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# **Lectures on geothermal in Central America**

by

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**Geothermal Training Programme**  
**2007 - Report 2**  
**Published in February 2008**



UNITED NATIONS  
UNIVERSITY

GEOHERMAL TRAINING PROGRAMME  
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Reports 2007  
Number 2

## LECTURES ON GEOTHERMAL IN CENTRAL AMERICA

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Lectures given in August 2007  
United Nations University, Geothermal Training Programme  
Reykjavík, Iceland  
Published in February 2008

ISBN – 978-9979-68-228-8  
ISSN 1670-7400

## PREFACE

The UNU Visiting Lecturer 2007 was Mr. José Antonio Rodríguez, General Manager of LaGeo S.A. de C.V. from El Salvador. Antonio Rodriguez obtained his MSc degree in geophysics from the University of British Columbia in Vancouver in 1986, and worked as a geophysicist in Canada until 1992 when he returned to El Salvador. He joined the Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL) in San Salvador as a Geothermal Resources Manager in 1995. He was appointed General Manager of the Geothermal Division of CEL in 1998, and the General Manager of LaGeo in 1999 when geothermal energy was separated from CEL. Mr. José Antonio Rodríguez gave a series of lectures on geothermal development in Central America. His lectures were excellent and very well attended by members of the geothermal community in Iceland as well as the UNU Fellows and MSc Fellows.

Since the foundation of the UNU-GTP in 1979, it has been customary to invite annually one internationally renowned geothermal expert to come to Iceland as the UNU Visiting Lecturer. This has been in addition to various foreign lecturers who have given lectures at the Training Programme from year to year. It is the good fortune of the UNU Geothermal Training Programme that so many distinguished geothermal specialists have found time to visit us. Following is a list of the UNU Visiting Lecturers during 1979-2007:

1979 Donald E. White	United States	1994 Ladislaus Rybach	Switzerland
1980 Christopher Armstead	United Kingdom	1995 Gudm. Bödvarsson	United States
1981 Derek H. Freeston	New Zealand	1996 John Lund	United States
1982 Stanley H. Ward	United States	1997 Toshihiro Uchida	Japan
1983 Patrick Browne	New Zealand	1998 Agnes G. Reyes	Philippines/N.Z.
1984 Enrico Barbier	Italy	1999 Philip M. Wright	United States
1985 Bernardo Tolentino	Philippines	2000 Trevor M. Hunt	New Zealand
1986 C. Russel James	New Zealand	2001 Hilel Legmann	Israel
1987 Robert Harrison	UK	2002 Karsten Pruess	USA
1988 Robert O. Fournier	United States	2003 Beata Kepinska	Poland
1989 Peter Ottlik	Hungary	2004 Peter Seibt	Germany
1990 Andre Menjoz	France	2005 Martin N. Mwangi	Kenya
1991 Wang Ji-yang	China	2006 Hagen M. Hole	New Zealand
1992 Patrick Muffler	United States	2007 José Antonio Rodríguez	El Salvador
1993 Zosimo F. Sarmiento	Philippines		

With warmest wishes from Iceland

Ingvar B. Fridleifsson, director, UNU-GTP

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## LECTURE 1

# GEOHERMAL DEVELOPMENTS IN CENTRAL AMERICA

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### ABSTRACT

Central America has geothermal potential all along the Pacific coast, due to volcanic activity. Currently, more than 400 MWe are being exploited commercially, and there are projects ongoing to bring another 200 MWe online in the next few years. However, the demand growth and the possibility to construct large projects and transport electricity through the regional interconnector (SIEPAC) have made it possible for all the countries to plan large hydro projects to meet demand.

## 1. REGIONAL DATA

Central America, historically and as considered in this study, consists of six countries: Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama. Belize is not considered, as it is historically, politically, and culturally different, its electricity grid is not interconnected to the rest of the countries, it is not part of the SIEPAC project, and it seemingly has no geothermal potential.

The population of the region is approximately 39 million, over an area of 501,000 km<sup>2</sup>. The total GDP of the region is \$98.4 billion, for an average per capita GDP of \$2,557. There are vast economic and social differences among the neighbouring countries.

The Pacific coast of the region is situated along the “ring of fire”, where the Cocos plate is subducting under the Caribbean plate. This tectonic activity gives rise to a volcanic chain along the Pacific Rim, from Guatemala to Northern Costa Rica, where the geothermal potential is concentrated. As Honduras has a very small Pacific coast along the Gulf of Fonseca, and Panama is in a tectonically distinct setting, these two countries are generally regarded as having much less geothermal potential than their other four neighbours, and most of that in low-temperature resources.

Aside from small-scale fruit drying projects and tourism developments, very little direct use is made of geothermal heat in the region, and economic resources dedicated to geothermal are highly concentrated on power projects, so it is for this reason that the present study will discuss electricity generation almost exclusively.

The total installed electricity generation capacity of Central America is 9,270 MW, with a maximum available capacity of 7,500 (variable). The peak load is 6,225 MW, with an average growth rate of 5 %/year. Annual (2005) generation is 35,758 GWh, with 2,697 GWh (7.5%) coming from geothermal power plants, compared to 12,970 GWh (36.3%) produced from thermal plants, and the remainder

from hydro and cogeneration (Figures 1 and 2). These average statistics, however, hide the sharp differences in the composition of generation from one country to another: Costa Rica produces renewable energy almost exclusively, and on the other hand Nicaragua, the country with the largest geothermal potential in the region, relies on thermal sources for 80% of its electricity. It should be pointed out that, although the margin between reported available capacity and peak demand is seemingly comfortable, there has been severe electricity rationing in 2006 and 2007 in Nicaragua and Costa Rica, and Honduras and El Salvador have reported very slim operating margins, specifically during dry season. Furthermore, international power trade has dropped to roughly 15% of what it once was, due, largely, to the fact that surplus power now commands a high price, and local governments have moved to ensure supply in their own country by making exports more difficult.

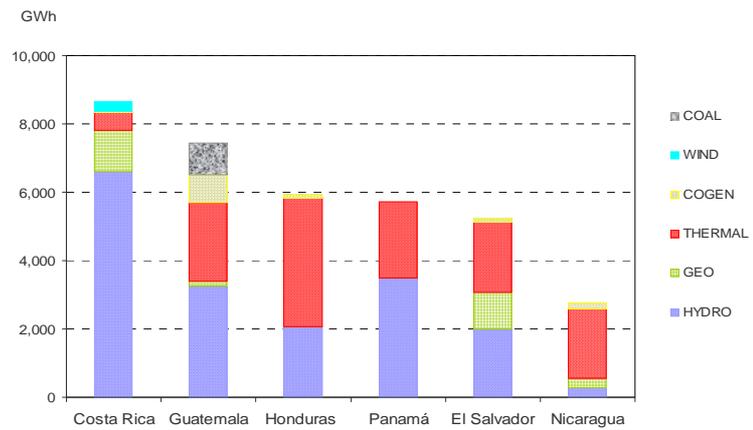


FIGURE 1: Generation by resource 2006 in Central America

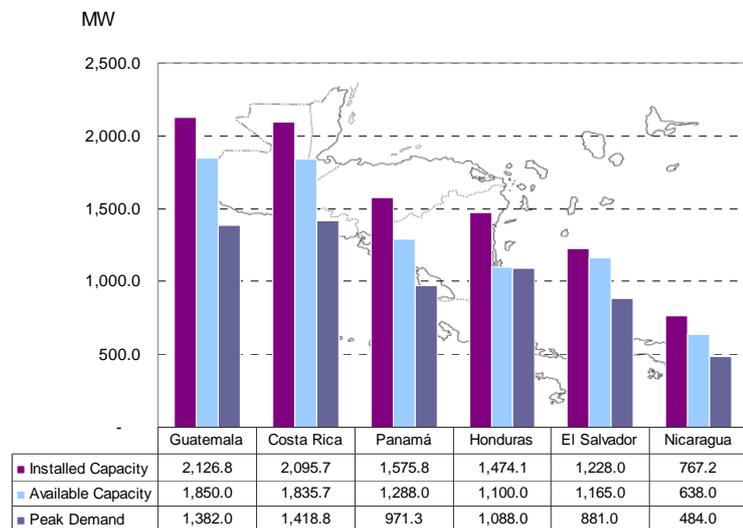


FIGURE 2: Installed capacity and peak demand 2006 in Central America

Given the accelerated rate of growth of electricity demand, and the fact that there is only minor local production of fossil fuels in Guatemala, the region faces difficult choices to increase the supply of electricity in the future. The recent rise in the price of oil combined with a strong dependence on oil-based generation, have put upward pressure on electricity tariffs, which are unlikely to drop significantly in the near future. Most of the countries in the region consider a national strategy to develop indigenous sources of electricity in order to reduce their dependence on imported fuel, and so investors are favoured with different types of incentives to develop hydro, wind, and geothermal energies.

## 2. DIRECT USE

Most direct use of geothermal heat in the region is informal, as a substitute for firewood to cook small meals. There are two formal projects that are worthy of note: Eco-Fruit in Guatemala, and Tabacón in Costa Rica. Eco-Fruit is a brand name of Agro-Industrias La Laguna, that produces dried fruit products using heat from shallow (125 m deep) hot water wells near Lake Amatitlán, with reservoir temperature of 125°C. Tabacón is a luxury resort/spa built on the side of Arenal volcano, located where warm and cold water streams come together.

Since there is no need in Central America for space heating, widespread use of geothermal for other than electricity production is unlikely in the future.

### 3. POWER PROJECTS

There are seven geothermal power plants in operation in Central America. In Guatemala, Ormat owns and operates the 27.8 MW Zunil binary cycle project and the 20 MW Calderas project in the Amatitlán resource (Figure 3).

In El Salvador, LaGeo owns and operates the 95 MW Ahuachapán double flash power plant, and the 109 MW Berlín single flash facility with bottoming cycle (Figure 4). In addition, two other fields, San Vicente and Chinameca, have been awarded in concession to San Vicente 7, a subsidiary of LaGeo, and exploration work is under way. Recent drilling results for San Vicente cast doubt on the economic viability of a power generation project there.

Nicaragua has two working power plants: Momotombo (70 MW single flash + 7.5 Mw binary), owned by the government and operated by Ormat, and San Jacinto Tizate (10 MW backpressure), owned by Polaris (Figure 5). Polaris has announced the future expansion of capacity at San Jacinto, to 32 MW. The El Hoyo-Monte Galán and Managua-Chiltepe geothermal areas have been awarded in concession to GeoNica, a joint venture company between Enel of Italy and LaGeo of El Salvador, and are currently in the exploration stage.

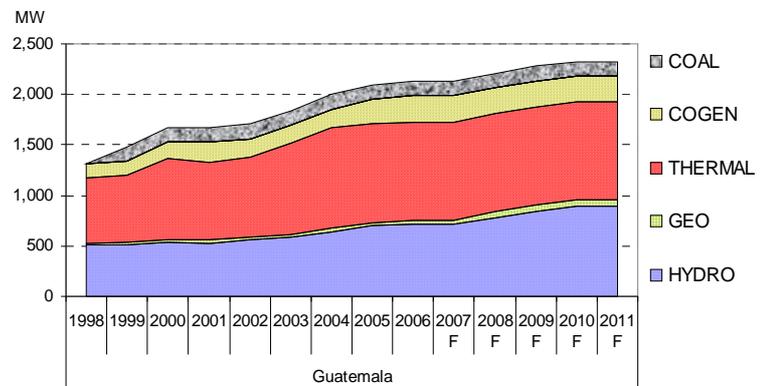


FIGURE 3: Installed capacity and projection in Guatemala (1998-2011)

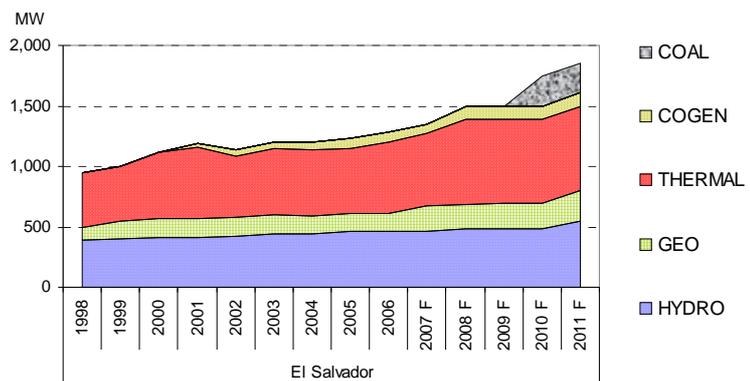


FIGURE 4: Installed capacity and projection in El Salvador (1998-2011)

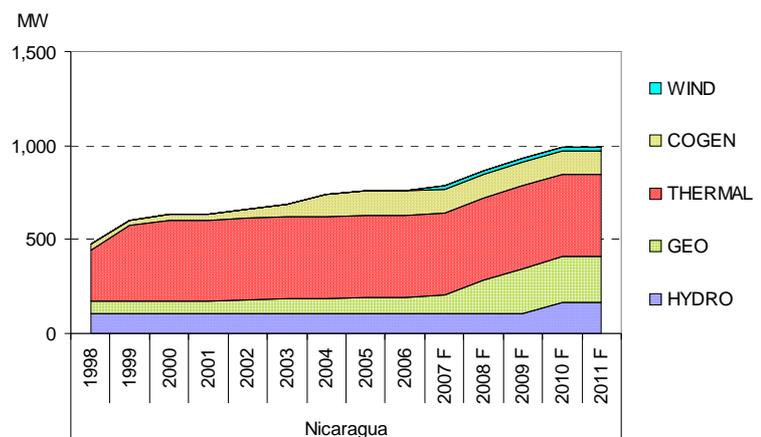


FIGURE 5: Installed capacity and projection in Nicaragua (1998-2011)

Honduras, though having little geothermal potential in comparison with its neighbours, has contracting the development of Platanares geothermal area, to GeoPlatanares, possibly suitable for a low-temperature binary cycle development (Figure 6).

The electricity sector in Costa Rica is run by ICE, the state-owned utility company, which operates most of the 160.5 MW Miravalles geothermal project (Figure 7). Of this, all is owned and operated by ICE, except the 27.5 MW Miravalles III unit, which is under a BOT contract with Mesoamerica Group. Additional exploration work is under way in Las Pailas, NW of Miravalles.

