The Geothermal Energy Industry of El Salvador

by

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Abstract

El Salvador lies in a region of frequent volcanic activity, where geothermal resources abound. It is the smallest Central American country, but the largest producer of geothermally-generated power. Since exploration first began in 1954, El Salvador has developed its geothermal energy industry into a critical component of the national economy. Today, 24% of the electricity generated in El Salvador is from geothermal resources.

This paper examines the history and development of El Salvador's geothermal energy industry, focusing on the technical, socio-political, economic and environmental challenges the nation faced, and highlighting the three necessary conditions which were in place to propel the industry forward: a strong national objective, a liberalized power sector, and an economically competitive resource.

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1 Introduction

At the 2000 World Geothermal Conference in Japan, reports indicated that geothermally-fueled electric power was being generated in 21 nations around the world, with an installed capacity that had reached 7974 MWe (Huttrer, 2001). In Central America, which lies within the volcanically active Cocos-Caribbean subduction zone, geothermal energy is a popular and profitable energy alternative. El Salvador, the smallest of the seven[2] Central American countries, having an area of 21,040 km^2 and a population of 6.47 million (2003), 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.

El Salvador, which is commonly called *Land of Volcanoes*, is characterized by major geothermal zones, hot wells, hot springs and fumaroles. Earthquakes and other seismic activity occur frequently, some with devastating consequences. Exploration for geothermal potential in El Salvador began 50 years ago, in 1954 (Huttrer, 2001) 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, channelling 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.

A 1999 U.S. Department of Energy (Battockletti et al) report estimated that El Salvador has geothermal power potential of over 2210MWe. Today, over 24% (Rodriguez and Herrera, 2003) of El Salvador's electricity output is from geothermal energy, representing almost 940GWh of power (2003), and making El Salvador a 'leader per capita in the sector' (Washington Post). This paper focuses on the history and development of the geothermal energy industry in El Salvador since its inception fifty years ago. Specifically we will examine the policies and actions which led to such growth of the sector and look at the technical, socio-political, economic and

[2] Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama

environmental challenges encountered in the process. Our goal is to extract the key lessons that other developing countries can use for their own geothermal and renewable energy resource development.

We begin with a brief overview of geothermal energy, and then concentrate on the history, exploration and development of the two main geothermal fields in El Salvador, Ahuachapán in the west, and Berlín in the east. Our discussion will then shift to the developmental challenges which the Government of El Salvador faced. We close with a statement of best practices, making broad recommendations for other developing countries hoping to mature their own geothermal energy sector.

2 The Power Sector in El Salvador

In 2002, the total installed capacity across all available resource types in El Salvador was 1136.2MW, and peak demand was 752MW (Rodriguez, GRC 2003). During that year, there was total generation of approximately 4250GWh (Figure 1) and electricity consumption of 3777 GWh. The estimated growth rate of electricity demand is 6.4%. As of 1998, there was 65% electrification in El Salvador, with the majority of the coverage (92%) in urban areas and only 38% coverage in the rural areas.

