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LaGeo S.A. de C.V.

GEOTHERMAL ACTIVITY AND DEVELOPMENT IN EL SALVADOR – PRODUCING AND DEVELOPING

Julio Guidos and Jorge Burgos
LaGeo S.A. de C.V.
15 Av. Sur, Col. Utila, Santa Tecla
EL SALVADOR
jguidos@lageo.com.sv, jburgos@lageo.com.sv

ABSTRACT

The exploration of geothermal resources in El Salvador began in the mid 1960s with the aid of the United Nations. Geothermal reconnaissance in the country provided 18 areas classified as low- and high-enthalpy areas. Technical studies were focused more on power generation. The geothermal energy production in El Salvador dates back to 1975, with the first 30 MW Unit in Ahuachapán and has been one of the main sources of electricity in the country, supplying up to 41% of the national electricity demand in 1981. Since 1996, Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL), the National Electric Utility Company, has embarked on projects to recover and expand geothermal electricity generation, all in the midst of wholesale reform of the electricity legislation and regulation. Geothermal generation now competes favorably with other energy sources in an open market. Today, there are two geothermal fields in operation: Ahuachapán and Berlin with an installed capacity of 95 MW and 109 MW, respectively. Geothermal power production has increased from 400 GWh in 1995 to 1293 GWh in 2007. The geothermal resources provide 25% of the electricity needs of the country. The country is in the process of developing geothermal energy projects in the areas of San Vicente and Chinameca, where drilling is being undertaken to confirm the resource. Exploitation is scheduled to continue in 2012 in San Vicente and currently taking place in Chinameca, where temperatures of about 250 °C and 230°C respectively have been measured in the recently drilled wells.

1. INTRODUCTION

The main use of geothermal energy in El Salvador is power generation. Although there is some potential for direct use to dry grains and fruit, none is of significant economic value. Geothermal electrical power, on the other hand, has competed successfully in the local and regional markets for the last few years, and in fact, its use has increased from 400 GWh in 1995 to 1,293 GWh in 2007 y 1,460 GWh in 2011.

The geothermal energy production in El Salvador dates back to 1975, when the operation of the first 30 MW unit in Ahuachapán field started. At present, there are two geothermal fields that have operating power plants: Ahuachapán and Berlín, both owned and operated by LaGeo, a spinoff privatized company of the government electric utility (CEL) and now jointly owned by both CEL and Enel Green Power of Italy.

The installed capacity is 95 MW in the Ahuachapán double-flash power plant, and in the 109 MW Berlín single-flash facility with bottoming cycle. In addition, two other fields (San Vicente and Chinameca) have been awarded in concession to San Vicente 7, Inc., 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.

Since 1996, El Salvador has adopted new electricity legislation aimed to open the market and introduce competition, so now prices for kWh are set by the process of supply and demand, rather than by executive decree. Several new organizations have been created to control and regulate the power market, which is becoming very strong and has a dynamic role in the national economy.

2. GEOTHERMAL RESOURCES IN EL SALVADOR

Since 1954, when El Salvador first began its geothermal exploration, four priority sites have been identified for their geothermal power potential. These are (from west to east as depicted in Figure 1: Ahuachapán, San Vicente, Berlín and Chinameca.

Estimates from the IILA indicate that there is a total of 644 MWe (2009) of geothermal power potential in El Salvador. The two main geothermal fields are at Berlín, with an installed capacity of 109 MW, and Ahuachapán, with an installed capacity of 95 MW.

The other three areas continue to be explored, but are not yet generating any capacity. In this paper, the focus will only be on one of the two main fields.

El Salvador, the smallest of the five Central American countries, having an area of 21,040 km^2 and a population of 6.2 million (2,012), is the largest producer of geothermal energy in the region. In fact, it was the first Central American country to construct and utilize geothermal power plants.