In Panamá (Figure 8), there has been some exploration work done, however, none has proceeded to further development.

In total, there are 490.5 MW of geothermal installed capacity in Central America, of which approximately 405.0 MW are available.

Estimates for the geothermal power capacity for the whole of Central America vary considerably, but conservative estimates are for about 2,000 MW of high-temperature hydrothermal electricity production in total. This means that the installed capacity of geothermal power in Central America could quadruple using currently available technology.

**4. THE FUTURE**

As the price of a barrel of oil increases, the need to develop alternative sources of electricity accentuates, and in response, most countries in the region offer potential investors incentives to develop geothermal energy projects. These are, for example, tax exemptions for 10 years

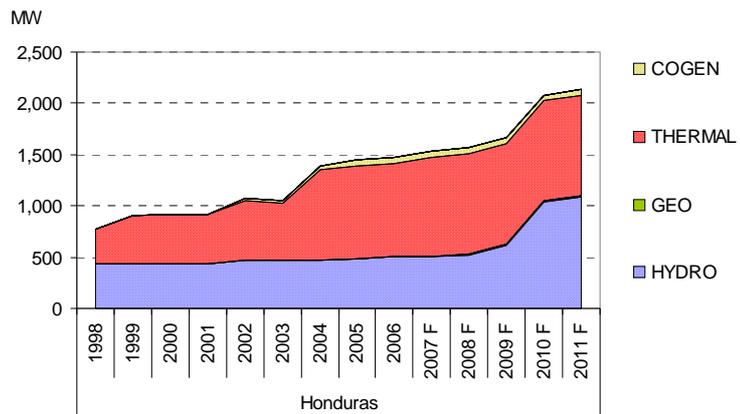


FIGURE 6: Installed capacity and projection in Honduras (1998-2011)

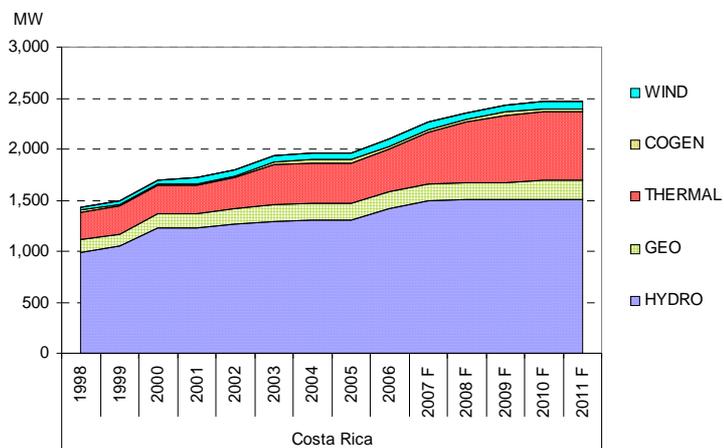


FIGURE 7: Installed capacity and projection in Costa Rica (1998-2011)

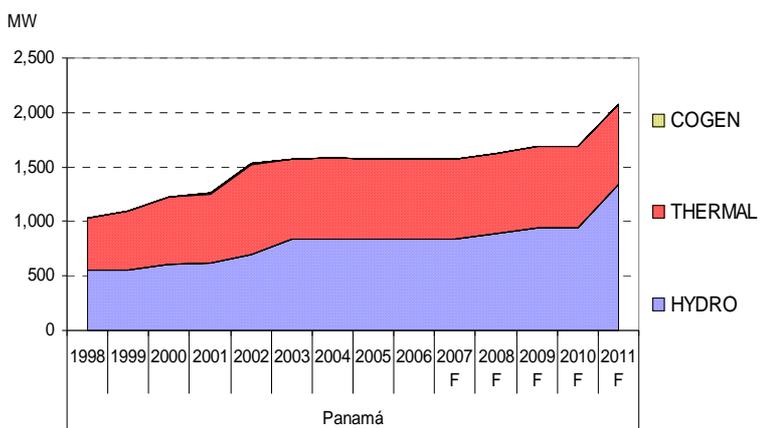


FIGURE 8: Installed capacity and projection in Panamá (1998-2011)

(Guatemala), and preferential treatment in power purchase tenders, in the form of a 5% price advantage (Panama).

The annual growth of about 5% for the regional demand means there is need for about 300 MW of new capacity each year. The GTPO, a meeting of the electric system operators of each country, expects that most of the supply growth in the next decade will come from new hydro plants, with some of the geothermal projects currently in exploration stage expected to come on line. Although there is a projection of growth based mostly on renewables, there are still large thermal projects expected to be constructed, like a large coal plant in Cutuco, El Salvador.

The SIEPAC project is projected to be completed in 2009, and that also will have an impact on the electricity markets. It consists of a 1,790 km long transmission line of 230 kV, with the capacity to transport 300 MW. This line will enable large scale power exchanges between neighbouring countries, and thus make regional generation projects more feasible.

<b>Country</b>	<b>Future Project</b>
<i>Honduras</i>	* Geo Platanares, 35 MW. In process a drilling contract with PSB.
<i>El Salvador</i>	* Binary Cycle of Berlin will begin in August 2007. * Optimization Ahuachapán is under way and there are already tangible results. * In exploration San Vicente and Chinameca fields.
<i>Costa Rica</i>	* Las Pailas 35 MW Programmed in 2011
<i>Nicaragua</i>	* Polaris Geothermal 35 MW
<i>Guatemala</i>	* Amatitlan from 20 to 50 MW

FIGURE 9: Geothermal projects

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## LECTURE 2

# PHASED DEVELOPMENT AT AHUACHAPÁN AND BERLÍN GEOHERMAL FIELDS

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### ABSTRACT

Ahuachapán and Berlín geothermal fields in El Salvador have gone through several phases in their development. In the case of Ahuachapán, the installed capacity has remained constant, but the exploitation strategy has evolved over several years, causing wholesale changes in field management. In Berlín, the exploitation strategy has remained roughly constant, but the installed capacity has grown over time, also causing necessary modifications to field management practice.

## 1. INTRODUCTION

El Salvador has a decades-old history of exploiting its geothermal resources for the generation of electricity. In fact, considering that the first commercial power came on line in 1975, Ahuachapán was one of the first geothermal resources utilised to produce power for a developing country. Curiously enough, the history of development in both Salvadorian fields currently in production – the other being Berlín – is quite different, owing as much to the geographic location and the characteristics of the resources themselves. Although there are some benefits to standardisation, the differences in the resources and the development periods make it impossible to standardise everything, and each field must be developed in accordance to its own characteristics and the state of the art in the time period when it is developed. In the case of El Salvador, this has meant that work has been done in phases, and that the Salvadorian geothermal projects have been a “work in progress” for a long time.

## 2. AHUACHAPÁN

### 2.1 History

The Ahuachapán Geothermal field is located in the Western part of El Salvador, close to the border with Guatemala. Initial exploration efforts started in the early 1960's when the United Nations Development Programme (UNDP) supported the national electric utility, Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL), with surface exploration and 3 deep exploratory wells, The first of these, AH-1, in Ahuachapán. This well yielded a commercially viable steam flow rate and with this result CEL decided to continue with the commercial development of geothermal resources.

The Mitsubishi Unit 1 (30 MW, single flash condensing type) came on line in June 1975 and a few months later in July 1976 an additional, identical Mitsubishi 30 MW unit was added. In March 1981 a new Fuji 35 MW Unit 3 (double-flash) came on line using the separated brine to produce low pressure steam (1.4 bar), bringing the total installed capacity in the field to 95 MW.

The initial mass extraction (Witherspoon, 1977) was around 600-700 kg/s and almost 550 kg/s of disposal brine was injected in the centre of the field since 1975. During the first years of commercial exploitation mass injection was implemented and was carried out in wells located at the centre of the field. Brine was injected in the wells AH-17, AH-19, AH-8, AH-29 y AH-2 (see Figure 1), but due to some cooling effects in production wells this procedure was stopped (Campos T, 1985) and in November 1982 a concrete canal was completed to conduct the residual brine to the Pacific Ocean.

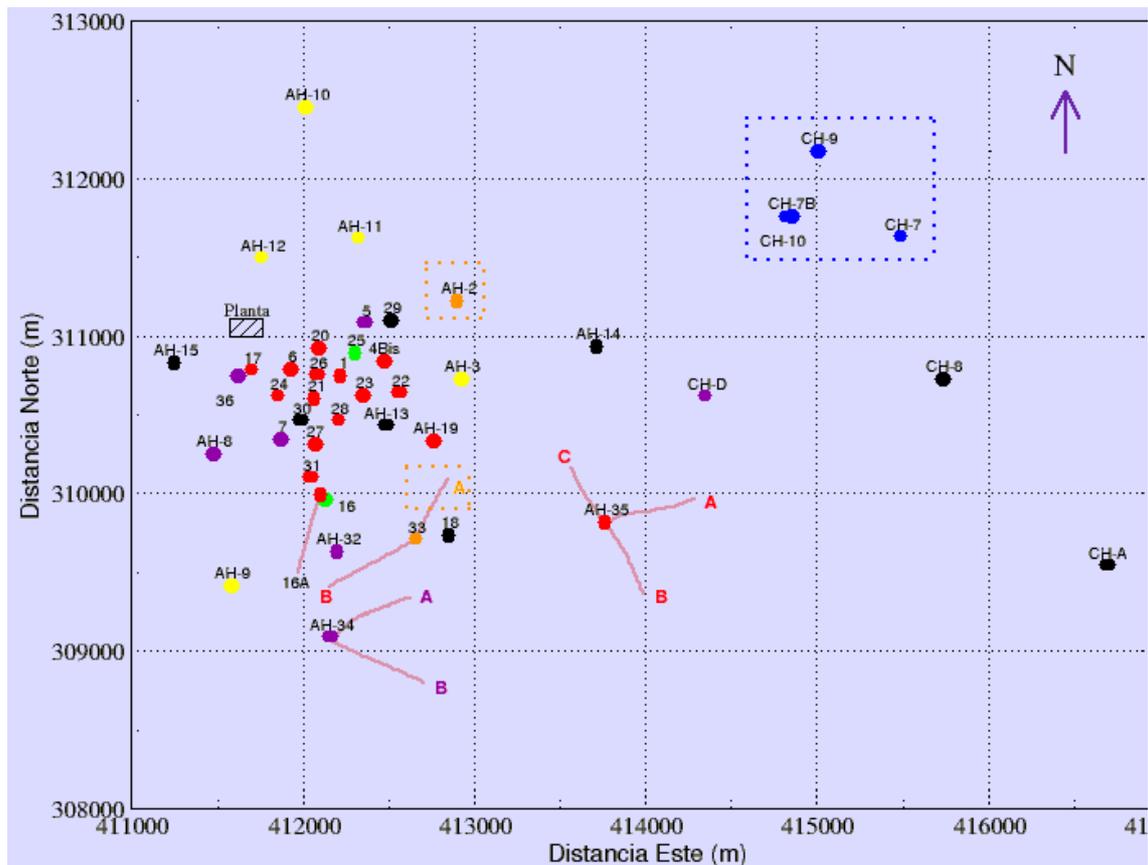


FIGURE 1: Well locations at Ahuachapán geothermal field

At present 50 wells have been drilled in the Ahuachapán-Chipilapa area (Figure 1), 17 of these are currently connected to the power plant for steam production, 5 wells are connected for injection, wells AH-1 and AH-7 are connected but they are not able to produce steam due to low wellhead pressure, wells AH-25 and AH-30 are normally used to monitor the reservoir pressure, well AH-32st and AH-35C are scheduled to be connected later in 2007, and other wells are used to monitor and characterise the systems, or as standby producers. At least 6 wells are abandoned (AH-3, AH-10, AH-11, AH-12, CH-A, CH-A1).

## 2.2 Conceptual model

Several conceptual models have been elaborated for the Ahuachapán field: LBL 1991, Electroconsult 1993, and ENEL-LaGeo 2004. In the last one the main difference with the previous was the consideration of possible expansion of the reservoir to the South-West as presented in Figure 2. In

accordance with these conceptual models, the field appears to be dominated by seven major and five minor faults trending SW-NE and SE-NW. Those faults have been identified by lithological logs, aerial photographs, structural mapping, and geophysical data.

Three aquifers have been identified: the shallow, the regional saturated and the saline “reservoir” aquifers. This classification is based on the chemistry of the fluids, losses of circulation during the drilling operations, and the pressure response of the aquifers to seasonal variations in precipitation. The three aquifers appear to coincide with lithological units. The fluid pressure in the different aquifers reflects limited hydraulic connection between them as their hydraulic potentials are different. The hydraulic potential is lowest in the saline reservoir aquifer and therefore there is a potential for cold water recharge from the overlying regional saturated aquifer.

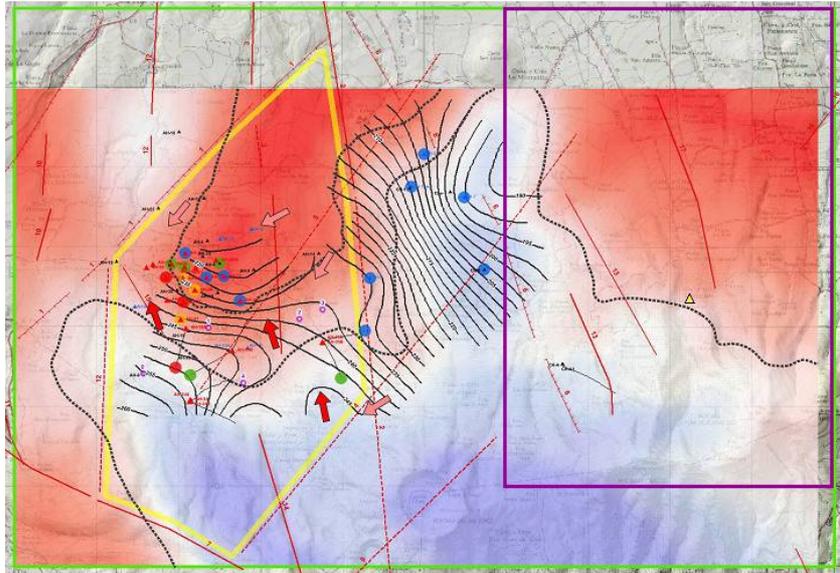


FIGURE 2: Conceptual model of the Ahuachapán field

The groundwater flow in the shallow aquifer does not seem to be significantly affected by the faults. A study of well circulation losses suggests a rather uniform permeability in these less consolidated materials (alluvial). In the regional saturated aquifer groundwater flow tends to be influenced by the fault pattern, mainly by SW-NE trending faults. The flow in the geothermal reservoir is also controlled by the faults, most notably SW-NE trending. This is evidenced by the temperature distributions. According to MT data interpretations, the Ahuachapán field is represented by three layers sequence (resistor-conductor-resistor), typically, characterizing the andesitic geothermal environment. The reservoir is identified by a conductive layer and its base is marked by the transition zone between a conductive and a deep resistive layer, around the 25 ohm-m.