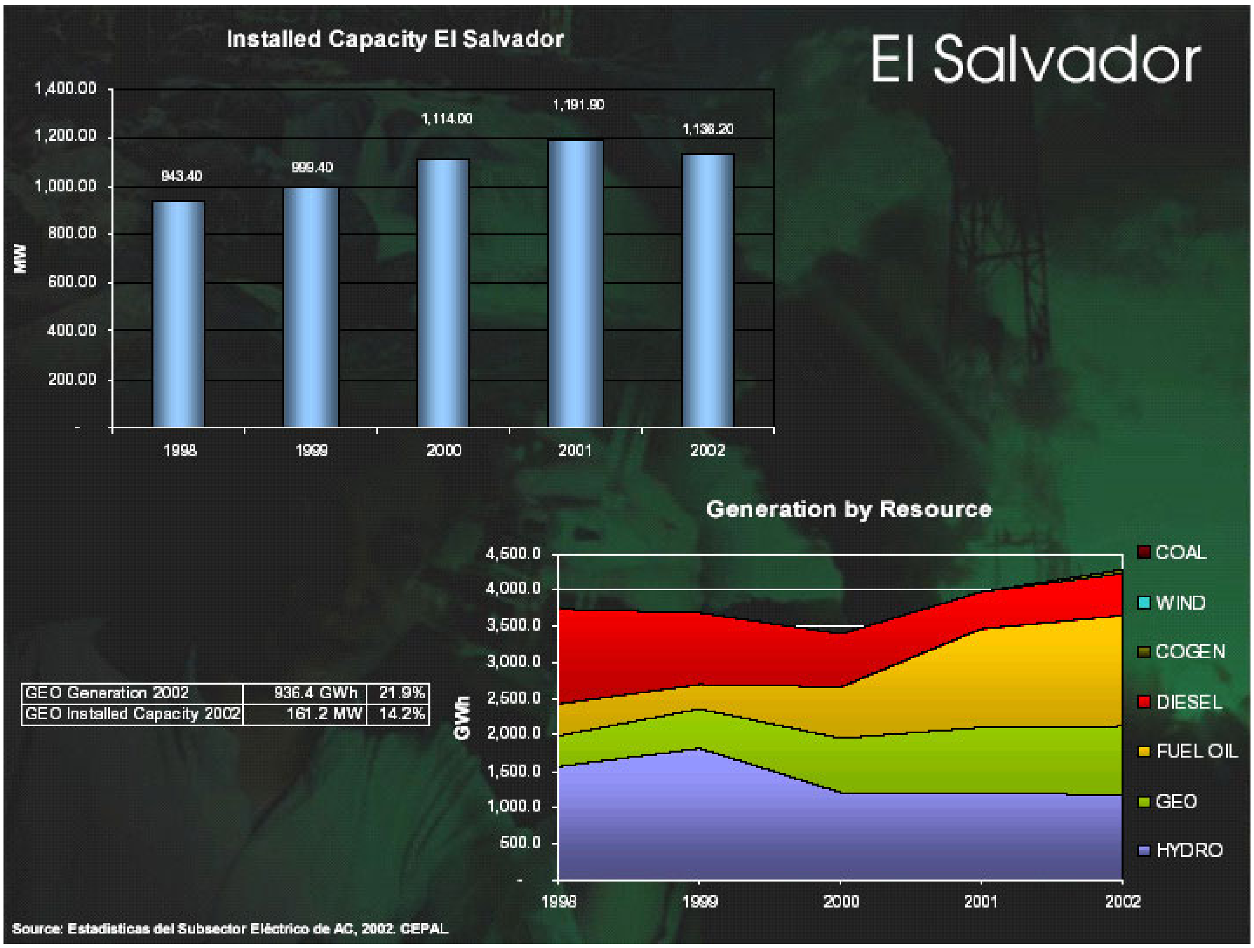

Figure 1- Installed Capacity and Generation by Resource in El Salvador

Source: Rodriguez, GRC 2003

As the Figure above illustrates, power generation in El Salvador is primarily from hydro, thermal (fuel oil) and geothermal resources. Geothermal is the cheapest energy generating source in El Salvador. As a consequence, since the mid 1970s it has become an important electricity source – a true, clean alternative to fossil-fuel generated energy.

In November 1996, El Salvador reformed its electricity industry. New deregulatory legislation reduced the State's involvement in the sector and created a more competitive environment for both wholesale and retail power (IADB). Most importantly, it allowed geothermal power to compete openly on the market with power from other sources. Geothermal energy production assets were sold by the national electricity company, Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL) to private, foreign buyers. In addition, a new company, Geotérmica Salvadoreña (GESAL) was created to take over the geothermal generation facilities in the country. Enel Green (ENEL) of Italy recently purchased 8.5% of GESAL and may buy another 30-35% of shares of the company.