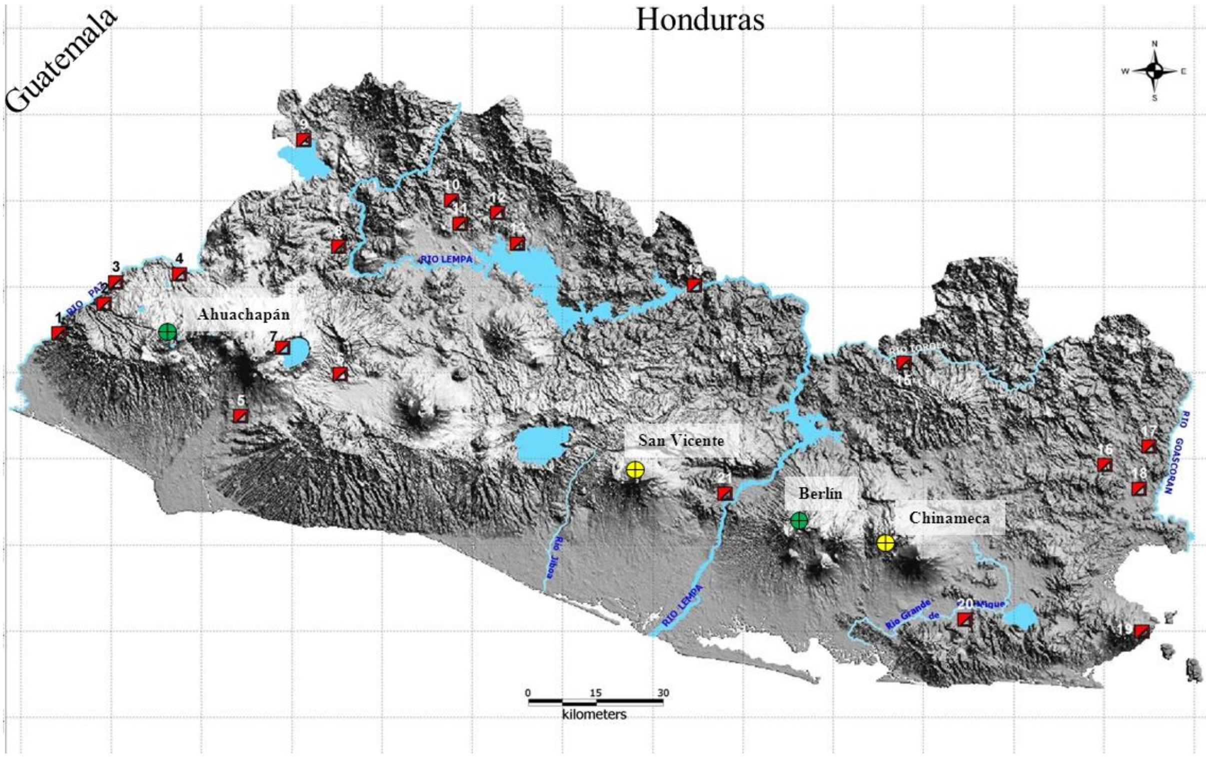

FIGURE 1: Geothermal resources in El Salvador

El Salvador, which is commonly called Land of Volcanoes, is characterized by major hydrothermal areas, hot springs and fumaroles. Earthquakes and other seismic activities occur frequently, some with devastating consequences. Exploration for geothermal potential in El Salvador began 50 years ago, in 1954, and continued extensively into the 1960s and 1970s. However, from 1980-1992, most geothermal exploration was suspended, due to a continued civil war which disrupted the national economy, channeling most resources toward military spending and away from social services, and resulting in a near collapse of the tax system. To make matters worse, this socio-political instability weakened the country's ability to secure development loans and foreign investment. Despite these circumstances, El Salvador has been able to develop a geothermal energy industry which can serve as a model for many developing countries.

IILA 2009 report estimated that El Salvador has a geothermal power potential of over 644 MW. Today, over 26% of El Salvador's electricity output is from geothermal energy, representing almost 1,421 GWh of the annual energy produced.

3. GEOTHERMAL DEVELOPMENT

The exploration of geothermal resources in El Salvador began in the mid 1960s with the aid of the United Nations. The geothermal reconnaissance of the country provided 18 areas classified as lowland high-enthalpy areas. Five of these areas were investigated: Ahuachapán (exploratory well AH-1 1200 m deep), Chipilapa (exploratory well CH-1 900 m deep), Parras Lempa (exploratory well PL-1 940 m deep), Berlín (exploratory well TR-1 1450 m deep) and Santa Rosa de Lima in the eastern part of El Salvador.

Temperatures found during the deep exploration were: a) 230°C in Ahuachapán, b) 300°C in Berlín and c) several resources below 200°C, all along the volcanic chain. Depths range from 800 m in the shallow areas of Ahuachapán to about 2,800 m in Berlín.

