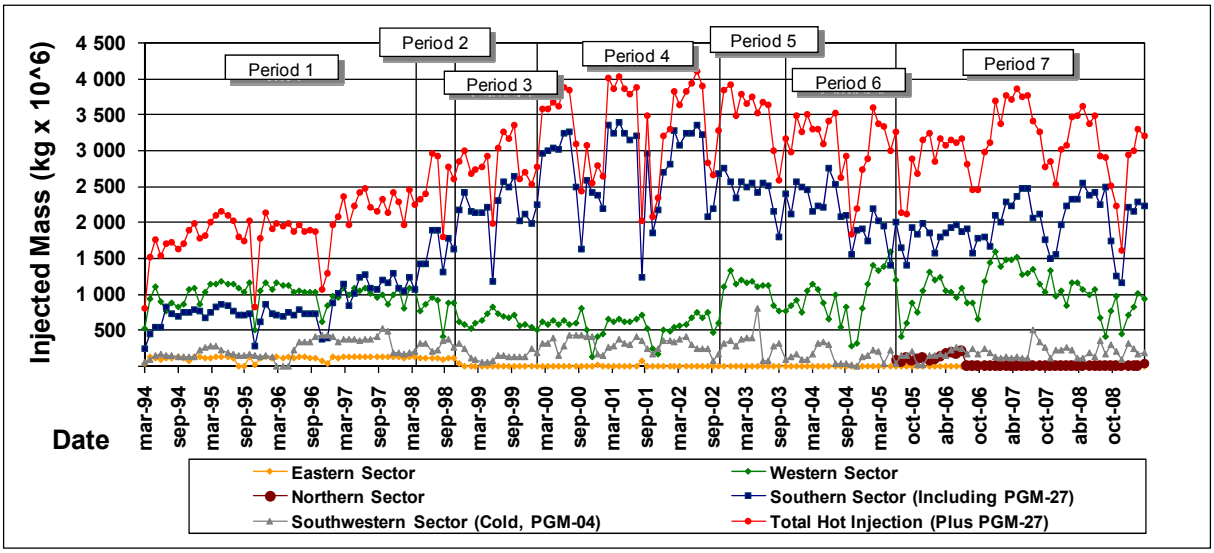

FIGURE 8: Fluid injection at the Miravalles geothermal field

Based on data and results from more than fifteen years of commercial exploitation, as well as numerical modelling studies, ICE has decided to stop building additional flash units in the known 21 km^2 geothermal area. No increase in the installed geothermal capacity is foreseen in the next few years unless a new reservoir is found.

Instead of increasing the installed geothermal capacity at Miravalles, 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. Five wells were drilled during the first phase of this project. At present there are 9 vertical geothermal wells drilled altogether. Downhole measurements indicate temperatures near 240 $^{\circ}$C. Some parameters of the wells are shown in Table 2. Two new deviated wells are being drilled at present (PGP-12 and PGP-24).

TABLE 2: Parameters of geothermal wells at Las Pailas geothermal field

Well name	Depth (m)	Temperat. (°C)	Enthalpy (kJ/kg)	Power (MW)
PGP-01	1,418	246	1,052	8.1
PGP-02	1,764	240	N. A.	N. A.
PGP-03	1,772	243	1,128	3.7
PGP-04	1,418	232	1011	4.5
PGP-05	1,827	160	N. A.	N. A.
PGP-06	1,327	200	N. A.	N. A
PGP-08	1,712	240	1700	2.7
PGP-09	1,742	203	N. A.	N. A.
PGP-10	2,673	230	N. A	N. A

The Las Pailas feasibility study was completed in September 2005 (ICE and GeothermEx, 2005) and suggested the construction of a 35MW plant. The feasibility study was concentrated in a zone adjacent to the National Park of Rincón de la Vieja volcano called "Las Pailas", where the geothermal wells are being drilled and the power house will be constructed. ICE has received approval (in August 2007) for the financing of this project by the "Banco Centroamericano de Integración Económica (BCIE)". The new power plant should be in operation during the second half of 2011.

4. GEOTHERMAL GENERATION IN COSTA RICA AND ITS REALTIONSHIP TO GLOBAL WARMING

In Costa Rica, most of the installed generation capacity is from hydro, with smaller amounts from fossil fuel (bunker and diesel), geothermal (all at Miravalles), and wind. It is important to note that, between the years 1994 and 2004 (just one decade), the installed geothermal capacity at Miravalles increased from 55 to 163 MW (a 196% increase), and the generation from 341 to 1,204.4 GWh (a 253% increase). The geothermal plants have a high availability factor: even though the installed geothermal capacity at Miravalles was only 8.6% of the total installed capacity in 2004, it provided about 15% of the total electricity generation in the country. Also, for the same year 2004, the plant factor was 86.5%, the highest of all types of energy in the country.