Population (millions) – July 2003 est.	6.47
Overall Electrification (% of population) – 1998	65%
GDP (billion US$) – 2002 est.	$29.41
Real GDP Growth Rate – 2002 est.	2.10%
Population below the poverty line – 1999 est.	48%
Inflation rate (CPI) – 2002 est.	3.80%
Total Installed Capacity (MW) – 2002	1136.2
Electricity Consumption (Billion kWh) - 2001	3.777
Electricity Production by source	
Fossil fuel	44%
Hydro	30.90%
Other (including geothermal) (2001)	25.10%
Electricity Demand Growth Rate - 1998 est.	6.40%
Estimated Geothermal Potential (MWe)	> 2210MWe

Table 1 – Energy and Demographic data on El Salvador

Sources: CIA World Fact Book; EIA Country Energy Data Report; IADB Report

3 What is Geothermal Energy?

Geothermal energy can be described broadly as the thermal energy 'stored at accessible depth in the earth's crust' (Mock et al, 1997). Since the beginning of recorded history, geothermal fluids have been used for cooking and bathing, however it was only in the 19th century that geothermal energy was captured for industrial purposes (Kirk-Othmer). In El Salvador, geothermal energy is harvested only for power generation. There is the possibility of using geothermal energy directly for drying coffee or grains (Rodriguez, 2000) this has been little explored, and direct use in El Salvador is negligible at best.

Most geothermal energy that is used for electrical power is obtained at depths of 0-10km. There are four main categories of geothermal resources: hydrothermal, hot dry rock, magma and geo-pressured. Hydrothermal resources are found at depths of 1-4km and spontaneously produce steam or liquid water up to 350˚C. They are the least difficult geothermal resource for electricity generation since the steam from the resource can be channelled into low-pressure steam turbines with low risk of scaling or turbine blade damage (Peters et al, 2004). Hot dry rock geothermal systems are typically available at any depth deep enough to obtain temperatures that exceed 150˚C i.e. temperatures hot enough for heat extraction. For high-grade regions, this depth might be 2-5km, whereas for low-grade regions, depths of 4-8km are required (Mock et al, 1997). Magma geothermal resources are an extreme case of hot dry rock (Kirk-Othmer). The difficulty with extracting heat from magma is finding the resource at an accessible depth. Accessible regions (<7km) of molten rock are found typically in volcanically active areas. Geo-pressured resources are comprised of 'hot high-pressure brines containing dissolved natural gas' (Mock et al). They contain both hot water under pressure, and methane in solution.

As will be discussed in the following section, the geothermal resources which have been exploited in El Salvador are primarily hydrothermal in nature. Currently, there is research and development being conducted by Shell International on the possibility of exploiting hot dry rock resources at one of the existing geothermal plant facilities in the east of El Salvador.

4 Geothermal Resources in El Salvador

Since 1954, when El Salvador first began its geothermal exploration, five priority sites have been identified for their geothermal power potential. These are (from west to east as depicted in Figure 2): Ahuachapán, Cuyanausal, San Vicente, Berlín and Chinameca. Estimates from the U.S. Department of Energy indicate that there is a total of 2,210-4,140 MWe (1999) of geothermal power potential in El Salvador. The two main geothermal fields are at Berlín, with an installed capacity of 66MW, and Ahuachapán, with an installed capacity of 95MW (Rodriguez, 2003). The other three areas continue to be explored, but are not yet generating any capacity. In this paper, we will focus on the two main fields.

In 2002, only 119MW of the installed 161MWe of geothermal generation capacity in El Salvador was available. Power generated from geothermal resources totaled 940 GWh, comprising 24% of the national total (Rodriguez, 2003).