Geothermal energy production in El Salvador dates back to 1975, when the operation of the first 30 MW unit in Ahuachapán field started. At present, there are two geothermal fields that have operating power plants: Ahuachapán and Berlín, both owned and operated by LaGeo. The second geothermal field, Berlín, started production in 1992 with two back-pressure units of 5 MW each. In 1999, the condensing units 1 and 2 were commissioned. At present, the total installed capacity is 95 MW in Ahuachapán double-flash power plant, and 109 MW in Berlín single flash facility with one binary cycle unit. Figures 2 and 3 show the development history of the two fields.

Ahuachapán was the first geothermal field in El Salvador to be developed for commercial electricity generation. The motivation for this exploration was the 'abundance of hot springs, hot wells, fumaroles and other manifestations of hydrothermal activity (Partida et al., 1997) in the southwestern volcanic belt of El Salvador, where Ahuachapán lies.

In 1966, with assistance from the United Nations Development Programme, the El Salvador Government identified the Ahuachapán region as a priority area for geothermal development. Well AH-1 was drilled in 1968. It was a water-dominant reservoir (Rodriguez, 2003) with a depth between 600m and 1500m, and proved to be feasible for commercial exploitation. The Ahuachapán Geothermal Project was then launched in 1972 with funding from the World Bank. The first single-flash unit of 30MWe came online in Ahuachapán in 1975. In 1976, a second 30MWe single-flash unit was added, thereby doubling the generating capacity. In 1981 a third unit, this time double-flash, came online, bringing the total capacity to 95MWe.

During the 1980s, the Ahuachapán geothermal field was severely overworked. In 1981, 41% of El Salvador's electricity demand was met by geothermal production, a peak which has never since been reached. This overuse occurred primarily because transmission lines from hydroelectric fields in the

North of El Salvador were continually damaged by guerrilla groups. This placed a prolonged, heightened demand for electricity from the geothermal field at Ahuachapán to make up for the reduced hydro output from the North. In addition, almost one third of the waste liquid from the Ahuachapán plant was being discharged into the Pacific Ocean, instead of being reinjected to the reservoir source. The resulting decline in wellhead pressures and steam deliverability caused the power output to drop from 95MWe in 1985, to less than half its capacity – 45MWe – by 1994. This pressure declined due to over exploitation is showed in Figure 2.