There is no evidence of the existence of a second deep reservoir. Chemical data and down hole measurements indicate temperatures of no more than 260°C into the deeper geothermal system.

### 2.3 Well production history

As mentioned above, commercial exploitation started in 1975. Figure 3 gives the reservoir pressure in well AH-25 measured at +200 m asl, and the total mass extracted from the field. Different field management strategies were implemented during 35 years of operation, in order to maximize production, optimize costs, and sustain long-term generation:

- I. Start of commercial exploitation 1975-1983, characterized for rapid pressure decline correlated with the mass extracted (more than a 15 bar pressure drop was observed), some injection experiments were carried out with unsuccessful results and were stopped.
- II. Stabilization by seasonal operation from 1984-1994. This period was characterized by reducing the declining trend, the power production was greater during dry season and smaller during rainy season to coordinate with hydro generation. No injection was implemented during this period. Pressure decline was around 1.5 bar during this period.

- III. Stabilization by “base” well operation 1994-1999. This period was characterized by the continuous use of the high enthalpy wells and reducing the mass extracted. With this strategy the pressure decline was quite low, less than 0.5 bar was observed. No injection was carried out during this period.
- IV. Increasing power production with more wells and use of the Chipilapa wells for injection, 2000-2005. 10 new wells were drilled in the centre (AH-4b, AH-16A), to the south west (AH-34's), to south east (AH-33's and AH-35's), new 24" injection line was built to Chipilapa, and later on in order to increase the injection capacity a pumping system was installed. The pressure decline was around 1.5 bar with a 15 MW increase in power production.

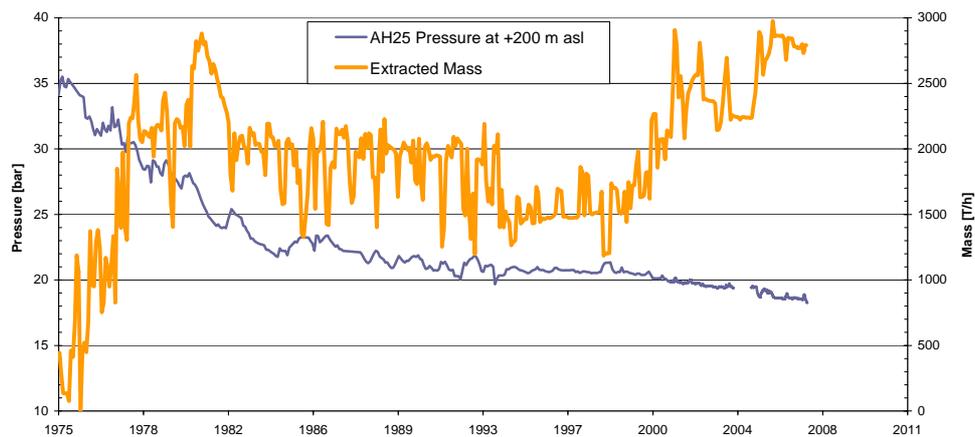


FIGURE 3: Reservoir pressure and mass extracted at Ahuachapán geothermal field

TABLE 1: Production wells data for Ahuachapán

Well	Wellhead pressure (kg/cm <sup>2</sup> a)	Líquid flowrate (kg/s)	Steam flowrate (kg/s)	Dryness (%)	Enthalpy (kJ/kg)	Total flowrate (kg/s)
AH-4 B	9.2	80.1	29.7	27	1243.0	109.8
AH-06	5.7	0.9	9.8	91	2568.2	10.7
AH-16A	6.8	45.5	8.8	16	1014.0	54.3
AH-17	11.8	0.4	14.1	97	2725.8	14.5
AH-19	8.4	33.1	6.2	16	1000.8	39.3
AH-20	6.4	63.2	11.4	15	981.3	74.6
AH-21	8.8	45.5	8.0	15	976.3	53.5
AH-22	6.7	24.8	5.0	17	1020.4	29.8
AH-23	5.9	25.8	6.8	21	1096.7	32.6
AH-24	Stand by					
AH-26	5.9	12.3	7.3	37	1436.8	19.6
AH-27	5.9	39.1	9.6	20	1071.0	48.8
AH-28	5.9	41.2	6.0	13	926.6	47.2
AH-31	6.4	62.6	9.7	13	953.4	72.3
AH-33 B	7.6	48.1	7.8	14	965.2	56.0
AH-35 A	7.8	52.3	9.3	15	988.8	61.7
AH-35 B	7.5	39.5	6.0	13	946.5	45.5
<b>TOTAL</b>		<b>614.5</b>	<b>155.7</b>	<b>Field enthalpy</b>	<b>1244.7</b>	<b>770.2</b>

Increasing the power production at lower reservoir pressure and using the 3 units already installed, 2005-present. The power was increased from 65 to 80 MW and the pressure decline is almost 1 bar. Units 1 and 3 were in commercial operation since the beginning, therefore the maximum power output was 65 MW. Unit 2 was used as stand by or back up unit. In 2005 a large extraction test was carried out (March-June) and Unit 2 was used as “base load”. Since November 2005 the three units are in continuous operation. Figure 4 shows the gross power output at the power plant since 1988.

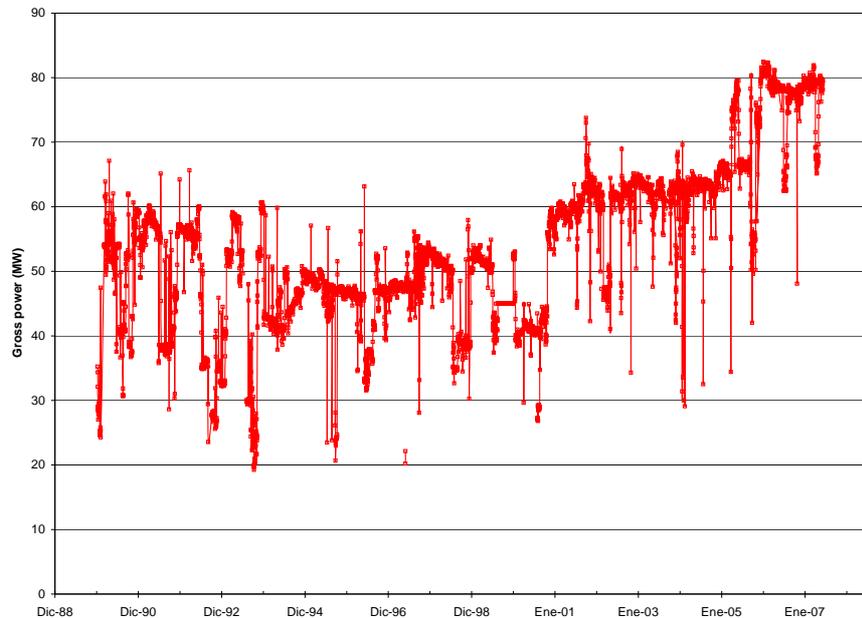


FIGURE 4: Gross power at Ahuachapán power plant

The behaviour of the wells follows the trend of the reservoir pressure. Figure 5 shows the history of well AH-6. Well AH-6 is a normal well affected by boiling. During exploitation the falling pressure resulted in boiling, the liquid flow rate declined drastically and the enthalpy increased. In the last 10-15 years the reservoir pressure has been almost stable and the conditions in this well have also been stable.

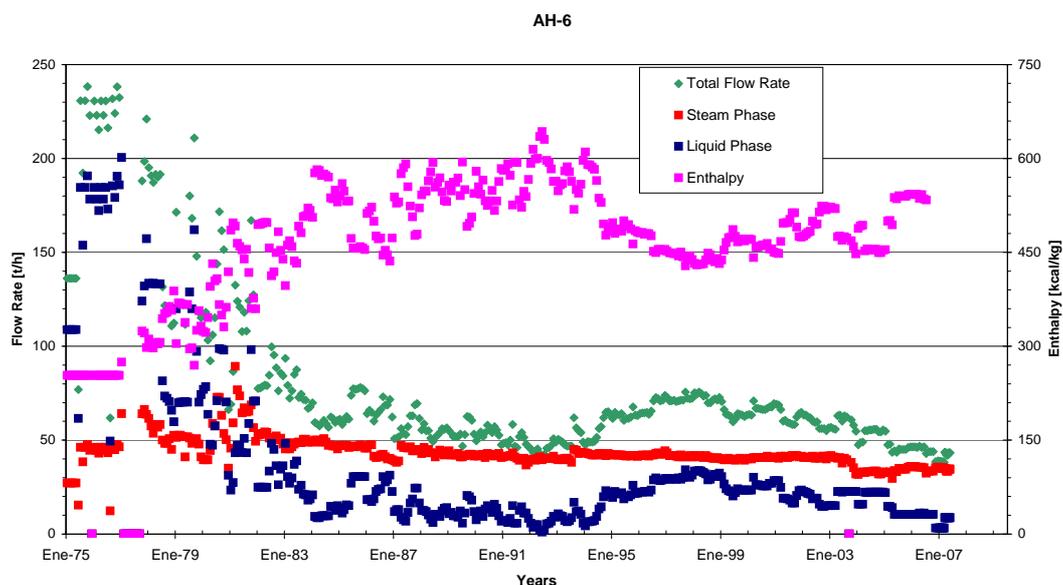


FIGURE 5: Production history of well AH-6

Another historic well is AH-21. This well is affected by dilution, and for that reason the enthalpy and steam flow rate are decreasing, as shown in Figure 6.

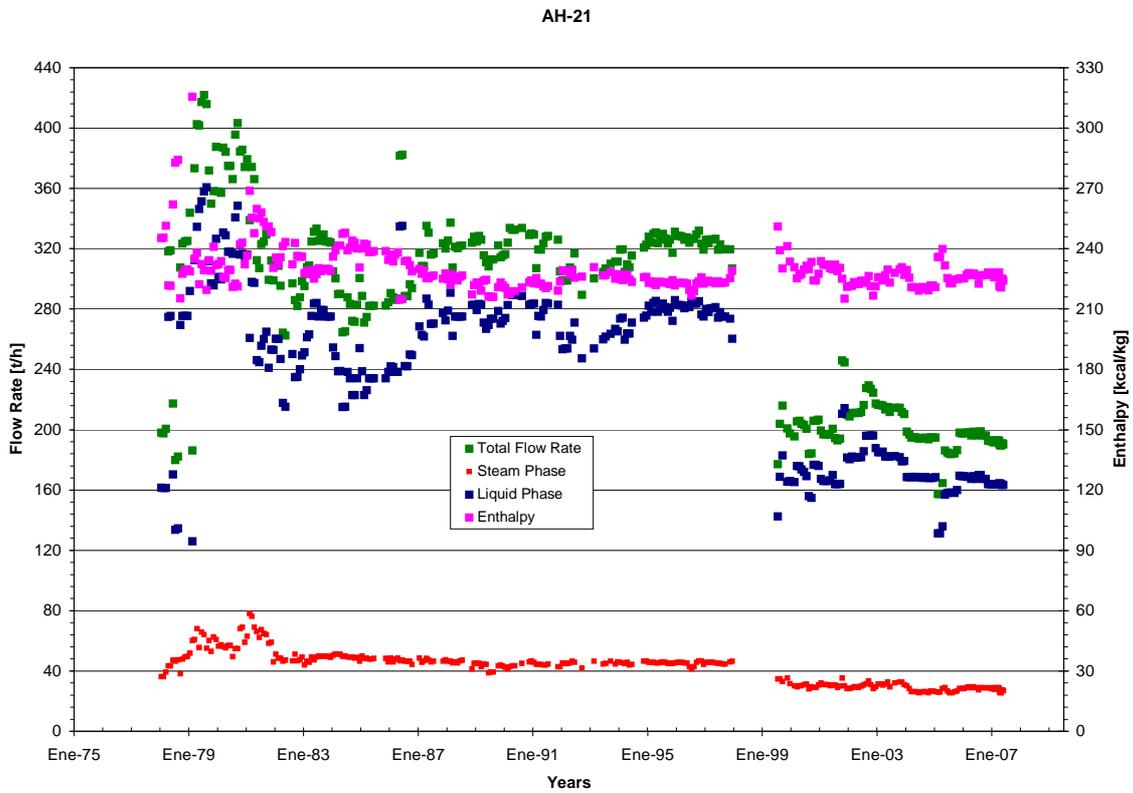


FIGURE 6: AH-21 production history

Figures 7 and 8 present the current flow rate and the dryness of the fluid.