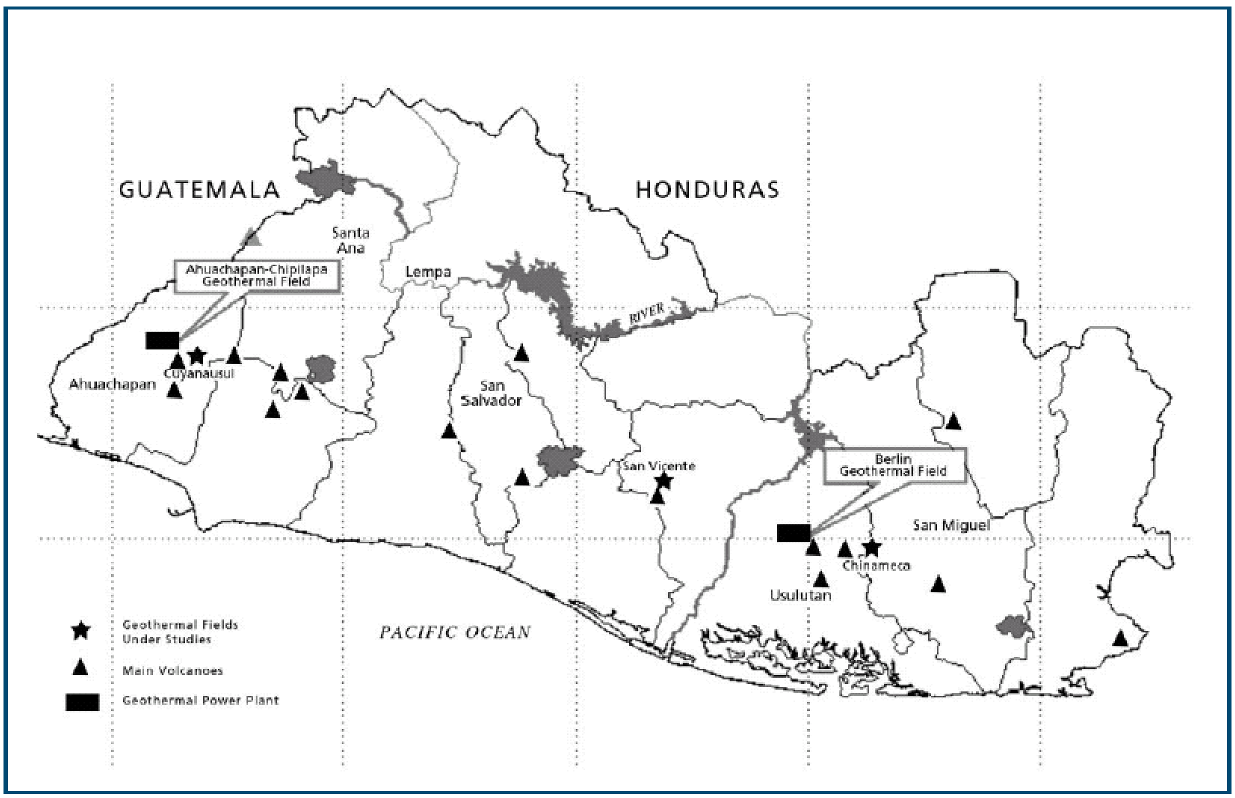

Figure 2 - General map of El Salvador and location of geothermal resources

Source: International Geothermal Development. July/August 2003

As Table 2 shows below, geothermal energy generation in El Salvador has been increasing steadily as part of the market share over the past five years. In addition, generation from the Berlín plan has skyrocketed over the same period.