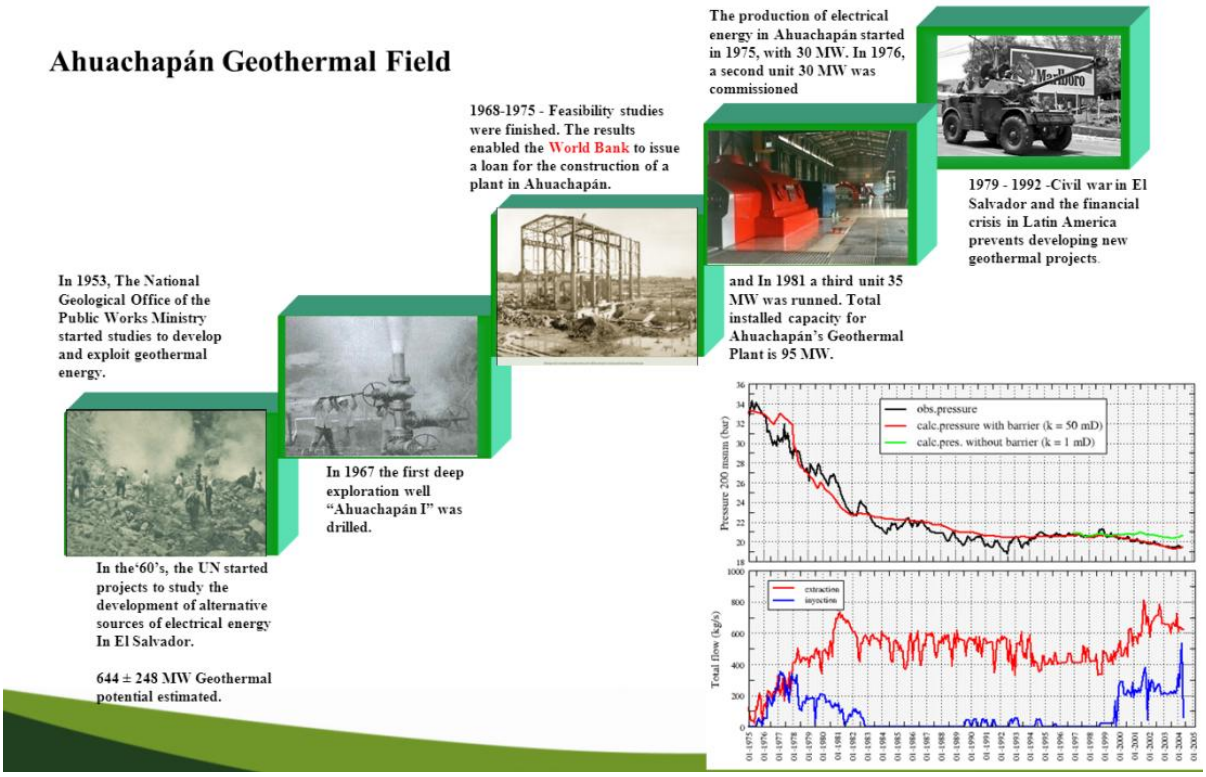

FIGURE 2: El Salvador geothermal development history, Ahuachapán geothermal field

In 1996, a US $50 million project, the Ahuachapán Stabilizaion and Rehabilitation Project, funded by the Inter-American Development Bank (IADB) was launched. The ultimate goal of the project was to "modernize the power plant while ensuring long-term production sustainability". It had four major components:

a) Drilling ten new production wells to the South of the production area, closer to the heat source and the recharge area.
b) Building a pipeline to inject brine into existing wells at Chipilapa, which is connected to the Ahuachapán reservoir. The goal is to reinject all waste brine into existing wells.
c) Constructing the gathering system from the new wells to the power plant and to injection wells.
d) Refurbishing some of the electrical and mechanical equipment in the power plant. This includes modifying turbogenerators to improve efficiency, and installing a fully computerized operating system.

Geothermal exploration in Berlín began in the 1960s by the United Nations, the Government of El Salvador, and the national electric utility company, Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL). During exploration, six wells were drilled to depths between 1,400m and 2,300 m. However, development of the Berlín site was soon stopped, despite finding temperatures up to 230°C, due to low permeability. During the early 1970s, the focus was shifted to Ahuachapán, which proved at the time to be more commercially exploitable.

In the late 1970s and early 1980s, five more exploratory wells were drilled to depths between 2,000 and 2,380m. All of the wells proved to be productive, with temperatures of 300°C, and estimated potential of 5-11MW each. However, the El Salvador civil conflict which spanned the rest of the 1980s decade, coupled with the overall financial crisis that Latin America faced during that time, interrupted all new power projects by the CEL.