Hydro power continues to be the cheapest energy source in Costa Rica. Geothermal energy is a bit more expensive than hydro but cheaper than wind and thermal energies. Geothermal energy therefore represents the best complement (second best price) to hydro energy (lowest price). As mentioned before, hydro energy cannot supply the demand of the country during the dry season (summer).
Geothermal energy is not only cheaper than thermal energy but also friendlier to the environment because of its lower emissions of CO_2 and H_2S (Figures 9 and 10). Geothermal energy in Costa Rica contributes to fight against the world wide warming problem, because, on average, geothermal energy only emits from 16 to 99 kilograms of carbon dioxide (CO_2) per MWh of generated electricity, which makes it one of the least-contaminating energy sources in the world.

Figure 9 shows the kilograms of CO_2 emissions caused by the consumption of fossil fuels for electricity generation, as well as the emissions from geothermal energy. The same figure shows the levels of CO_2 emissions from the Miravalles and Las Pailas geothermal fields. As can be seen in this figure, the CO_2 emissions created by electric generation from fossil fuels are rather high in comparison with geothermal energy in general, and with emissions from the Miravallles and Las Pailas fields. As an example, for a 100 MW plant, the kilograms of CO_2 emissions from the Miravalles geothermal field are less than ten thousand while for fossil fuels around eight thousand kilograms of CO_2 (eight times more) would be emitted.

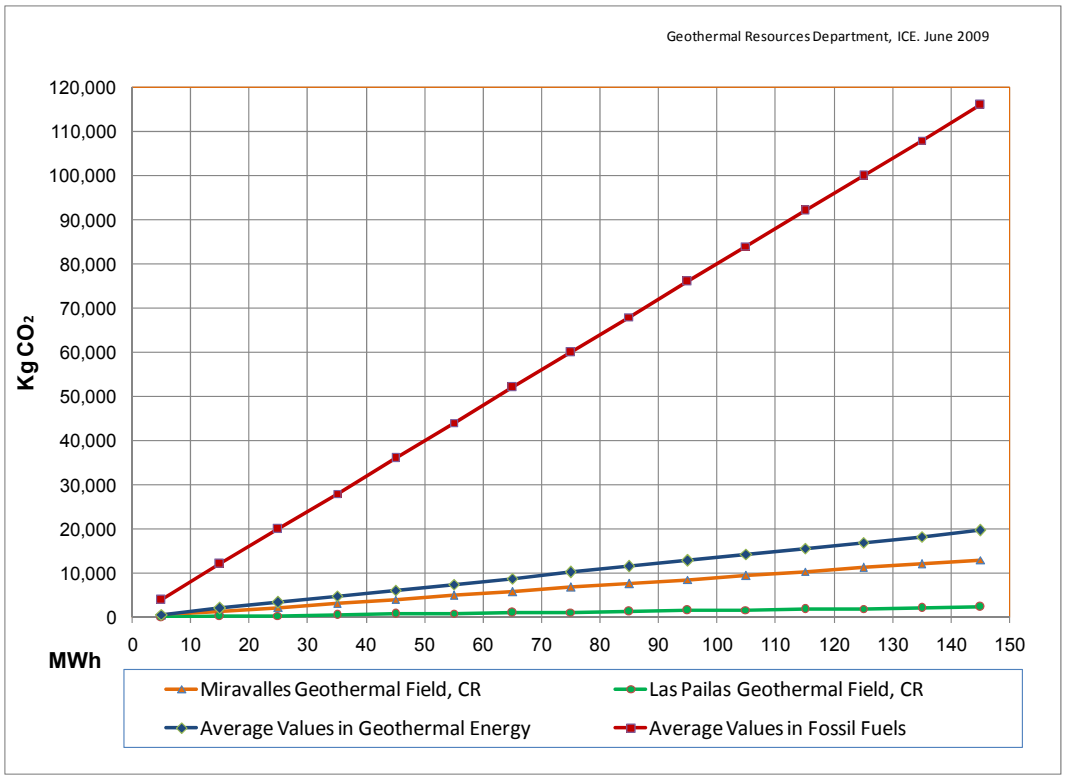

FIGURE 9: Kilograms of CO_2 emissions per MWh.

The emissions of H_2S are also very different for the cases of fossil fuels energy and geothermal energy. As an example, for the generation of 110 MWh a fossil-fuel fired plant would emit nearly 1,400 kg of H_2S, while the same generation from Miravalles Units 1 and 2 would emit less than 90 kilograms of H_2S (Figure 10). Figures 9 and 10 show that the CO_2 and H_2S emissions from fossil fuels for electricity generation are very high (8 and 15 times as much, respectively) in comparison to geothermal energy, demonstrating the great contribution from geothermal energy to the decrease of the global warming problem.