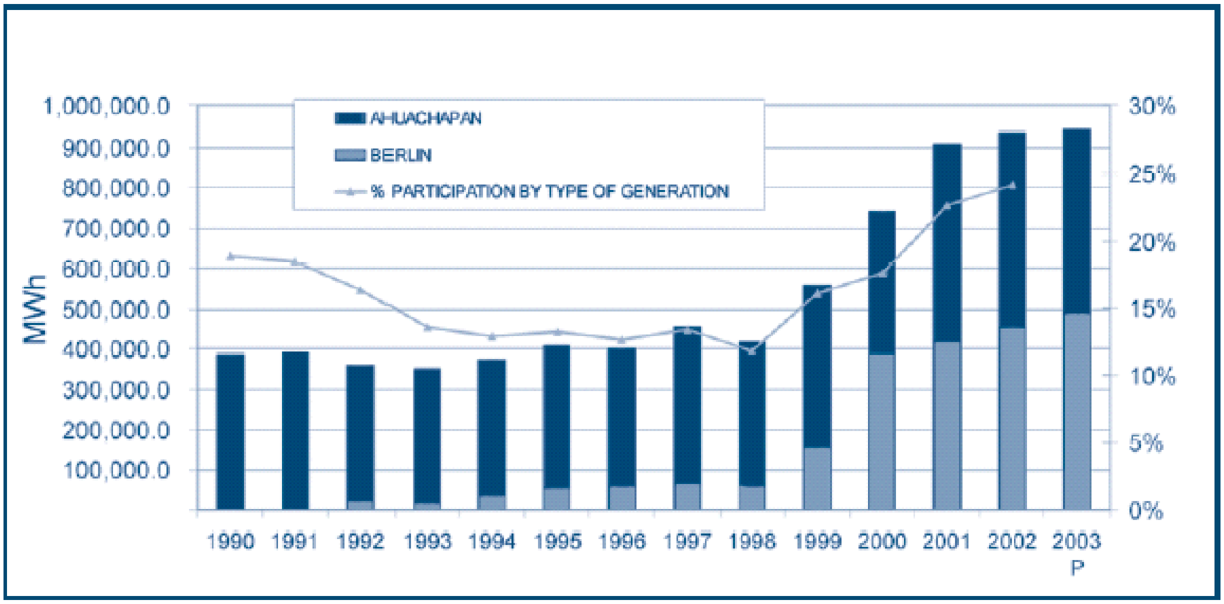

Table 2 – Geothermal generation and market share in El Salvador

Source: International Geothermal Development. July/August 2003

4.1 Ahuachapán

The Ahuachapán region is located approximately 80 km West of San Salvador, 18km east of Rio Paz and 15km from the Guatemalan border. It is an agricultural region which produces mainly coffee. Ahuachapán was the first geothermal site 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) in the south-western 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 exploit. 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 hydro 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 (DiPippo) 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 (Huttrer).

In 1996, a US $50 million project, the *Ahuachapán Stabilizaion and Rehabilitation Project*, funded by the InterAmerican Development Bank (IADB) was launched. The ultimate goal of the project is to 'modernize the power plant while ensuring long-term production sustainability' (Rodriguez and Herrera). It has four major components (Rodriguez; Rodriguez and Herrerra):

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.

As Table 2 shows, the generation at Ahuachapán has been steady and growing slowly over the last five to six years, thus making the stabilizing projected a success.

4.2 Berlín

The Berlín geothermal field is located in Eastern El Salvador, approximately 90km from San Salvador. It rests on the northern slopes of the Berlín-Tecapa Quaternary volcanic complex inside the Berlín Caldera (Rodriguez, 2000). 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 1400m and 2300m, (Huttrer). However, development of the Berlín site was soon halted, despite finding temperatures up to 230˚C, due to low permeability. During the early 1970s, focus shifted to Ahuachapán, which proved at the time to be more commercially exploitable.

Figure 3 - Berlín Power Plant

In the late 1970s and early 1980s, five more exploratory wells were drilled to depths between 2000 and 2380m. 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, halted all new power projects by the CEL.

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 1950m and 2300m, with highest temperatures of 305˚C found.

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

1. construction of the power plant;
2. drilling of 18 new production and injection wells, along with access roads;
3. installation of 16km of pipelines for the fluid gathering system;
4. erecting a 7km long 115-kV transmission line to connect with El Salvador's national grid;
5. constructing a workers camp to house 24 permanent employees.

The final cost of the project was approximately US $120 million.

Third Berlín Unit

A third unit at Berlín is being developed by ENEL, a private Italian company which has invested in Geotérmica Salvadoreña (GESAL) the local geothermal development company. ENEL is conducting further feasibility studies to determine the expansion of the current reservoir at Berlín. The aim would be to (Rodriguez, 2003):

1. integrate all geoscientific and well data in the field;
2. develop an updated numerical reservoir model;
3. drill 'step out' wells to the southeast and southwest of existing wells.

A July 16, 2003 news report (Rodriguez 2003) indicated that ENEL and GESAL will drill 10 new wells at the Berlín field, an exercise expected to be complete in 2004. If this drilling is successful, then these new wells will supply steam to a third geothermal power unit at Berlín.

Future of Berlín Field

Shell International is currently running a project on the Berlín geothermal field that will "hydraulically stimulate a hot, tight well to create an extensive network of fractures … at a depth of 2000m" (Rodriguez, 2003). The new reservoir could be used for energy production by "circulating water through the fracture network to additional production wells". Several reasons were cited for Shell's selection of the Berlín site for the project. First, the Berlín project already has a dry, hot well available for accepting the water necessary to fracture the rock – much of the groundwork is already done. Second, any additionally produced steam can be used by existing power generation installations. Third, there is already a lot of information from the project planning phase available. Finally, much historical data for calibration and monitoring of the hydraulic fracture process exists (Rodriguez, 2003). The success of the Shell project would likely pave the way for future, expanded use of hot dry rock methods for generating electricity in El Salvador.