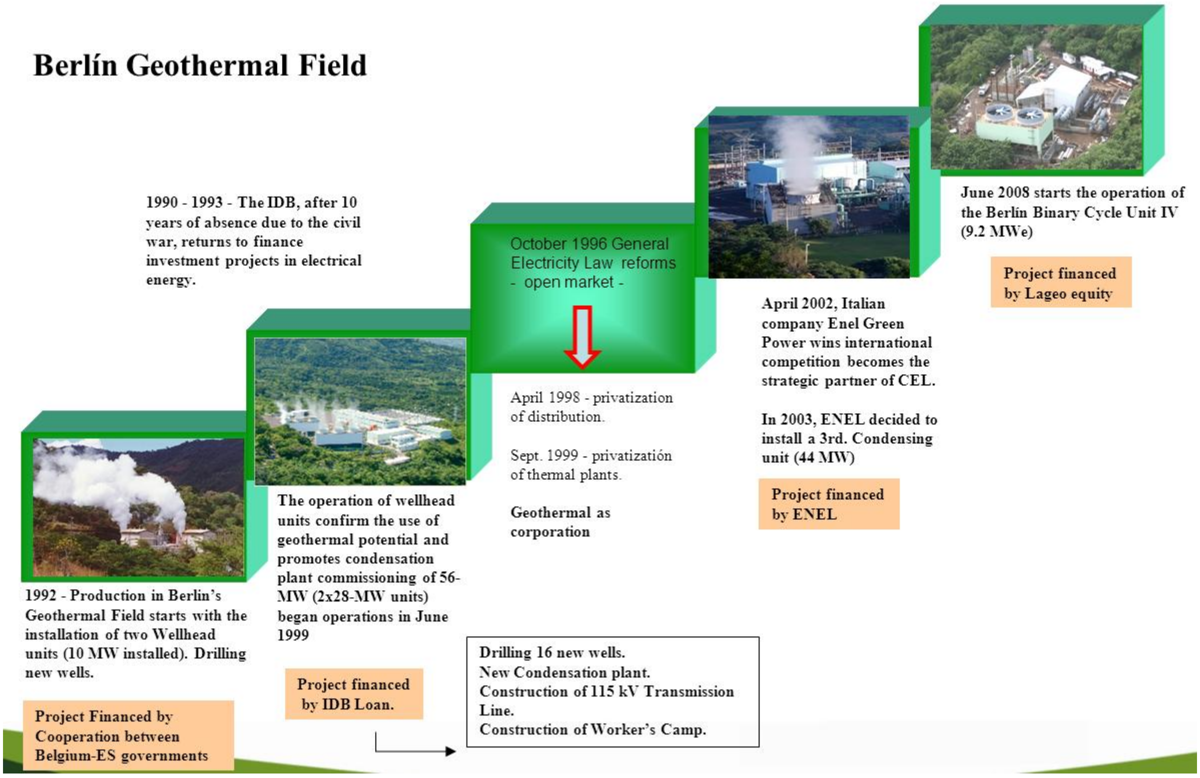

FIGURE 3: El Salvador geothermal development history, Berlín geothermal field

In 1992, however, at the end of the civil war, geothermal development recommenced with the installation of two 5MW plants at Berlín. Funding assistance was provided by the governments of France and Belgium. By 1993, the electricity demand in El Salvador was growing at a rapid annual rate of 12%, hence CEL decided to expand its power generating capacity to meet the growing demand. In 1996, CEL secured financing from the InterAmerican Development Bank for a 56MW (two 28MW units) condensing facility at Berlín. This plant was completed on July 10, 1999. Reservoir depths at the new facility are between 1,950m and 2,300m, with the highest temperature of 305°C found.

Five major components were identified as being integral to the 56MW Berlín plant project:

1) Construction of the power plant;
2) Drilling of 18 new production and injection wells, along with access roads;
3) Installation of 16 km of pipelines for the fluid gathering system;
4) Putting up of a 7 km long 115-kV transmission line to connect with El Salvador's national grid;
5) Creation of a workers' housing.

3.1 Implemented projects (1995-2008)

3.1.1 Ahuachapán geothermal field

There are three condensing units installed in Ahuachapán: two 30 MW single-flash units and one 35 MW double-flash unit. The Ex-post conditions in the operation of Ahuachapán power plant after the execution of new projects were: a) maximum instant power production of 85 MW, b) one single-flash unit running with the double-flash unit and c) the separated water from the field totally injected into the Chipilapa area. In August 2004, the canal to the sea was destroyed and two 6 km long pipelines were built to Chipilapa and reinjection of the brine started by a pumping station. Figure 4 shows the main projects executed in Ahuachapán during period 1995-2008.

Item	Project	Program	Target	Period	Power Plant Status after the project
1	Stabilization Ahuachapán	Addition of 20 MW	20 MW	1995 -1999	65 MW
		Reinjection of the Brine	50% Brine		50% Reinjection & 50% to tha ocean
2	Total re-injectión Ahuachapán	Reinjection 500 l/s Brine	560 l/s	2002-2004	100% Brine reinjection
3	Optimization Ahuachapán	Addition of 25 MW	20 MW	2003-2008	Production 85 MW Reinjection capacity 650 l/s
4					

FIGURE 4: Main projects implemented in Ahuachapán (1995-2008)

Figure 5 shows the pumping station system and Figure 6 the decommissioning of the canal to the sea.

FIGURE 5: Pumping station for brine injection in Ahuachapán

The generation at Ahuachapán has been stable and growing steady over the last five to six years, thus making the stabilization project a success.

FIGURE 6: Decommissioning of the canal to the sea in August 2004

3.1.2 Berlín geothermal field

There are three condensing units installed in Berlín: two 28 MW single-flash units and one 44 MW single-flash unit, and one 9.2 MW binary unit. The ex-post conditions in the operation of the Berlín power plant before the execution of the projects were: a) maximum instant power production of 9 MW, b) two back-pressure units, and c) the separated water from the field being reinjected to the northern part of the field. Figure 7 shows the main projects executed in Berlín.