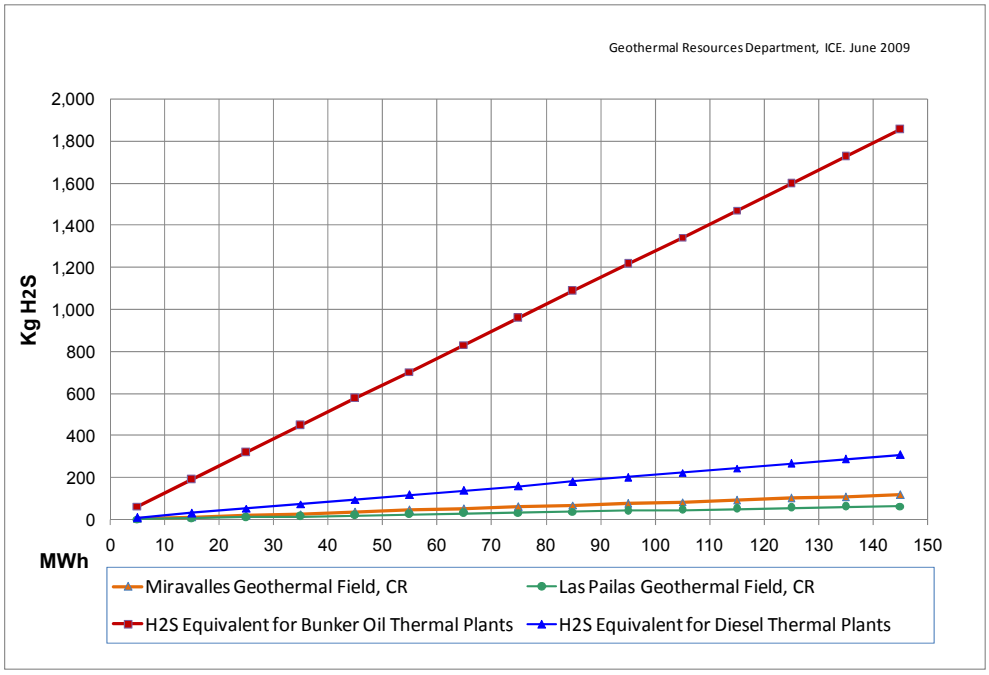

FIGURE 10: Kilograms of H_2S emissions per MWh

5. FINAL REMARKS

The success obtained in the geothermal wells and in the studies carried out at the Miravalles geothermal field provided the conditions to increase the installed capacity to 163 MW. Due to the excellent results at Miravalles, ICE is exploring other geothermal areas and is planning to develop a new field on the slopes of the Rincón de la Vieja volcano, called the "Las Pailas geothermal field".
The contribution of geothermal energy to the "Sistema Eléctrico Naciónal" has been of great benefit, not only because of its lower price in comparison to thermal units, but also its high availability and confidence in the electric system.

The indigenous nature of the resource has reduced the country's dependence on foreign sources of energy as well as the dependence on oil.

The main contribution of geothermal energy to reduction of the global warming problem is found in its low emissions of CO_2 (8 times less) and H_2S (15 times less) compared with fossil fuel energies. This is why geothermal energy is considered "green energy".
Despite the beneficial aspects of geothermal, there is still a long way to go to take advantage of this natural source of energy. A report from the International Development Bank notes the following limitations to the development of renewable energies such as geothermal:

- Institutional limitations: low priority for the development of these projects;
- Weak regulatory framework for establishing the rules for development;
- Lack of technical knowledge and insufficient information;
- Difficulty of access to loans to finance these types of projects;
- Lack of international cooperation; and
- Resistance from some social groups.

ACKNOWLEDGEMENTS

The authors thank Roger Henneberger (GeothermEx, Inc.) for editing and improving the manuscript.

REFERENCES

Brown, K. and Webster-Brown, J. 2005: Environmental impacts of high enthalpy system development. *International Geothermal Association, World Geothermal Congress 2005, Izmir, Turkey.*

Gore, A., 2007: Una verdad incómoda, Gedisa S.A. *Editorial,* (2nd ed.), March, Barcelona, Spain.

ICE, Rogers Engineering and GeothermEx., 1976: Proyecto Geotérmico de Guanacaste. Informe de previalidad técnica, reporte interno, San Francisco, California, USA.

Memoria Del Foro Chileno Alemán, 2004: Energías para el futuro: Geotermia. Santiago de Chile, September, 14 – 16, 2004.

Moya, P., 2006: Costa Rican geothermal energy development, 1994-2006. *Proceedings of the Workshop for Decision Makers on Geothermal Projects in Central America, San Salvador, El Salvador, UNU-GTP and LaGeo, CD SC-02,* 14 pp.

Moya, P. and Yock, A., 2007: Assessment and development of the geothermal energy resources of Costa Rica. *Procceedings of the Short Course on Geothermal Development in Central America Resource Assessment and Environmental Management, San Salvador, El Salvador,UNU-GTP and La Geo, CD SC-04,* 18 pp.

Semana Magazine,2007: *Semana Magazine, Colombia, July 17th, 2007*. Web page: www.semana.com.

www.eere.energy.gov/consumer/renewable_energy