4.3 Other Geothermal Areas

Cuyanausal

Cuyanausal is about 8km east of Ahuachapán. Geothermometer temperatures from fumaroles in the area indicate a resource with temperatures exceeding 250˚C (Rodriguez, 2003). An exploration project is being conducted by ENEL. ENEL plans to develop a 'geoscientific model of the field and drill two exploratory wells' (Rodriguez, 2003). Two of GESAL's 5MW wellhead units will be installed and other wells drilled if the wells intersect a commercially exploitable reservoir (Rodriguez, 2003).

San Vicente & Chinameca

San Vicente is located in Central El Salvador, Chinameca, further to the east. Both sites have commercial geothermal potential. Huttrer (2000) indicates that the potentials of each of these areas are estimated at 50MWe. In May 2001, a concession agreement was awarded to a private company[3], specifying the development of a 50MW geothermal power plant at each of these fields.

[3] Orpower 7, a subsidiary of ORMAT International.

5 Challenges to Geothermal Development

The decision to develop a geothermal resource is a big one, particularly for a developing country which typically cannot afford to finance the upfront exploration drilling costs, and the development costs on its own. Apart from needing an accessible resource at sufficient depths, the resource itself must be exploitable at an affordable cost, and the resulting cost of production must be cheaper than, or on par with fossil fuel-generated (or hydro-generated) power, in order to ensure participation in the market. El Salvador has faced several challenges during the development of its geothermal sector. We now consider these challenges from a socio-political, economic, technical, and environmental perspective.

5.1 Socio-political and Economic challenges

Civil War 1980-1992

A decade-long civil war in El Salvador from 1980-1992 had a devastating impact on the country's economy. It is estimated that the losses due to damaged infrastructure, declines in production capability, and reduced export earnings reach $2.2 billion. More importantly, the civil war caused severe damage to electricity transmission lines, which contributed to overuse of geothermal power plants. In addition, this socio-political civil conflict seriously retarded the development of the geothermal sector, decelerating its advancement over that time period. All investment in geothermal projects was halted, and the development of the Berlín geothermal field was stalled for more than 10 years.

The unstable economic and political climate that the civil war created made it difficult for El Salvador to attract foreign investment from both private investors and international donors, who felt that the risks were too high – they had little confidence in the country's ability to service any new debt. Furthermore, during that decade, Latin America as a whole was experiencing a serious economic crisis, with GDP falling consistently from 1980 to 1989.

After the civil war ended in 1992, financing for geothermal projects, particularly from multilateral organisations, was more readily available. In 1994, the InterAmerican Development Bank (IADB) and the Overseas Economic Cooperation Fund (OECF) of Japan financed over 80% of the $332 million Electric Power Sector Program. Components of this plan included the construction of the 56MW geothermal generation plant at Berlín as well as the stabilization and rehabilitation of the Ahuachapán plant.

5.2 Technical Challenges

Waste Disposal

El Salvador's most pressing technical challenge in geothermal development was finding an affordable and practical solution for disposing waste liquid. This has been a chronic problem at the Berlín field, and today remains the greatest difficulty at this plant (Rodriguez, 2000). Data analysis has been done to determine appropriate locations for new injection wells; however 'the problem of drilling successful wells for disposal of waste fluids has yet to be solved' (Rodriguez, 2000).

Sustaining well pressures

The situation at Ahuachapán, as described in a previous section, was that of falling reservoir pressures due largely to insufficient reinjection. Today, though reservoir pressures have been stabilized, the power output from the plant is still well below capacity. The problem of maintaining the sustainability of the resource is common in geothermal power generation. The rate of extraction of the resource must be slow enough to ensure that the accessible reservoir is not depleted.

Hot dry rock

Hot dry rock formations at accessible depths contain the greatest potential source of geothermal energy (Mock et al). Shell is conducting research at the Berlín field with hot dry rock technologies. The challenge with this exploration is the general difficulty that exists in understanding the formation of the hot dry rock reservoir (Hooper & Duchane).