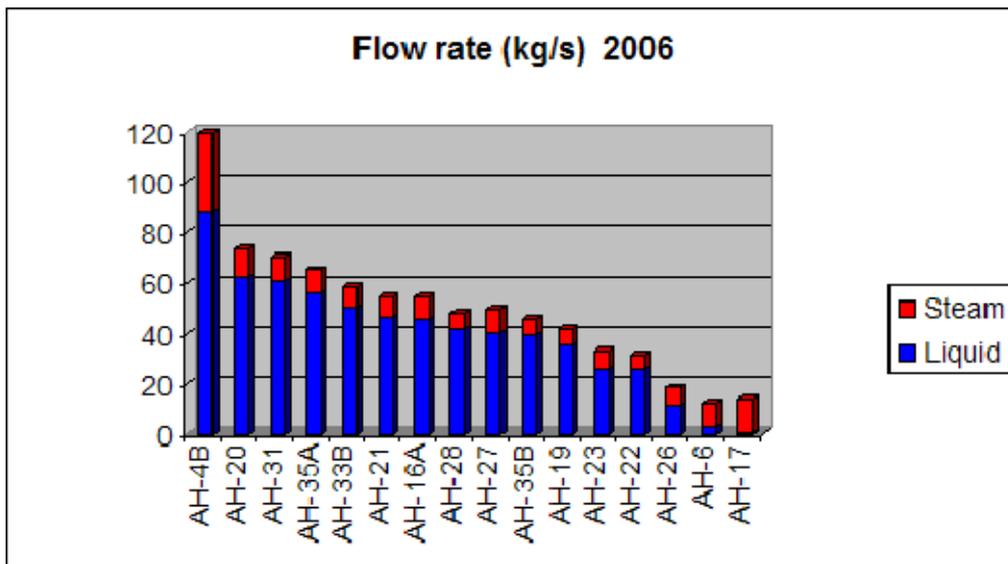


FIGURE 7: Flow rate by well

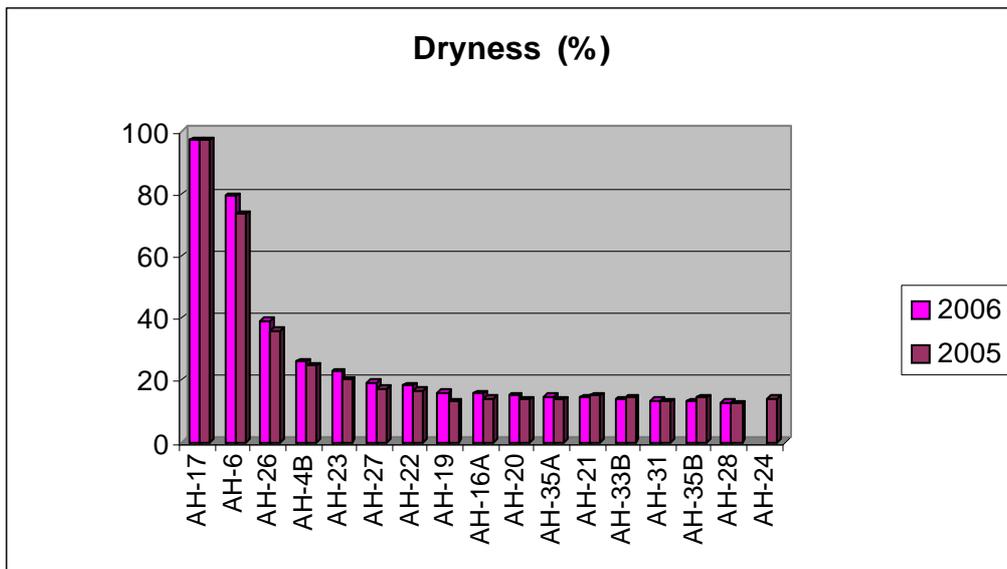


FIGURE 8: Dryness by well

A special case is well AH-4bis, which is affected by the reservoir pressure and the hot injection in the south (AH-33A). Figure 9 presents the reservoir pressure at well AH-25 and the steam flow rate of well AH-4bis. Well AH-4bis produces relatively high enthalpy fluid. Its main feed zone is from the shallow part of the reservoir and therefore is affected by boiling. From March 2005 the well operated with two separators and the steam flow increased from 19 to 32 kg/s. Normally, when the injection into AH-33A is more than 30 kg/s the steam flow rate from AH-4bis decreases and if the reservoir pressure declines the steam flow increases.

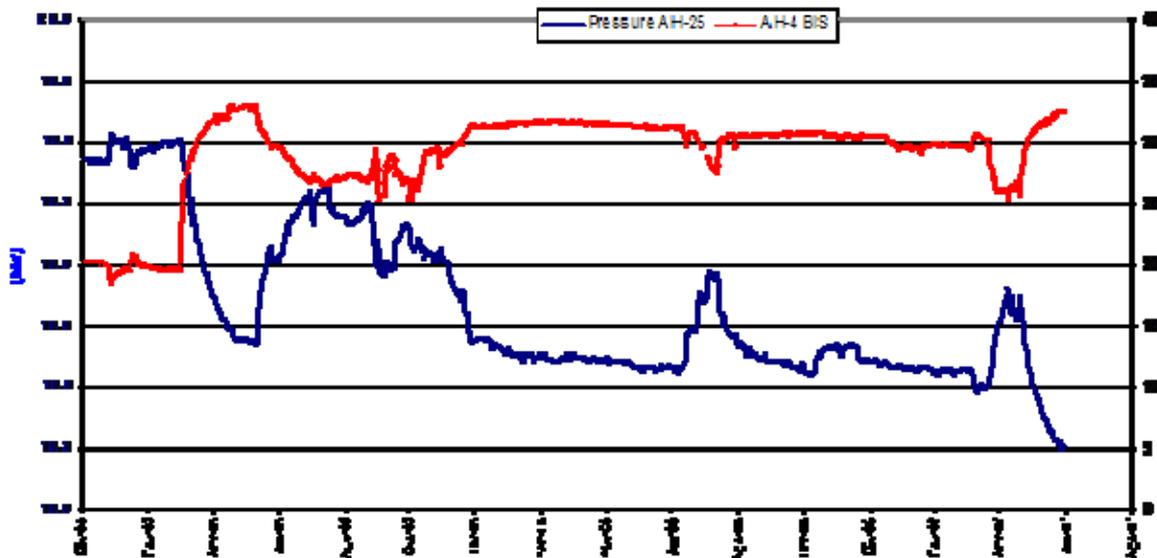


FIGURE 9: Reservoir pressure and steam flow rate in well AH-4bis

### 3. BERLÍN

#### 3.1 History

The Berlín geothermal field is located in the Eastern part of El Salvador, 110 km from the capital, close to the town of Berlín (named by German immigrants in the late 19<sup>th</sup> century). Exploration started in 1965, with assistance from the UNDP. One deep well, TR-1, was drilled to a depth of 1,500 m, but during discharge tests low steam and well head pressure was observed. Development efforts were then concentrated in Ahuachapán.

During the period 1975-1981 four additional wells were drilled in Berlín (TR-2, TR-3, TR-4 and TR-5) (Figure 10). In order to decide about the commercial development of the field, CEL ordered a complete evaluation of the field, but all development was soon stopped due to the start of the civil conflict that affected the area from 1980 to 1992.

In 1992, 2 x 5 MW back pressure units (ACEC/ABB) went on line using a doublet configuration of TR-2 as producer and TR-9 as an injector. During a failed drilling operation there was a blow-out at TR-6 at 115 m depth and the well was never completed. The intention was for TR-6 to be an injection well that would allow TR-9 to produce.

To complete injection capacity TR-8 and TR-14 were drilled in 1993-1994, TR-14 was connected in April 1994 and TR-8 in December 1994. TR-9 recovered temperature and went on line as a producer in February 1995. Power production during this period was around 6-7 MW. The production conditions from 1995-1999 were stable.

CEL contracted Electroconsult Spa to perform a new feasibility study from 1993-1995 (Electroconsult, Estudio de Factibilidad Primer Desarrollo a Condensacion Campo Berlín, 1994), and its main conclusions were:

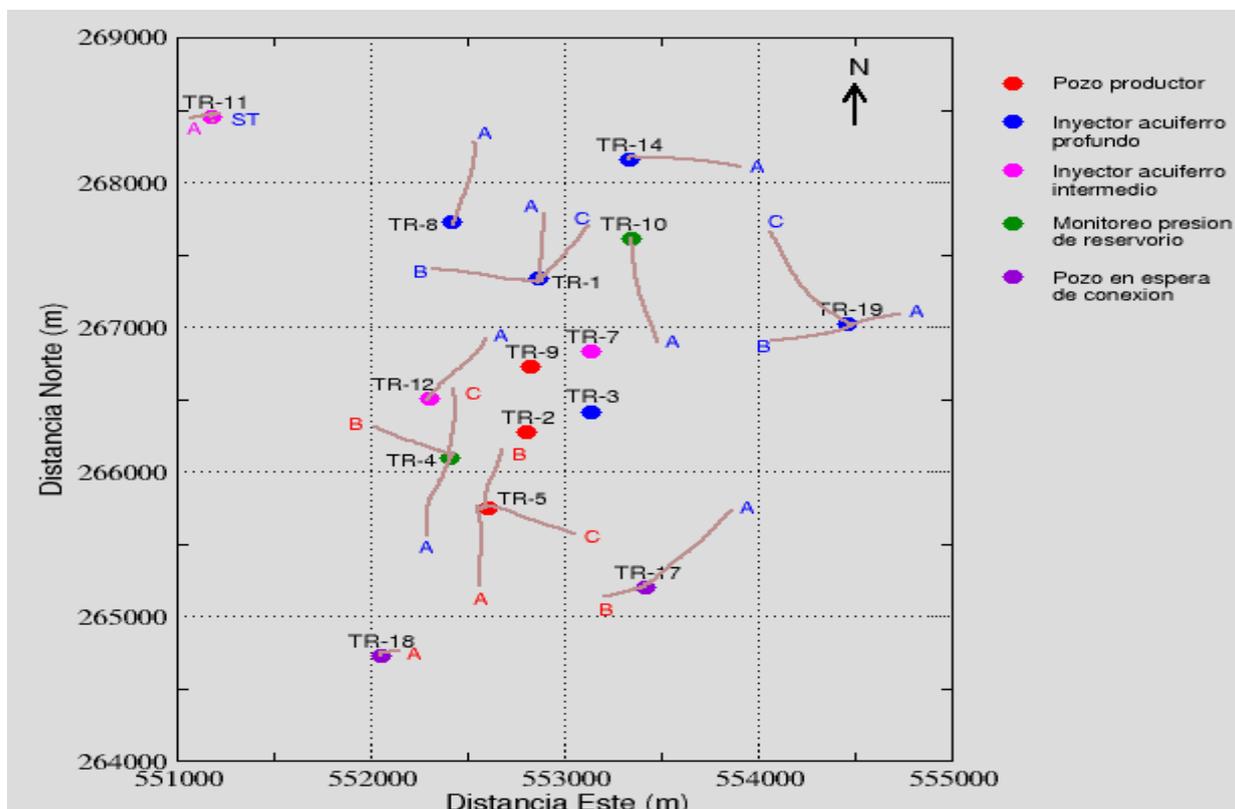


FIGURE 10: Well locations at the Berlín field

1. The proven field potential according to numerical models was at least 50-60 MW and could achieve 100 MW with high level of probability (95%).
2. The design of the future power plant and general installation could be done taking into account this possible field development.
3. The first condensing power plant could be size 2 x 25 MW.

The new power plant came on line in 1999 when 2 x 28 MW Fuji condensing type units were commissioned. 18 new additional wells were drilled, 6 for production (TR-5A/B/C, TR-4A/B/C) and 12 for injection (TR11,st,A/B/C, TR-1A/B/C, TR-12/A, TR-8A, TR-7). The Figure 10 shows the well location in the Berlín field.

In 2003 a new revised reservoir assessment was carried out as a joint effort between Enel and LaGeo. The main conclusion was that it was possible to increase the power production by at least 44 MW. Between 2004-2006, 9 new additional wells were drilled (TR-17/A/B, TR-18/A, TR-19/A/B/C) to complete the production and injection capacity for the new power unit (GE-Nuovo Pignone), which came on line in December 2005.

### 3.2 Conceptual model

The Berlín geothermal field is located on the northern slope of the Tecapa volcanic chain, inside a system of faults to the South of the Central American graben (Figure 11). The caldera rim geometry observed in the field suggest a collapse at the same time that trending faults NW-SE (Guallinac, El Hoyon, Las Curcitas) were also activated leading to the formation of NW-SE Berlín graben. This volcanic complex is composed of a series of volcanic cones that have erupted lava and scoria which emerge around the craters in the southeast part of the old Berlín volcano caldera. The more recent volcanic activity was the freatomagmatic explosion named El Hoyon 700 years ago.

Berlín field is controlled by NW-SE trending fault system. It is considered the most recent, active and important because it permits the ascent of the fluids from depth to surface.

From geophysical data, the reservoir top seems to be identified by the combination of the gravimetric high and the top of a medium resistive anomaly (30-100 ohm-m). The resistivity of the andesitic rocks of the reservoir could be lowered by the saline geothermal fluids.

In correspondence to the El Hoyon fault area, a deep vertical conductor (resistivity 15-20 ohm-m) has been located; it is likely to be the channel through which primary geothermal fluids flow from depth to the reservoir. The chemical compositions of the fluids sampled in the wells corroborate this assumption.

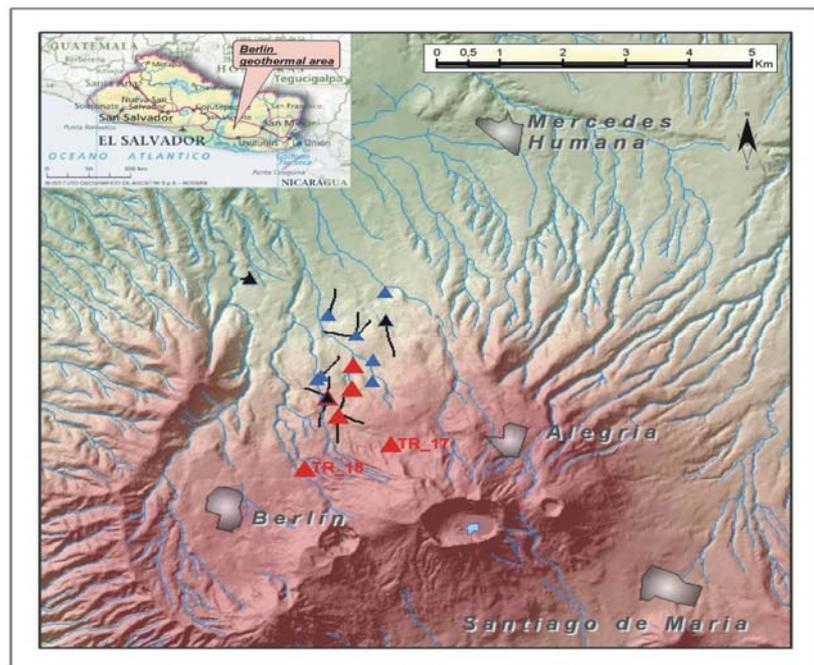


FIGURE 11: Setting of the Berlín Field

Boiling phenomena, if any, are negligible. The circulation seems to originate in the deep vertical conductor, then flow towards NE and beyond the northern boundary of the field, with increasingly degraded thermal characteristics.