Item	Project	Program	Target	Period	Power Plant Status after the project
1	Firts Condensing Units	Addition of 56 MW	56 MW	1995 -1999	56 MW
		Reinjection of the Brine	100% Reinjection		100% Reinjection
2	Third Condensing Unit	Addition of 44 MW	44 MW	2002 -2007	44 MW
		Reinjection of the Brine	100% Reinjection		100% Reinjection
3	Binary Unit	Addition of 9.2 MW	9.2 MW	2005-2008	9.2 MW
4	Total re-injectión Berlín	Reinjection 220 l/s Brine	220 l/s	2005-2008	Injection a high pressure and temperature

FIGURE 7: Main projects implemented in Berlín (1995-2008)

The ex-post conditions in the operation of Berlín power plant after the execution of the projects were: a) maximum instant power production of 100 MW and b) reinjection of the brine to the northern and eastern parts of the field. Figures 8 and 9 show the binary plant and the pumping station in TR-1 pad.

FIGURE 8: Binary plant in Berlín

FIGURE 9: Pumping station in well pad TR-1

3.1.3 Other geothermal areas

San Vicente & Chinameca

San Vicente is located in Central El Salvador, Chinameca, further to the east. Both sites have commercial geothermal potential. The potential of each of these areas is estimated at 50 MWe. In May 2001, a concession agreement was awarded to a private company, specifying the development of a 50MW geothermal power plant at each of these fields. Tables 1 and 2 show the main result obtained from the exploratory wells drilled in San Vicente and Chinameca fields.

TABLE 1: Temperature and depth of drilled wells in San Vicente field

Well	Type	T (°C)	Depth (m)
SV-1	Vertical	250	1346.5
SV-1A	Directional	240	2539.0
SV-2A	Directional	150	1331.0
SV-3	Vertical	91	853.25

TABLE 2: Temperature and depth of drilled wells in Chinameca field

Well	Type	T (°C)	Depth (m)
CHI-3	Vertical	229	1729
CHI-3A	Directional	234	1720
CHI-3B	Directional	237	1739
CHI-4 st	Directional	197	2000

4. FUTURE PROJECTS

For the next five years, the projects that LaGeo will work on are: 28 MW Unit 5 for Berlín, 5-9 MW repowering of Unit 2 of Ahuachapán, 50 MW Chinameca development, 5–9 MW binary plant for Berlín and feasibility studies for low-enthalpy areas.

5. FACTORS THAT IMPACT THE COST AND SUCCESS OF GEOTHERMAL DEVELOPMENT IN EL SALVADOR

1) Subsurface;
2) Surface;
3) Engineering.

5.1 Subsurface factors

- *Depth of resource:*
  The resources for shallow depth require less drilling length, however, they are usually of moderate temperature (<200 C).
- *Temperature:*
  The resources of high temperature (> 200 C) represent more volume of energy and fewer wells , however, represent longer drilling and problems with fluid chemistry.
- *Type of resource (steam, two phase or liquid):*
  Steam fields require less investment due to lack of separation equipment (two phases) or pumping (liquid) system. However, most of the fields are in two-phase operation.
- *Geothermal fluid chemistry:*
  Resources with fluids of high salinity, silica concentration, high acidity or high gas require special treatment that adds costs to the design, construction and operation of geothermal facilities.
- *Permeability of resource:*
  Resources with high permeability represent higher productivity (injectivity) and hence, fewer wells will be needed; however this requires a special methodology to define the geological structures which are permeable.

5.2 Surface factors

- *Weather conditions:*
  Dry bulb low temperature equipment allows better cooling system, thereby reducing the cost of drilling and equipment to meet a goal of efficiency in energy conversion.
- *Topography:*
  The difficult terrain increases the cost of civil works and the laying of pipes (pressure losses increase) and transmission lines of high temperature.
- *Environmental limitations:*
  Such as proximity to inhabited areas, protected areas, water aquifer (surface or underground) and expensive engineering solutions.

5.3 Engineering factors

- *Capacity of Facilities:*
  All types of installation follow the scale economy, greater capacity, lower cost per unit of generation.
- *Installation technology:*
  The technology used depends on the characteristics of the fluids and the variation of these characteristics over time. A poor choice of technology can be disastrous for the project.
- *Proximity to existing transmission lines:* The economics of geothermal development for purposes of generating electricity dependent on the demand will be satisfied. The closer you are to the transmission network, the costs in this area will be lower.

6. BARRIERS TO THE DEVELOPMENT OF GEOTHERMAL RESOURCES IN EL SALVADOR

6.1 Risk

This type of project has a high cost of research and risk, as the resource to be found in the depths of the earth by means of surface studies and drilling wells. This implies a high risk for developers and investors and it becomes difficult for private developers because they require a high initial investment, mainly in the area of potential exploration sites.