5.3 Environmental Challenges

Waste disposal into Rio Paz

An advantage of geothermal power generation for the environment is that the generation process emits very little pollutants such as sulphur, carbon dioxide and particulates. Nonetheless, the chemical composition of the waste liquid from the geothermal power plants can pose environmental risks. At Ahuachapán, at one point, the waste liquid was being discharged into the Rio Paz. This was problematic since it reduced the water quality of the river, which was used for irrigation and other purposes. In order to curb the levels of arsenic and boron in the river, this disposal practice had to be discontinued. Today, some waste liquid (about one third) is disposed into the Pacific Ocean. The environmental risks of this are yet to be determined.

Natural Disasters

In January and February of 2001, El Salvador experienced a series of debilitating earthquakes. These occurred when reconstruction efforts were still underway following 1998's Hurricane Mitch. The earthquakes left 2000 dead or missing and another 8000 injured. One and a half million people were left homeless. In addition to this loss of human life and property, the effect on the economy of El Salvador was devastating. Following this disaster, the government's focus shifted toward reconstruction and economic recovery. The priority became one of rehabilitating the affected population and reestablishing basic goods and services to all.

6 Policies and Actions

El Salvador has never had legislation specifically targeting geothermal development directly. Rather, several key components of government initiatives and policies with respect to the wider power sector have helped move the geothermal power industry forward over the past fifty years:

Reducing outages, increasing electrification

Firstly, the government of El Salvador has maintained a national objective of increasing electrification – which stands at 65% -- and reducing power outages. It is undisputed that the availability of adequate, reliable, affordable energy is integral to economic development. The thrust from the government comes not only in order to improve the investment climate, but also to improve production efficiency in industry and raise the standard of living for citizens. Large factories and industrial parks tend to have their own power backup generators. Infrastructure and weather problems cause frequent service interruptions. Hydroelectric power plants, which provide about 30% of the generating capacity of El Salvador are highly dependent on seasonal rains, whilst fossil fuel imports are relatively expensive. A 1999 DOE report states that geothermal power is the cheapest generating source for base load energy in El Salvador. This has helped prioritize geothermal power projects among other national objectives.

Electricity Reform Act

Perhaps the most important government action impacting geothermal power generation in El Salvador in the past decade has been the privatization of the power sector. In 1996, the Electricity Reform Act was passed, making the power sector in El Salvador among the most liberalized in the world (Engel, 2003). The reform of the power sector moved the market from a state-owned monopoly to an open power market with mainly private players. Today, the power sector has five types of market participants: generators, traders, transmitters, distributors and consumers.

A new autonomous agency, the *Superintendencia General de Electricidad y Telecomunicaciones* (SIGET) was created to oversee and regulate the electricity and telecommunications industries. SIGET is responsible for setting transmission and distribution costs, resolving disputes among market operators, and granting concessions for geothermal and hydroelectric development to private developers (Rodriguez, 2000).

CEL, the former state monopoly, now controls only the hydropower plants. Geothermal assets were used to create GESAL, which is a privatised, wholly owned subsidiary of CEL. Both the Berlín and Ahuachapán geothermal power plants are owned and operated by GESAL. GESAL's new strategic partner, ENEL, has much experience in geothermal resource development, and is currently exploring the feasibility of a third condensing unit at Berlín, as well as well-head generation development at Cuyanausul. The Berlín geothermal plant operates without a power purchase agreement to guarantee income (Rodriguez 2003). Thus far, this practice has caused no problems. Geothermally-generated electricity is sold on the open market in El Salvador and Guatemala.

7 Conclusion

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 24% 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 climate and increase electrification, and it was a reliable, indigenous source of power.

Second, the power sector should be structured to allow private sector 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 loathe to take on the high up front costs associated with these phases. In the case of El Salvador, the role of government was key in securing funding from development banks and friendly governments 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. Because fossil-fuels are very cheap in most countries, and electricity is requisite for economic development, many developing countries depend on heavy imports of oil to support their electric power industry. This will remain to be the norm until the exploitation and development of renewable, sustainable energy resources becomes economically competitive. Fortunately for El Salvador, this was the case.

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