The reservoir is generally located in the lithological Unit IV (Unit III composes the cap rock), a layer of fairly high permeability perhaps fractured or fissured, and its mean porosity is around 7% and the primary permeability is 60 mD.

The top of the reservoir is located on average at -1000 masl, while the base is still not known. The known minimum extension of the high enthalpy surface (bounded by 290°C isotherm) is 3x3 km, but it might spread further to the South.

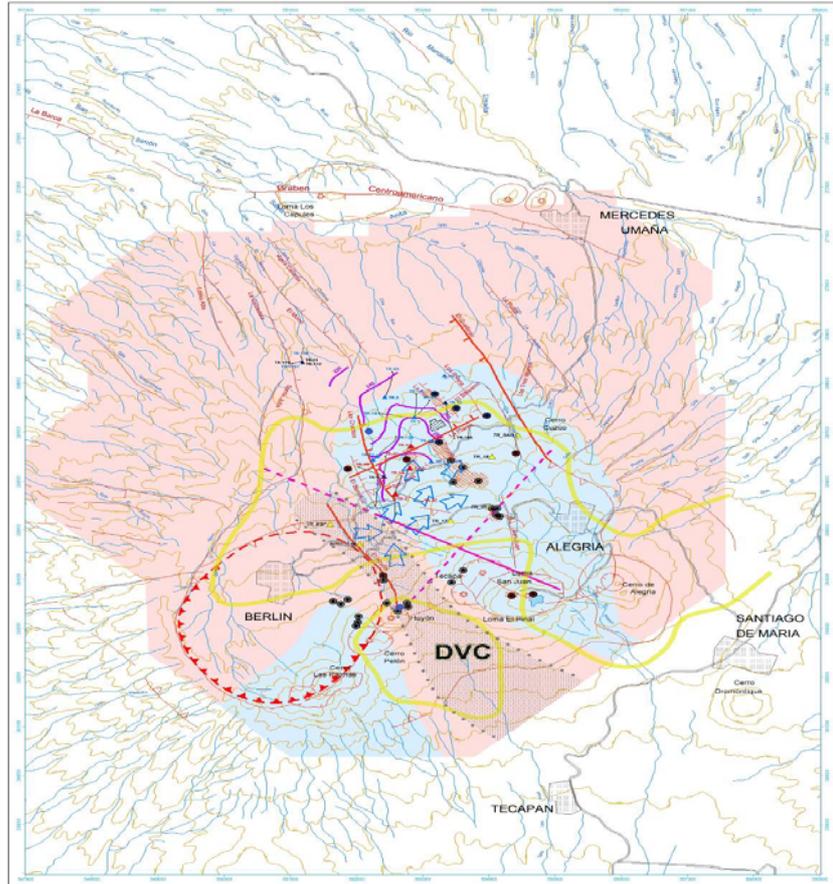


FIGURE 12: Conceptual model of the Berlín field

Figure 12 shows the updated conceptual model of the Berlín field (Enel, 2003).

### 3.3 Power production

Power production started in February 1992 when 2x5 MW back pressure units went on line. In 1999 2x28 MW condensing units were commissioned and the previous units were disconnected. In December 2006 an additional 44 MW was installed, bringing the total current installed capacity to 100 MW. Figure 13 shows how the gross power has been delivered to the national electric grid, versus reservoir pressure. The total daily production is around 2,300 MWh and the net injected power is 2,100 MWh. During maintenance (every two years for each unit) low values of generation are observed.

### 3.4 Production history

To date 39 wells have been drilled at the Berlín field, 14 producers wells and 19 injectors, 6 wells are abandoned (TR-1, TR-6, TR-11/B/C, TR-10A). The total steam flow rate is 215-220 kg/s and the injected brine is around 550-560 kg/s, therefore the total mass extracted is around 775 kg/s.

The steam field area is located to the South of the power house and the injection area is located to the North, however, some injection wells are located in the centre of the field (TR-7, TR-12/A) and due to the lack of injection capacity some producer wells are still used for injection.

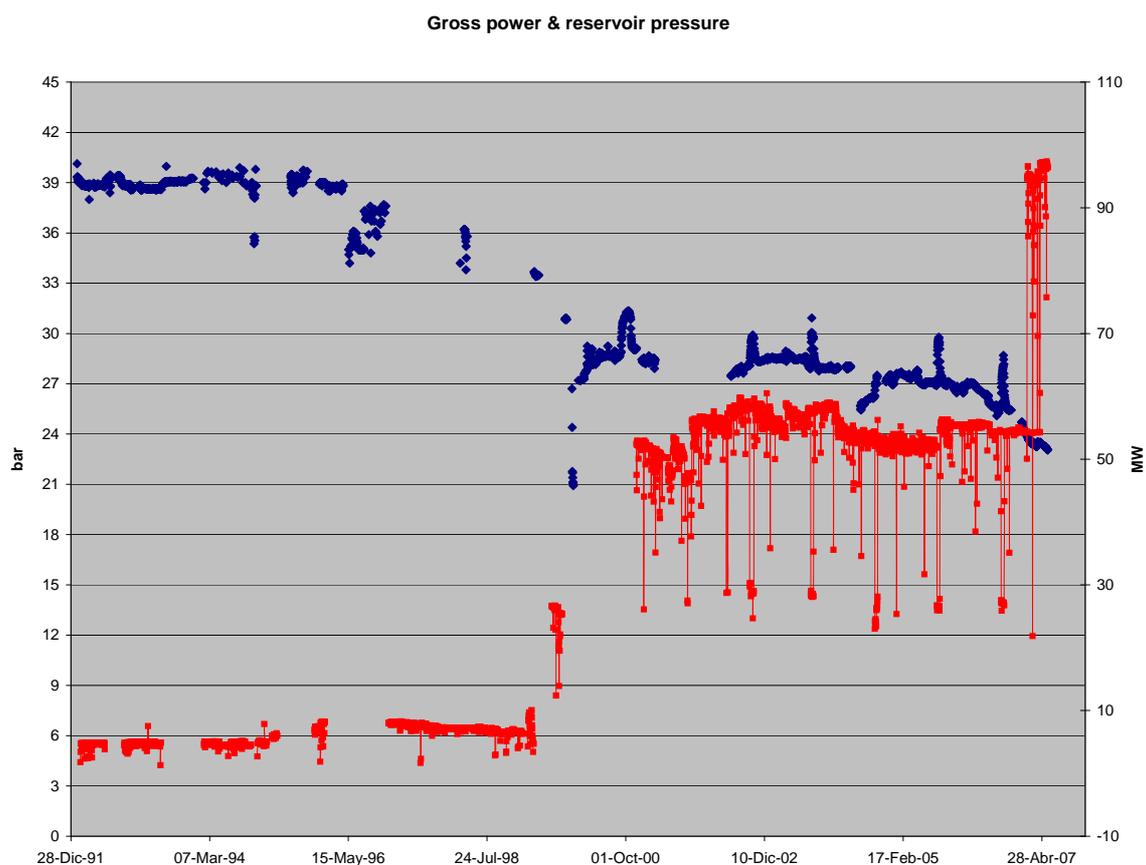


FIGURE 13: Gross power and reservoir pressure at the Berlín power plant

Table 2 shows the characteristics of the producer wells and Figure 14 shows the mass and pressure since January 2000.

TABLE 2: Well characteristics at the Berlín field

Pozo	WHP (bar)	Vapor (kg/s)	Líquido (kg/s)
TR-2	11	13	43
TR-9	10.1	5.7	22
TR-4B	12.2	13	34.7
TR-4C	12.3	15	45.9
TR-5A	11.1	18.5	67.7
TR-5B	22.0	16.1	73.5
TR-5C	11.1	21.4	67.3
TR-17	8.1	13.6	44.2
TR-17A	8.3	15.0	55.3
TR-18	11.3	22	81.2
TR-18A	15.4	57.8	0.0

In Berlín, it was found that acid stimulation with a mixture of HF/HCl improves the well permeability, and hence production. Figure 15 shows the behaviour of well TR-5C where acid jobs were used. This result has been observed, even in wells that do not have skin effect due to drilling, although the reasons are still not well understood.

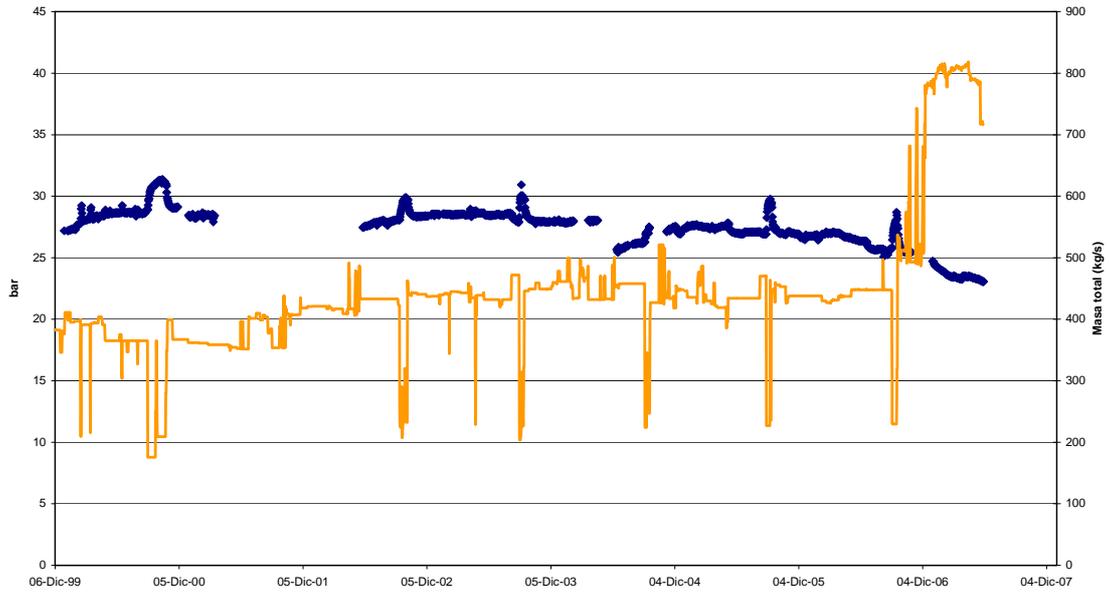


FIGURE 14: Total mass and pressure trend at the Berlín Field

Well TR-5C

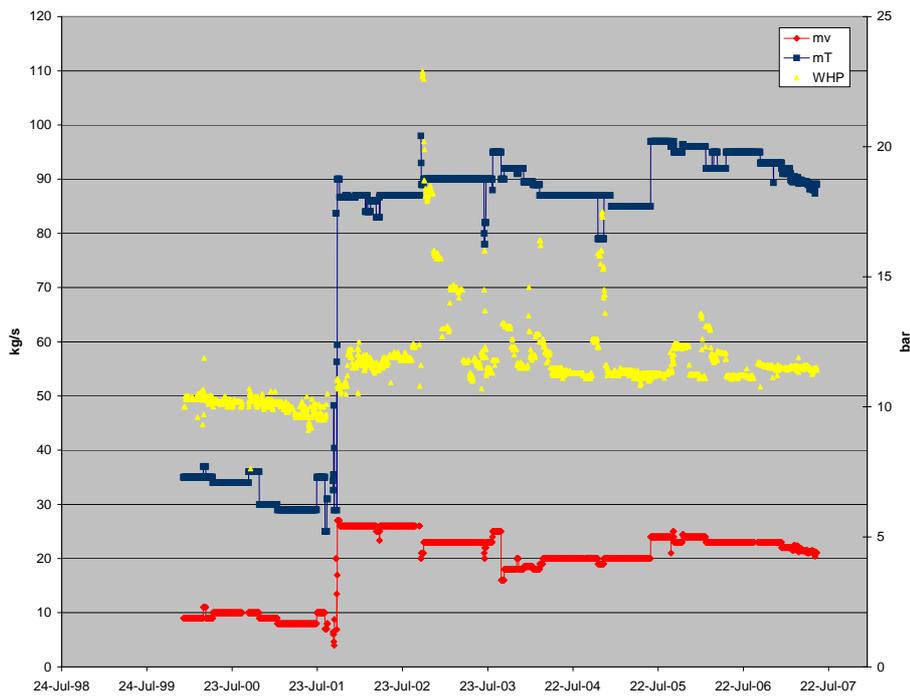


FIGURE 15: Production history of well TR-5C

An expected drilling result was TR-18A, which produces dry steam at high pressure, probably because it intersected the steam cap of the reservoir. Figure 16 shows the short term production history of the well which started exploitation in December 2006.