Identify and mitigate risks mean a costly upfront investment in time and money which ultimately makes geothermal energy in a difficult position of competitiveness. Problems on competitiveness are accentuated if the fiscal and regulatory framework of the country does not help in mitigating the risk. There are six stages of developing a geothermal project: 1) Recognition, 2) Feasibility, 3) Feasibility of resource use, 4) Development 5) Commercial Exploitation and 6) Abandonment. The investment risk changes as the execution of each stage advances (Figure 10).

6.2 Delay in approval of concessions and EIAs

The major difficulty of this type of projects is obtaining concessions and EIA approvals. This results in a delay in developing such projects. Typically, this increases the costs of implementation, and may limit the opportunity for undertaking the work.

Usually, difficulties in obtaining a response from the institutions have been experienced.. Despite the negative impacts of fossil fuels and greenhouse gases, gaseous fuels and import of non-native, thermal projects face environmental paperwork easier than renewable projects. In El Salvador, this occurs because many institutions such as the MARN do not have departments that specialize in renewable energy projects.

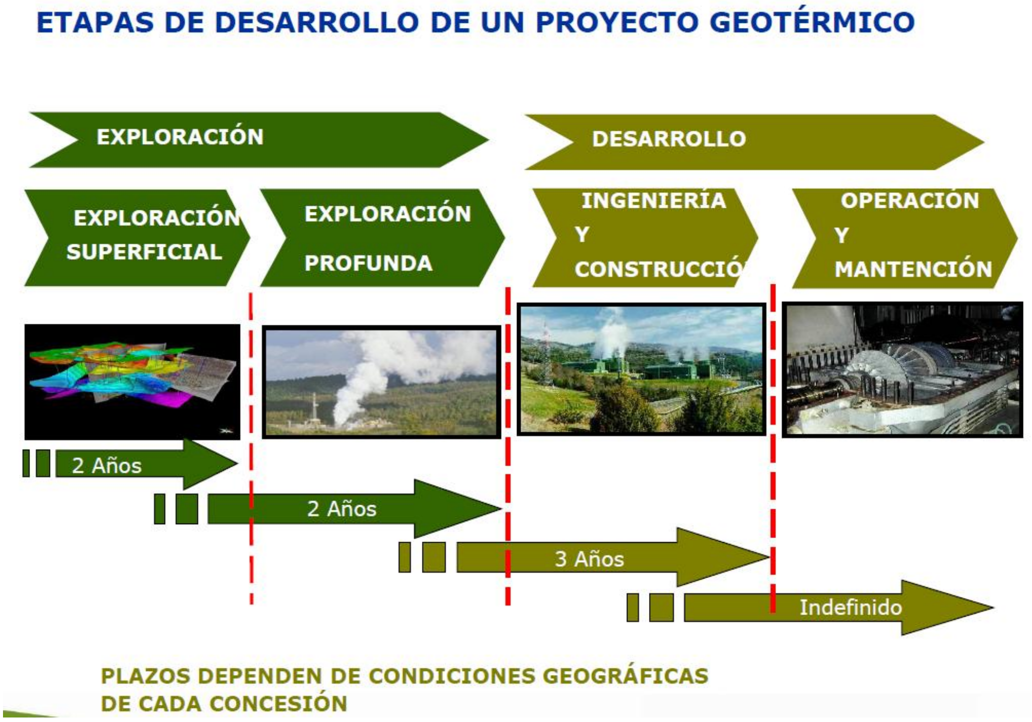

FIGURE 10: Stages of geothermal exploration and development

Figure 11 shows the phases of a 40 MW geothermal project and the execution times of each of the activities involved.