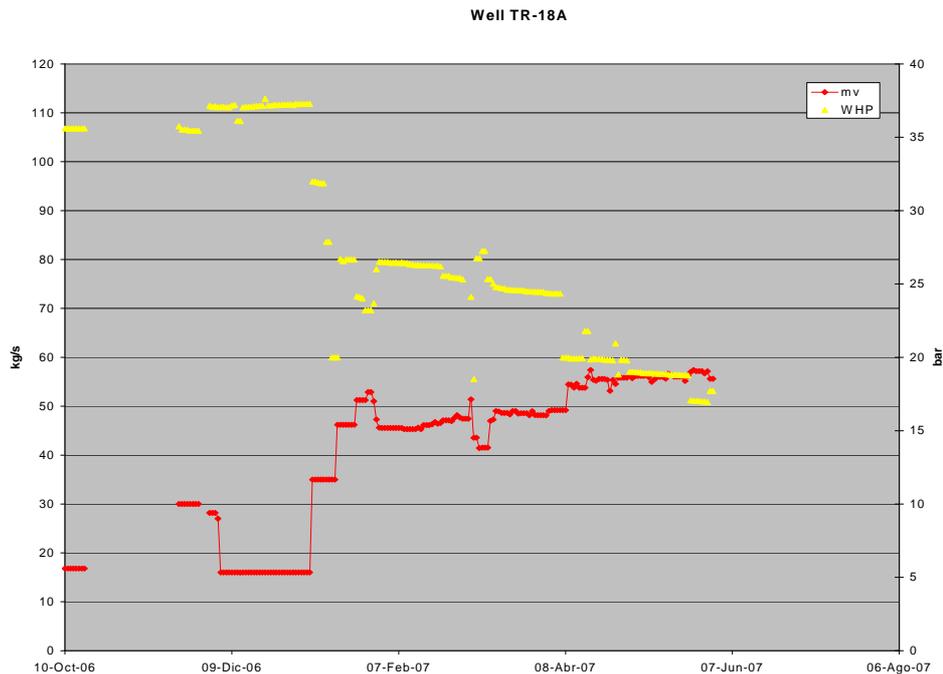


FIGURE 16: Production history of well TR-18A

#### 4. CONCLUSIONS

Geothermal fields in El Salvador have long been a “work in progress”. In Ahuachapán, the installed capacity has not changed, but the exploitation policy has evolved significantly over the years, and now exploitation is done over a larger area and coupled with reinjection in Chipilapa. In Berlín, on the contrary, the exploitation strategy has remained more or less constant, but the installed capacity has been growing over the years. In both cases, the evolution has led to a greater power output as the field is better understood.

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### LECTURE 3

## **GEOHERMAL, THE ENVIRONMENT AND NEIGHBOURING COMMUNITIES**

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### ABSTRACT

Geothermal developers often assume that the environmental impacts from their projects are minimal, considering the low level of greenhouse gas emissions, and the positive impact on the local economies, and so are surprised to see sometimes strong local opposition to geothermal projects. In fact, the impacts to the physical, chemical, and biological environment can be quite significant, and the prevention, mitigation, or compensation measures must be taken into consideration from the project design stage in order to ensure compliance with legislation and acceptability by the local neighbouring communities.

### 1. INTRODUCTION

Geothermal power projects are widely believed to be an environmentally friendly alternative for electricity generation, in particular because they produce only small amounts of greenhouse gases. However, in practice, some geothermal projects receive very strong opposition from local and environmental groups, to the point where some projects have been held up for years, or sometimes even scrapped altogether. For successful development of a geothermal project to move forward smoothly, the legitimate concerns of the local communities and environmental groups must be addressed to their satisfaction, even though sometimes this means going beyond the mandates of law.

### 2. CORPORATE SOCIAL RESPONSIBILITY

In order to put together a solid social responsibility policy, the geothermal developer must correctly identify the legitimate stakeholders in each project and the issues that are critical to each one. Normally, every corporation will identify three stakeholders: clients, shareholders, and employees. Often it is believed that if the interests of these three groups are satisfied, and the geothermal developer observes the local legislation, creates jobs, pays taxes, and reduces carbon emissions, and then a project should move ahead without difficulty. Developers are then surprised to see opposition from local groups whose concerns were overlooked, and most often this opposition is dismissed as coming from the “radical fringe”.

However, local communities may have legitimate claims that a large geothermal project will significantly alter their way of life, certainly during construction, and further during the project’s life.

In El Salvador, areas with geothermal potential are typically situated in the middle of very poor communities who may resent the impact of access roads, well pads, pipelines, and a power plant in their neighbourhood and their environment. It requires some research, understanding, and negotiation, to be able to address their legitimate concerns – beyond strictly legal compliance – before a project can move ahead without problems. In the case of LaGeo, this requirement is addressed in the Corporate Social Responsibility policy, which requires the corporation to become actively involved in the local development plans, in both elaboration and execution.

### 3. LEGAL FRAMEWORK

**Environment.** On December 1989, the Presidents of the Central American countries signed the Agreement for the Central American Environmental and Development Commission (CCAD), which primary target is to contribute to the sustainable development of the region, strengthening cooperation and integration for environmental management. This institution arose from the free and sovereign will of the Governments of Central America. The Central American Integration System (SICA) endorsed by the United Nations General Assembly, was formed in 1993. Many of the regional environmental initiatives that have subsequently become law in each member country have arisen from these two bodies.

In 1997, the Ministry of Environment and Natural Resources of El Salvador (MARN) was created as a governing institution for environmental matters to ensure compliance with the Agreements, Conventions and Protocols of the United Nations endorsed by the Republic of El Salvador. The vision of this institution is “to direct an effective environmental management through policies and norms and facilitate the sustainable development of Salvadoran society.”

The environmental law in El Salvador was passed in 1998, while the national environment policy and benefits of natural resources (water, air, biodiversity, etc.) were passed in 2000. All of these became instruments for the public sector that defined a legal framework for environmental matters.

As a regional integrated organisation, the CCAD has formulated an environmental plan for 5 years (2005-2010) for the entire Central American region, which will incorporate the application and compliance of environmental legislation as a high-priority objective.

All projects must be submitted to the MARN for prior approval before construction begins. The request for approval must contain an environmental impact assessment (EIA), and the project is submitted to a public hearing process if the MARN deems that the environmental impact will be significant. The concerns expressed in public hearing are documented by the MARN, and they may require modifications in project design before final approval. If the concerns expressed at the public hearing are not properly addressed by the developer, project approval may be denied. In actual practice, several permits have been denied by the environmental authorities, but all clean energy projects have been approved. It must be observed, however, that most of the opposition to geothermal projects may not be channelled through official procedures, and may surface after the start of construction, even when the developer is in possession of all the necessary permits.

When a developer obtains a permit, he must submit an environmental bond guarantee to MARN that he will execute all the environmental mitigation/compensation measures that are stated in the permit. Failure to comply will result in MARN cashing the bond.

**Electricity.** The electricity sector suffered a profound reform in 1996, then subsequent, complementary reforms in 2003 and 2007.

Before 1996, the electricity sector was the sole business of the state-owned vertically integrated monopoly, Comision Ejecutiva Hidroelectrica del Rio Lempa (CEL). The 1996 reform defined an

open electricity market, with free access to the grid for anyone who complied with technical specifications. CEL was unbundled into 5 distribution companies, 4 generation companies, one transmission company, and the independent system operator. A regulatory agency, Superintendencia General de Electricidad y Telecomunicaciones (SIGET) was created to oversee both the electricity and telecommunications sectors. Electricity tariffs were based on wholesale spot-market price averages, estimated to be the marginal cost of electricity, plus use-of-grid charges for transmission and distribution. The 2003 reforms gave more power to SIGET, and the 2007 reforms define a market based on marginal variable cost plus capacity payment, not on price bids.

According to the Salvadoran Constitution, the subsurface is property of the State, which can award concessions to private entities for its exploitation. The office in charge of awarding concessions of geothermal areas for production of electricity is SIGET. In order to obtain a concession, the interested developer must apply to SIGET with a feasibility study and the approved environmental impact assessment document. SIGET then holds a public hearing for opposition to the project (separate from MARN), competing projects, and/or other parties interested in developing the resource. If there is no significant opposition or competing projects, SIGET holds a public bidding process to award the concession, and awards it to the highest bidder.

The developer's rights and obligations are specified in the concession contract. This contract specifies the area of the concession, installed capacity allowed for the power plant, the information that will be collected and given to SIGET during construction and operation, the time schedule for the project, and the rules for sustainable exploitation of the state-owned resource.

#### **4. ENVIRONMENTAL AND SOCIAL MANAGEMENT IN LAGEO**

In practice, the first people to do reconnaissance work in a new geothermal prospect are those in charge of environmental and social issues (before even the geologist set foot on site!). The first order of business is to establish an environmental and social baseline in the project area, and identify potential points of conflict for the early exploration phases. This involves holding discussions with local leaders and organisations, and compiling existing information on the socioeconomic status of the neighbouring communities. Local leaders are thus informed of the exploration program, and educated about the basics of geothermal development.

The EIA document submitted to MARN must contain the observations of the environmental and social teams, plus the baseline studies, and the impact of mitigation/compensation measures that the company deems necessary and adequate for the first stages of the project. At this time, LaGeo becomes involved only in small projects to assist local population, in order to demonstrate good will, but no long-term commitments are made until it is certain that a project will be developed, after the exploration/confirmation stage.

The social and environmental teams are in charge of internal follow-up and evaluation of LaGeo's compliance with the obligations acquired with both MARN and the local communities. Obligations acquired with SIGET are supervised by teams under the Projects and Production managers.

After the exploration/confirmation stage is completed and if it is feasible to develop an area economically, a development project will be defined, which will have its own, separate, EIA, permitting process, and discussion with neighbouring communities. At this stage, significantly more resources are committed to improve environmental and social conditions in the sphere of influence of the project. Typically, 2-3% of the project budget is set aside for these issues, though the amount committed depends on the conditions found in the baseline study of each field.

Geothermal projects in El Salvador are situated around volcanic areas with communities living in extreme poverty. There is widespread unemployment, and roughly half of the young men emigrate

North in search of better opportunities, even if it means to risk going illegally into the United States. Incomes are as low as \$6/day for a farmer/labourer. Social services, such as access to clean water and health and education services, are scarce. There is a very serious problem with delinquency, especially among gang members that are deported from the U.S. In areas around Berlin power plant, there are also very serious seismic and landslide risks, which the local population associate with geothermal development. The aim of the social programs and the environmental mitigation/compensation programs are often to help alleviate poverty and reduce the geological risk of neighbouring communities. This is seen in LaGeo as more than a legal obligation, a moral imperative, corporate social responsibility, and just good business practice.

## 5. SOCIAL AND ENVIRONMENTAL PROJECTS

The social and environmental projects associated with a large-scale geothermal development project are defined in the EIA in part, and also negotiated with the local communities. They can be quite varied, and target the physical, chemical, and biological environmental impacts, as well as socioeconomic and cultural aspects.

**Physical environment.** The construction of well pads, pipelines, access roads, and a power plant impacts the natural flow of rainwater, and can cause disturbances downhill from where the infrastructure is built (erosion, flooding, etc.). The design of the civil works must take these impacts into consideration, and measures to solve potential problems must be taken. In fact, LaGeo has assisted in construction of dam structures and slope stabilisation in areas where there is no geothermal infrastructure, in order to protect neighbouring communities from potential damage. The noise levels are a nuisance to neighbours, especially during drilling, well tests, and pipe blow-outs. Care must be taken in the project construction stage to build adequate sound barriers and mufflers to minimise the impact. All of LaGeo's projects include a reforestation component, that actually improves the environment around the wells and power plant over what is encountered before construction begins.

**Chemical environment.** The main impacts come from odours during well tests and power plant operation. The H<sub>2</sub>S levels are monitored to ensure they are held below acceptable levels, as defined by MARN. Well discharges are announced publicly days before, and programmed jointly with neighbours, when there are people living near the well. This gives people a chance to get away if they are bothered by the sound or odours. Other impacts come from possible brine or mud spills. These must be foreseen during the design stage, and there must be monitoring of contaminants to ensure compliance with legal and moral obligations. Adequate disposal of drilling mud and adequate reinjection infrastructure should ensure that all effluents are properly contained.

**Biological environment.** The impacts to the local flora and fauna come from cutting trees and reducing wildlife habitat to make way for infrastructure. However, as El Salvador has very little original forest cover left as a result of centuries of subsistence-level agriculture, geothermal projects can actually help improve conditions from what was found in the baseline study. Native species of trees have been planted along pipelines and around well pads and power plants. Where the ground was too hot for other species, and over filled mud sumps, eucalyptus was planted. There is now denser tree cover in the area of influence of the Ahuachapan and Berlin projects than there was ten years ago. The main threat to wildlife is the local population, who hunt species to extinction. In order to address this, an employee awareness program for wildlife conservation has been maintained for several years, and agreements have been worked out with MARN and the Zoology Foundation to construct and maintain a large animal shelter around the geothermal installations. This is becoming a small tourist attraction.

**Integration with communities.** If the relationship with local communities is not managed properly, the locals will see the geothermal developers as invaders who will exploit "their" subsurface for profit, give nothing in return to the community, and damage the environment. News of bad experiences with

one project, even one by another developer in a neighbouring country, will spread quickly, and spark resistance to all geothermal developments. In LaGeo, helping the local communities with their development is therefore seen not only as a fair and just action, but also as good business practice to ensure sustainability.

Initially, when LaGeo was created, projects with neighbours were mainly for assistance with minor community problems (paving parts of roads, supporting local sports teams, etc.). With time, work with the communities has become more focussed, and much more effective. The basis for the support programs has been the local's own development plan, where major problems are identified, and actions are planned to resolve these issues. LaGeo can contribute to the development of these areas by supporting these local plans. Small assistance projects are still carried out, but the main focus now is for deeper solutions for health and education programs, and self-sustaining productive projects. Because the needs are so many, the social assistance projects now number near one hundred and fifty around Ahuachapan and Berlin. The funds are taken from both the investment budget and the operating budget.

One example of a successful project in education is called "Window to the World". Children from neighbouring communities that have very limited access to education are provided with English language education to a basic level, and taught computer skills, including internet navigation. This opens young minds and gives new opportunities in a globalised world. As El Salvador has opted to open its economy to trade and commerce, these skills may prove useful for many young people in the near future. LaGeo provides the teachers, the computers that are taken out of the company's inventory, the physical space for the classroom, and the internet server (with filters).

An example of a successful productive project is the harvest of bananas in Ahuachapan. Some locals were invading LaGeo's lands in Ahuachapan, and started setting up makeshift cardboard houses and planting subsistence-level crops (corn and sorghum). This posed a threat to LaGeo's legal tenure of the land, and ensured that these people would continue living in extreme poverty conditions for many years. A negotiation committee was set up jointly with the local municipality, and a solution was found: LaGeo would keep legal tenure of the land; the locals would be allowed to plant and harvest non-subsistence level crops (bananas) on LaGeo's land at no additional cost, that would allow them to raise their quality of life in the future; condensate run-off would be used to irrigate the crops; the Government would provide an agricultural engineer to supervise the crops. The result was that thirteen families raised their standard of living from extreme poverty to non-poverty conditions. Their children can now attend school and not look for income elsewhere. The people in charge have learned how to manage a small business. And, finally, the Ahuachapan power plant is seen as a source of wealth for the neighbours, and not an invader.

## 6. CLEAN DEVELOPMENT MECHANISM

El Salvador has subscribed the UN Kyoto Protocol to reduce greenhouse gas emissions, and so the clean-energy projects within its borders that displace other, fossil-fuel projects, are candidates to be certified for emission reductions (CER's) within the framework of the Clean Development Mechanism (CDM) of the Kyoto Protocol. Industrialised countries seeking to reduce their emissions may meet their targets in part by financing clean energy projects in developing countries by purchasing CER's from these projects. Geothermal developments are natural candidates to sell CER's (1 CER = 1 ton of CO<sub>2</sub> avoided) to interested buyers, as the energy produced is both clean and stable.

In order to be certified, a project must undergo a fairly lengthy process. First, the national government must produce a baseline study of how the developing country's emissions will grow in the future, assuming a business-as-usual scenario. Then it must be proved that a clean energy plant will avoid a fossil-fuel-fired plant from being built, or at least will displace the burning of certain amounts of fossil fuels. This displacement is then measured in terms of CO<sub>2</sub> emissions displaced. For a project to be

eligible, it must be marginally economical, and the sale of CER's must bring it above a threshold IRR. If the project is economical above threshold on its own right, then it is deemed business-as-usual, and does not meet the Kyoto Protocol's "additionality" requirement. All this must be validated by independent auditors who are certified by the UN, and then the project must be registered in the UN, in order to be credited with a certain estimated amount of CER's per year, which can then be sold. Validation must be repeated every year, in order to certify that the underlying assumptions were correct.

LaGeo has one project certified - the 44-MW Berlin Third Unit - and another project - the 9.3-MW Berlin Binary Cycle - has been validated and is awaiting certification in the UN. Both projects are already contracted until 2012 (when the Kyoto Protocol ends), Berlin Third Unit to the Government of Holland, and Berlin Binary Cycle to the Government of Belgium. The sale of CER's adds about 3% to the IRR of a geothermal project in El Salvador.

Certification and yearly validation come with requirements that the project is environmentally benign beyond just emissions reductions, and that it is accepted by the community. A project that is rejected by the neighbours, or that pollutes the groundwater, will not be validated. In their contracts with LaGeo, the Governments of Holland and Belgium required that the social and environmental programs that were in place would continue, to which LaGeo responded with alacrity. It is, in fact, a way of rewarding good business practice to ensure its sustainability.

## 7. CONCLUSIONS

The environmental and social impacts of geothermal projects must not be overlooked, and indeed should be considered as an integral part of project design, in order to ensure that the facility can comply with legislation and is accepted by the neighbouring communities. This kind of development is seen in LaGeo as both a moral imperative and good business practice. The economic rewards of the Corporate Social Responsibility Policy are possible, but are not the driving force behind the policy.

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## LECTURE 4

# CORPORATE CULTURE AND HUMAN RESOURCE MANAGEMENT IN LAGEO

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### ABSTRACT

LaGeo made a transition from division of a government-owned monopoly to a for-profit, competitive company, while simultaneously reducing the number of personnel by 40%, and almost doubling production, between 1998 and 2000. Employees were allowed to define the corporate culture of the new organization, based on values. This corporate culture enabled the Company to retain and transfer talent and experience key to the development and growth of geothermal projects in a competitive electricity market.

## 1. INTRODUCTION

Any corporation dedicated to developing and operating geothermal resources must attract and preserve a highly specialised group of professionals in various areas of expertise, ranging from earth science, drilling engineering, mechanical engineering, electrical engineering, to general administration. The geothermal workplace requires joint efforts from different experts and, consequently, the processes and work atmosphere must encourage and facilitate teamwork. Decisions are often made by a team with a dose of uncertainty. The organisation must allow for discussion and dissent, so that the burden of responsibility is shared and not placed on a single decision maker. These points, along with others discussed further, make human resource management for a geothermal company somewhat special. This paper summarises how the corporate culture and human resource management in LaGeo are focussed to achieving the goals of geothermal development.

## 2. ORIGINS OF LAGEO

Early geothermal development in El Salvador was carried out by the Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL), the state-run electric utility company. The first exploration efforts were carried out in the late 1950's, and by 1963, there was an idea that El Salvador had potential to generate electricity from geothermal sources. The first deep wells were drilled in the late 1960's, and the first power plant, Ahuachapan, started operating in 1975. From this date until 1998, the geothermal fields were operated by one group of specialists, and the power plants by another, separate group. Both groups were a part of CEL, and worked with a culture that was part of both a government organisation and a monopoly. Electricity prices were set by political considerations, and by CEL's need for income. There was no competition, so efficiency was not paramount. Each group (field and plant) would blame system inefficiencies on the other group. In 1998, still under CEL, the

geothermal power plants and fields were joined under a single management, which forced scientists and engineers to work together. The total sum of personnel, of what was called Geothermal Division, was 450 including field, power plant, exploration, and chemistry/petrology lab. Accounting and administrative duties were centralised in CEL, and were not part of the Division. Available capacity in 1998 was 61 MW, and generation was 451 GWh in the year.

In 1999, in response to legislation that reformed the electricity sector, Geotermica Salvadoreña S.A. de C.V. was separated from CEL to form a company that would compete in the open electricity market against other hydro and thermal generators, under private sector legislation, although ownership of the shares and appointment of the Board of Directors was still retained by CEL. By late 1999, capacity in Berlin had been expanded by a new 56 MW condensing plant, available capacity was up to 107 MW, and generation in 1999 was 604 GWh. Personnel, including all areas of the former Geothermal Division, plus accounting, marketing, and administrative staff, numbered 275.

It can be observed from the information above that, in order to survive in a competitive market, the geothermal operation was forced to become much more efficient. This abrupt change caused a cultural shock in the organisation that was channelled positively by strategic planning.

### 3. STRATEGIC PLAN: VISION, MISSION, AND VALUES

The first efforts to elaborate a strategic plan for what was to become a geothermal spin-off company of CEL were done in late 1998, with the assistance of PREEICA, a project financed by Canadian international cooperation (CIDA). PREEICA provided consultants to assist CEL's personnel in creating the vision and the organisational structure of the new company. CEL management gave ample freedom to the geothermal staff to create the new geothermal company in the best way they could think of. The target date for separation was fixed at November 1, 1999. Elaboration of a full corporate philosophy took two additional sessions with the help of PREEICA, both held in 1999, with the participation of 28 employees from diverse hierarchical levels and areas and geographic locations.

The result was a clearer picture of how employees visualised the ideal Company. Brief Vision and Mission statements were approved by consensus, as well as a definition of seven corporate values – expressions of what behavioural patterns the Company would value and reward in its employees and suppliers. These values later became the real guiding principles for the entire organisation. Curiously enough, the values were what we perceived was lacking in modern society and in most workplaces, and this we would like to change. El Salvador had been (in fact still is) in an environmental crisis for several years and, thus, everyone agreed to conserve and protect the environment, especially since LaGeo would be using an environmentally benign source of energy. There is palpable injustice in Salvadorean society (as in most developing nations), and in local companies, so it was thought that employing fair directors and clear rules applied equally to everyone would be valuable assets. Good business practices that provided savings or additional income for the Company were things to be rewarded and cheered by everyone, not envied.

Other ideas that were brought into play were more standard for modern business planning: the hierarchical pyramid should be flattened, so lower level employees would have easier access to the top management; processes should be reviewed to make them simpler, clearer, and more agile; the Company should ensure that everyone had opportunities for development and growth in their area of specialisation; teamwork had to be encouraged and valued.

Of course, the plan included hard business targets for market share and return on investment, which focussed everyone's attention on their day-to-day goals, but in the end it was the "soft" parts of the plan – the values that touched people's aspirations – that had a bigger impact in the long term. It was observed that all businesses must work for efficiency and profit, but *how* this is done is just as important, and determines the sustainability of the efforts.

#### 4. BRINGING IDEAS DOWN TO EARTH

Though the initial strategic plan was full of idealistic fervour, a high level of expectations was raised in most employees when the plan was announced. The labour union was the first to oppose the plan, on the (political) grounds that it was a “trap” designed to get employees to work harder and get nothing in return. There were other experiences of idealistic business plans in other companies that only came down to messages posted on the wall, not to actual behaviour expected from administrators and directors. The top management had to prove that the plan was going to be taken seriously in all of its aspects: technical, financial, and human. Some clear measures had to be taken quickly so that everyone could see where the organisation was being conducted and confidence could be built.

One of the first measures to be adopted within the company was to put a limit on the “salary gap”. The salary gap was defined as the total compensation (salary plus benefits) of the highest-paid employee divided by the total compensation of the lowest-paid employee. This factor had to be no more than 15. In actual practice, it has never reached more than 12. This was important because it puts everyone in the company in the same situation. The only way that a top executive has to increase his own salary, is to improve everyone else’s. The limit of 15 was taken from several studies done in various countries proving that Latin America is the most unequal region in the world, and that the salary gap was the source of much social discontent. LaGeo, ideally, had to be a part of the solution, not part of the problem.

Another similar measure that has been very effective was to require that all benefits had to be offered to all employees. There could be no exclusive benefit packages offered to top managers, if the same could not be offered to everyone. Even personalised parking spaces were banned. Performance bonuses are defined as a result of the company’s performance, and offered to everyone as a share of the profits. Outstanding individual performance is rewarded on a case-by-case basis, often on a non-monetary basis.

Other ideas were also implemented which illustrate that work based on values was more fulfilling than work based solely on profit. For example, once a year, around the anniversary of the start of independent operations, LaGeo holds the “*Ausoles de Acero*” (literally “steel geysers”, from the nahuatl word *ausol*, or “noisy water”) ceremony, where a committee selects the individual that best exemplifies a given corporate value, from among five nominees. Individuals are selected from among LaGeo employees, or employees of suppliers or subcontractors. The winners are given a small “steel geyser” statuette, and a chance to address the entire company. The reasons for each nomination are published, and must be based on concrete, unquestionable evidence. Other activities have included movie forums to illustrate a certain value, guest speakers participate in discussions, employees get organized to do a specific task outside of the company (like clean a beach, or work with handicapped children), and many other examples. The objective is to get people to think about values and how to incorporate values into their work.

#### 5. PUTTING TOGETHER A SYSTEM

If the efforts mentioned above are not part of a system, which is itself a product of Company policy, they will eventually die away. Several documents have been produced to direct people as to what behaviour is expected of them.

The Code of Ethics provides general guideline of the standards of conduct expected of Directors and employees, and the procedures to deal with violations. There is an (elected) Ethics Committee that oversees the implementation of the Code of Ethics. This Code, comprising a “Harassment and Discrimination Policy” and an “Employment Equity Policy”, was developed and put to work.

All of these parts of the Integrated Management System, an ISO-inspired-but-not-certified system, document and regulate how the different parts of the Company should work together and with suppliers and clients to ensure right behaviours to achieve the objectives. The system itself, and the procedures outlined, must contain the observation of values, in order to be effective.

## 6. SPECIALISATION IN GEOTHERMAL

Because LaGeo produces energy only from geothermal sources, and because LaGeo's strategic plan considers expansion of capacity exclusively with clean, renewable resources, employees must be motivated not only by the workplace in general, but by geothermal science and technology specifically. Furthermore, long-term operational survival of the Company hinges on the ability of the staff to: (i) find geothermal resources, (ii) develop the resource from greenfield to a power plant, (iii) operate the resource sustainably, in accordance to contractual obligations with National authorities, and (iv) do all of the above efficiently, so that geothermal can compete in the electricity market against other energy sources.

In order to develop technical competencies as part of the Human Resources Competency System, it is very important that the personnel be educated to varying degrees in geothermal science and technology. In the past, there were four international schools of geothermal that offered opportunities for training: the International School of Geothermics at Pisa, Italy, the Geothermal Institute of the University of Auckland, New Zealand; the United Nations University, Geothermal Training Programme in Reykjavik, Iceland; and the Kyushu University through its Geothermal Research Centre at Fukuoka, Japan. For various reasons, the alternatives for Salvadorian scientists and engineers have narrowed over the years, and at the moment the only international school that holds its doors open is the UNU-GTP. In view of this reduction of opportunities for specialisation, and in order to support continued growth in geothermal in El Salvador and Central America, LaGeo opted to develop an in-house training programme, called DICITEG for its Spanish acronym (diploma course on geothermal science and technology).

The DICITEG is given by LaGeo employees that have been trained in one or more of the international schools, and also hold ample practical experience in the field they teach. There are four modules of the DICITEG that are imparted when needed. The first module covers general geothermal concepts and electricity markets, and is given to all personnel, regardless of background or hierarchical level within the Company. The other modules are more specialised. The detailed contents of DICITEG are shown in table 1.

Of course, there are still options for training abroad that are open to Salvadorians. The UNU-GTP Diploma course and M.Sc. programme offer the most in-depth specialized courses, but there is international cooperation offered for training in broader but related areas, which can then be adapted to the needs of geothermal. For example, there are opportunities for Diploma courses and M.Sc. degrees in environmental studies and renewable energies, and courses offered by manufacturers for power plant operation and maintenance, as well as new technologies. Many of these opportunities are offered to English speakers only, so LaGeo has been running English-language courses for interested employees.

In short, creating a stable base of motivated geothermal specialists who interact permanently with other administrative and operational staff requires a large effort to train employees in geothermal, but also the general work environment must be conducive to achieve the Company strategy. Without the latter, the former would not be possible.