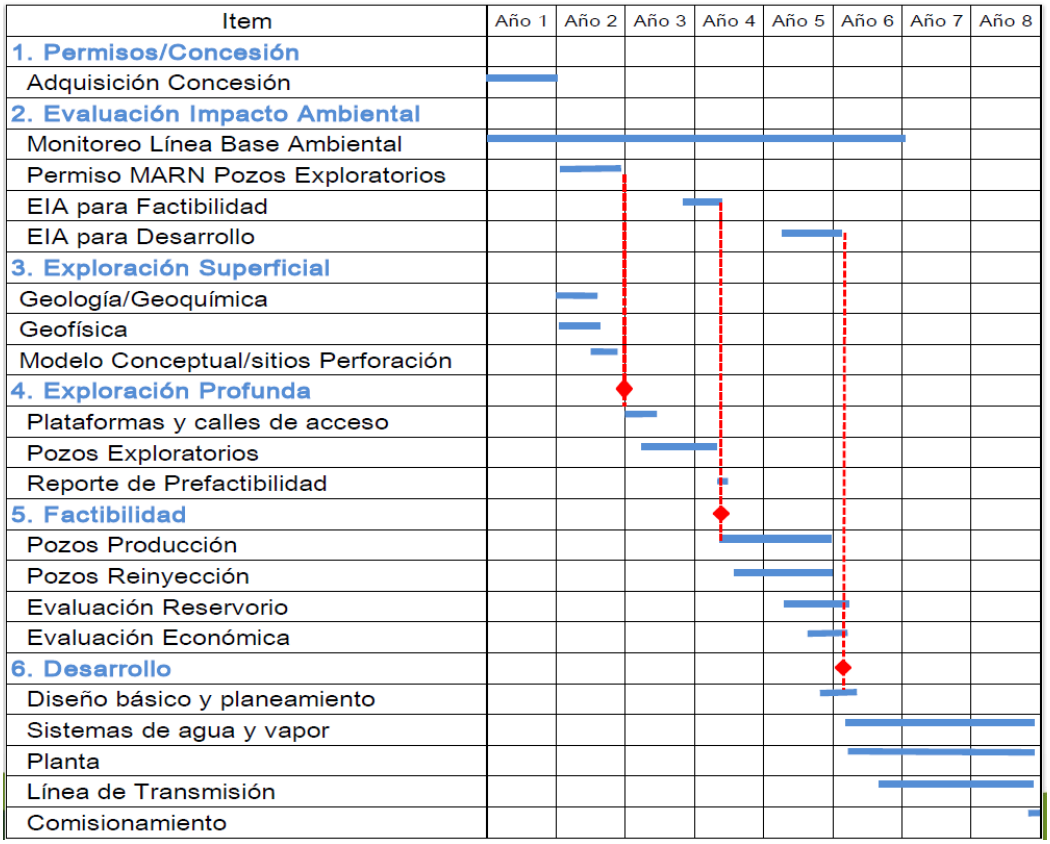

FIGURE 11: The phases of a 40 MW geothermal project

6.3 Lack of incentives

Ongoing projects have not been supported by the Fiscal Incentives Act, because they are larger than 20 MW and much of the benefits do not apply for this size of project. VAT on real state production (land, wells, etc.) is not deductible from sales. Exploration cost is not deductible as risk from taxes. Municipal taxes are not uniform.

6.4 Opposition of community

The opposition to the development of geothermal projects is closely associated with the opposition of mines, and environmental groups by the negative impact that may occur to the environment. This requires an arduous negotiation with the communities. However, well designed and managed geothermal projects have little impact on the environment.

7. CONCLUSIONS

Over the past fifty years, El Salvador has developed its geothermal energy industry into a critical part of the country's economy and electricity portfolio. Today, almost 26% of electricity consumption in El Salvador is from geothermal resources. For other developing countries seeking to develop a geothermal industry, there are several key lessons to be learned from the experience of El Salvador.
First, there must be a national objective for geothermal resource development. In El Salvador, the government found it prudent to make geothermal development a priority because it proved to be a cheap source of energy, it could help with efforts to improve the investment scenario and increase electrification, and it is a reliable, indigenous source of power.

Second, the power sector should be structured to allow private sector's participation in the development of the industry. A key contributor to the development of the sector in the past few years was the reform of the power sector to allow open competition among the different power sources: hydro, thermal, and geothermal. At the same time, government involvement, particularly in the feasibility and exploratory phases, is critical since private companies are taking on the high up front costs associated with these phases. In the case of El Salvador, the role of government was the key in securing funding from development banks and friendly organization to exploit geothermal resources.
The combination of El Salvador's national objectives and the deregulation of the sector have resulted in geothermal energy becoming a competitive energy source for generation of electricity. The future of the geothermal energy sector looks bright, with several new projects and expansions of existing plants in the pipeline. El Salvador is an example of success among developing countries.

An interesting observation is that the development of geothermal in El Salvador did not rest on the argument of sustainability. The motives for exploration, particularly in the last five years, were profits, and not clean energy. The government wanted the lowest cost energy-generating source, and geothermal met that requirement.

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