TABLE 1: Syllabus for DICITEG

Level	Content	Directed to	No. of hours
<b>I</b>	<b>Introduction to geothermal energy</b> <ul style="list-style-type: none"> <li>▪ Basic concepts of geothermal energy</li> <li>▪ Geothermal power plant basic operation</li> <li>▪ El Salvador electric law framework</li> <li>▪ El Salvador environmental law framework</li> <li>▪ Safety and environmental integrated system (quality control)</li> <li>▪ Budget planning, accounting, and financial aspects</li> </ul>	All personnel	8
			8
			4
			4
			4
			4
<b>II</b>	<b>Geothermal resources</b> <ul style="list-style-type: none"> <li>▪ Geology of geothermal systems</li> <li>▪ Chemistry of fluids</li> <li>▪ Geothermal resource assessment</li> <li>▪ Database information systems</li> <li>▪ Geothermal exploration</li> <li>▪ Conceptual models</li> <li>▪ Special exploration</li> <li>▪ Risk assessment</li> </ul>	Laboratory and reservoir staff	24
			8
			8
			8
			24
			8
			16
			8
<b>III</b>	<b>Geothermal engineering</b> <ul style="list-style-type: none"> <li>▪ Well drilling</li> <li>▪ Gathering system</li> <li>▪ Geothermal project development</li> <li>▪ Geothermal power plant design</li> <li>▪ Chemical evolution</li> <li>▪ Financial aspects of geothermal projects</li> <li>▪ Well logging and field monitoring</li> <li>▪ Geothermal power plant efficiency analysis</li> <li>▪ Geothermal field management</li> <li>▪ Reservoir engineering</li> </ul>	Engineering and power plant staff	16
			8
			8
			16
			8
			8
			8
			8
			8
			8
<b>IV</b>	<b>Geothermal power plants</b> <ul style="list-style-type: none"> <li>▪ Geothermal power plant types</li> <li>▪ Thermal conversion efficiency</li> <li>▪ Input and auxiliary equipment</li> <li>▪ Turbine, condenser and ejector</li> <li>▪ Auxiliary equipment</li> <li>▪ Pumps and cooling towers</li> <li>▪ Generator and auxiliary equipment</li> <li>▪ Automatic control and instrumentation (DCS)</li> <li>▪ Substation and transmission lines</li> <li>▪ Power generation plant operation</li> <li>▪ Electric market operation in Central America</li> </ul>	Power plant and engineering staff	16
			4
			4
			8
			8
			8
			8
			8
			8
			8
			8
			4

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## LECTURE 5

# ECONOMICS AND FINANCING FOR GEOTHERMAL PROJECTS IN CENTRAL AMERICA

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### ABSTRACT

In Central America, geothermal power is cost-competitive with other sources of electricity. The major risk is in the exploration stage, and this is also the main difficulty in obtaining financing for a project. Once a prospect is proven, and steam is flowing out of wells, there are a wide variety of options for funding that can be used to finance a geothermal development.

### 1. INTRODUCTION

The present study covers economic aspects of geothermal power projects in Central America, assuming that the developer is apart from the State, and thus participates in an electricity market, and is subject to market rules, plus external regulations regarding permits and licenses. This will apply to geothermal power projects in practically all countries in Central America, with the exception of Costa Rica, where the electricity sector is controlled by the State.

The main point of this study is to demonstrate that, in a market driven electricity sector, the development of a project is the result of economical and technical decisions made by the developer, hence the project is not at the mercy of financial institutions. Banks and lending institutions are seen as key suppliers, like those that provide turbines or drilling services.

### 2. ECONOMICS OF GEOTHERMAL POWER PROJECTS IN CENTRAL AMERICA

In general, efficient single-flash geothermal power projects built today have capital costs of between \$2,500 and \$3,000/kW installed, for plants typically of 50 to 100 MW in size. Assuming a plant factor of 0.90, zero financial costs, and 15 years for depreciation, thus the capital cost translated to energy is between \$30 and \$40/MWh. Adding financial costs will increase this by about another \$15 to \$20/MWh, depending on the conditions of financing, and this still does not include operations and maintenance cost of between \$10 and \$12/MWh. In total the reported levelized cost of geothermally produced electricity for plants built today is typically around \$55 to \$65/MWh in most parts of the world. Figure 1 shows the Levelized Cost of energy (LCOE) versus capital cost. Figure 2 presents the LCOE versus debt percentage and Figure 3 shows the LCOE versus financial cost.

Central America does not have an abundance of natural resources to be utilised for generation of electricity. I.e. there are no significant deposits of coal, oil or gas, so fossil fuels must be imported from South America or other parts of the world at a relatively high cost. Hydroelectric potential is limited and also heavily dependent on seasonal rainfall. Additionally, the size, of individual power

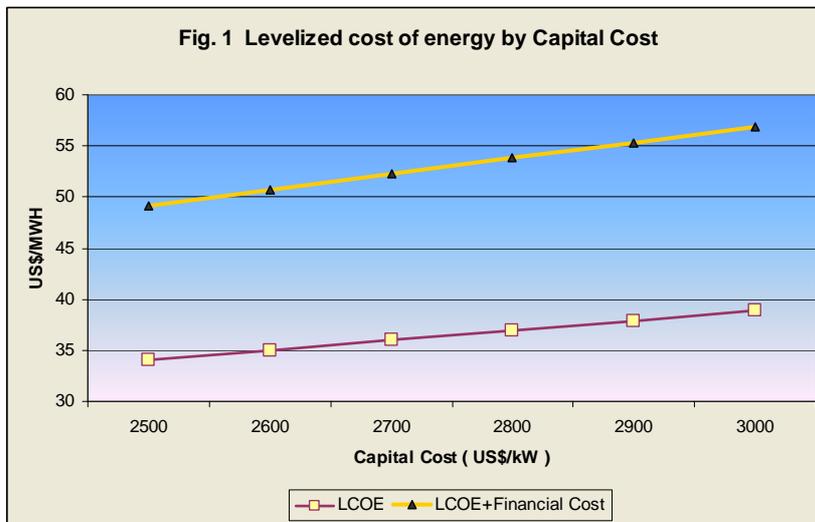


FIGURE 1: Levelized cost of energy by capital cost

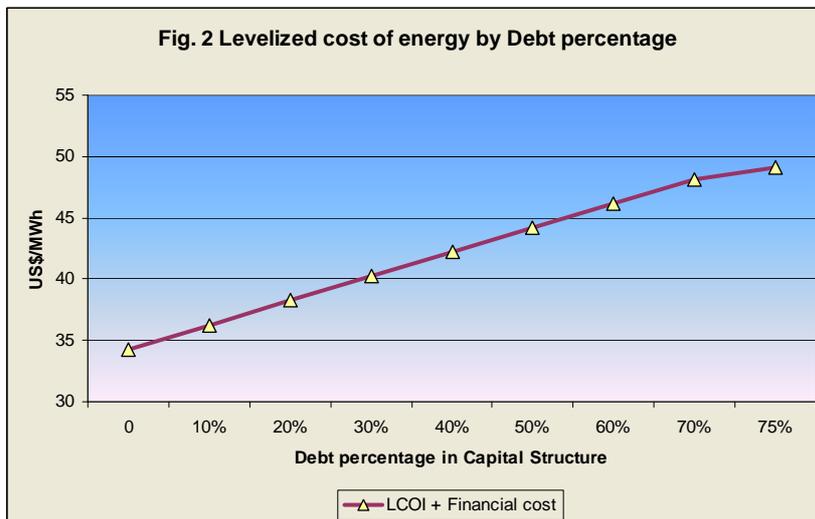


FIGURE 2: Levelized cost of energy by debt percentage

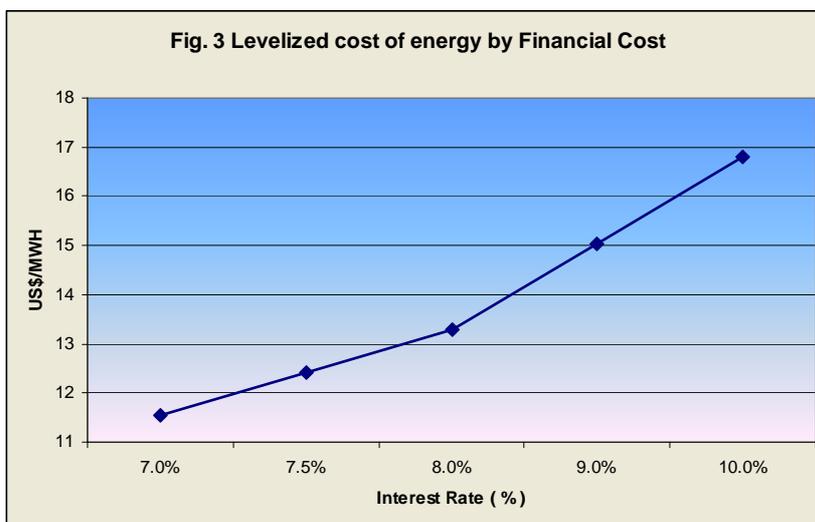


FIGURE 3: Levelized cost of energy by financial cost

plants, has depended on the needs of each country, and new capacity has been built for relatively small increases in demand, with no extra thought on economies of scale. For these reasons, wholesale prices of electricity throughout the region are around \$90/MWh. Geothermal, therefore, is cost competitive with other electricity sources, and has the added bonus of being clean, local, stable, and reliable. Because variable costs are very near zero, in marginal-cost market schemes geothermal plants are always dispatched as base-load, making geothermal a very tough competitor on local markets.

In this purely economic view, geothermal is expected to grow in Central America in the near future, and the limitations are resource availability and local human know-how, not the availability of funds. There is a wide variety of funding sources available today, especially because financial institutions are eager to finance clean energy projects worldwide.

The immediate economic risk in developing geothermal lies in the exploration stage. Once the potential of a field is proven and steam is gushing out of production wells, the alternatives for funding multiply, and lenders are eager to participate in the project.

### 3. FINANCING

When deciding to finance a geothermal project, the developer has several alternatives:

- a) Equity financing
  - i. Own equity,
  - ii. Equity partner through negotiation,
  - iii. Equity partner through the stock exchange.
- b) Bank (loan) financing
  - i. Private banks,
  - ii. Multilateral institutions.
- c) Debenture through the stock exchange.

These alternatives are not mutually exclusive: a project can be (and usually is) financed through various means.

**Equity financing.** Equity financing must be used to some extent in practically every project, usually between 20 and 50%. It is mostly used for the exploration stage of a project, as the developer risks his own money on an indirect assessment of resource potential. Equity can come from a developer's own cash flows, especially when there are other projects that are producing and are already paid for. Equity partners can be obtained through negotiation or through the stock exchange. Partners obtained through negotiation will usually require an active participation in the administration of the project, and thus will be willing to take greater risks in exchange for larger returns, whereas equity partners incorporated through the stock exchange will be more passive, and rely more on the developer's expertise. Typically, passive partners will be more risk-averse than active partners.

All equity partners will require a larger return on investment for their risk than what a bank would require, as they are not guaranteed a return. It is therefore wise to limit the equity investment, though it may be difficult to obtain anything else for the exploration stages. Developers should be prepared to finance 100% of the exploration costs with their own equity.

**Bank financing.** Banks, on the other hand, are guaranteed repayment through collateral and rights to the project's cash flows. For these reasons, they are usually more demanding of the power purchase contracts and other agreements with suppliers than equity partners, and will try to limit their exposure through standardised contracts.

The developer should never lose sight, however, that once he has invested his own equity and owns producing wells, he has a wide choice of lending institutions, and can select the one that offers the best conditions.

Private banks are usually more agile than multilaterals, and the negotiations for a loan agreement for a geothermal project can take less than six months. The loan conditions (interest, payment period, grace period) are typically slightly less favourable for the developer in dollar terms than those of multilateral banks, but they do take less time to negotiate, and are normally more flexible. Private banks are often limited in the amount they can lend, so often they can provide financing jointly with a multilateral bank.

Multilateral lending institutions are much larger and more bureaucratic than private banks. They respond to a mandate to promote development in a region, and therefore have other requirements (often affecting public policy) on their loans additional to guarantees for repayment. Development banks require a very long period to approve a loan, normally more than one year, but typically offer more favourable terms on their loans, and can lend larger sums. Multilaterals will often require the project to contract third-party supervision to report to both the developer and the bank about the progress of the project.

It must always be remembered that it is the bank's business to lend money, and ensure that the money will be repaid. Even in countries with high credit risks, multilaterals have mandate to promote development projects, nowadays, specifically those that use clean energy sources. Although the developer can sometimes feel that the banks are in control, it is in the bank's interest to approve loans, just as it is for drilling contractors to drill wells, or for equipment manufacturers to sell turbines.

**Financing through the stock exchange.** Debentures through bonds in the stock exchange can also be a very interesting and flexible way of financing projects. Though the interest rates and terms will typically be very similar to a bank loan, the form of repayment can be more flexible, and repayment itself can be done through another debenture, if the project is proven to be firm over several years of operation. The guarantees required are also more flexible than those required for a bank loan. However, a bond issue in the stock exchange requires more time than a bank loan negotiation, and the requirements for a publicly traded company are likewise more stringent than for a private project company.

Like with bank financing, it may not be possible to structure debenture financing for the exploration stage of a project, as the risks may be deemed too high for stock exchange approval.

In Central America, all of the above mentioned financing options are used to some extent, by different developers. Typically, more than one financing mechanism is used for each project, but some of the developer's equity is always required, especially in the exploration stages.

#### 4. CARBON CREDITS

The current interest to reduce emissions of CO<sub>2</sub> worldwide gives a new boost for geothermal developments, and can be considered an additional source of revenues for a new geothermal project that can help pass the hurdle rate for IRR. There are currently three geothermal projects in Central America that are certified to emit certificates of emission reduction (CER's): San Jacinto Tizate, in Nicaragua; and Berlín Units III and IV in El Salvador.

The Clean Development Mechanism (CDM), defined under the UN Kyoto Protocol, allows countries that commit to reduce CO<sub>2</sub> emissions to purchase CER's from "clean" certified projects in developing countries that have signed the Kyoto Protocol. For a project to be certified, it must contribute to reduce emissions below the country's "baseline". One CER is awarded for each ton of CO<sub>2</sub> that the project displaces. For example, a geothermal project that displaces a bunker-fired thermal plant will be allowed a number of CER's each year equivalent to what the thermal plant would have produced in that year, but did not because the geothermal plant generated instead. Each CER can then be sold in the international carbon market ([www.pointcarbon.com](http://www.pointcarbon.com)). Prices for CER's in the spot market can be very volatile, but contracts can be made to reduce volatility. In all, certification can add roughly 5 to 7% of revenues to a geothermal project, without significant additional cost. This can have an impact of between 1 and 2% on IRR.

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