# Geothermal Resources and Development in Guatemala Country Update

Francisco Asturias, Edna Carolina Grajeda

Enel Guatemala S.A. Diagonal 6 10-01, Guatemala City Guatemala 01010,

Instituto Nacional de Electrificación 7a Av. 2-29 zona 9 Guatemala City, Guatemala 01009

*alberto.asturias@latinamerica.enel.it; cgrajeda@inde.gob.gt*

**Keywords:** private producers, geothermal energy, Amatitlán, Zunil, energy matrix

## ABSTRACT

In the last years the production of the geothermal energy in Guatemala, has been carried out by private producers. In 2007, a 24 MWe (installed capacity) binary power plant was commissioned by Ortitlán in the Amatitlán field. The same year, INDE decommissioned a 5 MW backpressure unit. INDE plan to relocate the backpressure unit to the Zunil I field. These geothermal power plants have been under production and they represent a small percentage of the country energy production. More than 10 geothermal fields remain under prefeasibility studies.

The accessible resource base potential of geothermal resources in Guatemala is estimated to be 1000 MWe. Early reconnaissance of the geothermal resources identified 14 geothermal areas. The Zunil and Amatitlán areas were given first priority for continued exploration and development. Pre-feasibility studies have also been carried out by INDE in the areas of Tecuamburro and Moyuta. A re-evaluation of the Moyuta area in 1990 indicated that the reservoir consists of two subsystems with lateral flows to the north and south with estimated temperatures of 210°C and 170°C respectively. Advanced pre-feasibility studies in 2005 by the consulting firm WJEC estimated a reservoir potential of 50 MWe for 30 years in the Tecuamburro area. Geothermal development in the Zunil I field began in 1981 and to date 15 production wells and 5 reinjection wells have been drilled. In 1999 a 28 MWe (installed capacity) binary power plant was commissioned by Orzunil. Production of brine from the reservoir has declined do to low field permeability and poor hydro geological connection between the reinjection zone and production zone. Direct use of geothermal energy has been successfully carried out by Bloteca and Agroindustrias La Laguna. Dry steam and hot water produced from a shallow low temperature reservoir located 8 km northwest of the Amatitlán field is used in the industrial curing process of construction blocks and dehydration of fruit.

As a country, there is a need to change the energy matrix, using renewable energy, in order to be independent from fossil fuels but at present, the geothermal potential remains under developed.

Laws have been promoted in order to incentive private investors to participate in the geothermal development but the financial factor has been the main issue.

## 1. INTRODUCTION

Geothermal resources in Guatemala are abundant and provide a sustainable source of energy. Geothermal resources are located along the volcanic highlands of the Central American Volcanic Arc Chain, in the south central part of the country. The same heat energy that drives volcanic activity is also stored in geothermal reservoirs and range from low temperature to high temperature resources. In Guatemala the geothermal resource potential is estimated at 3,320-4,000 MWe from which the accessible resource base is 1000 MWe (Battocletti, 1999). Gross generation of electric energy in the country in 2008 was 7,917.4 GWh, 34% is hydro and almost 3% is geothermal (CEPAL, 2008). The total installed capacity in Guatemala is 2,227.1 MWe , the installed capacity of geothermal energy is 44 MWe. Both geothermal plants are owned by Ormat, at Amatitlán geothermal field they initially financed the development and construction of the project, as well as the drilling of wells. The power plant currently generates approximately 17MW and is scheduled to reach its design capacity towards the end of the second quarter of 2009, upon the connection of an additional well that was recently drilled.

**Table 1: Installed capacity evolution**

INSTALLED CAPACITY EVOLUTION MW

| YEAR | TOTAL | HIDRO | GEO | VAPOR | DIESEL | GAS | COAL | COGENE RATION |
|---|---|---|---|---|---|---|---|---|
| 1990 | 810.9 | 488.1 | 0 | 116 | 7.4 | 199.4 | 0.0 | 0.0 |
| 1995 | 1,082.3 | 502.1 | 0 | 79 | 128.8 | 317.4 | 0.0 | 55.0 |
| 2000 | 1,668.3 | 530.9 | 29 | 79 | 422.2 | 301.5 | 142.0 | 163.7 |
| 2001 | 1,672.1 | 524.9 | 33 | 79 | 404.2 | 289 | 142.0 | 200 |
| 2002 | 1,703.0 | 558.1 | 33 | 79 | 409.2 | 209 | 142.0 | 182.7 |
| 2003 | 1,842.8 | 584.4 | 33 | 79 | 612.2 | 209.5 | 142.0 | 182.7 |
| 2004 | 1,997.1 | 639.7 | 33 | 79 | 631.2 | 289.5 | 142.0 | 182.7 |
| 2005 | 2,087.7 | 699.8 | 33 | 79 | 631.2 | 264.5 | 142.0 | 238.2 |
| 2006 | 2,039.1 | 742.9 | 29 | 0 | 649.2 | 172.5 | 139.0 | 306.5 |
| 2007 | 2,154.0 | 775.7 | 44 | 1.5 | 671.4 | 215.9 | 139.0 | 306.5 |
| 2008 | 2,227.1 | 752.6 | 44 | 4.5 | 706.9 | 215.9 | 152.4 | 350.8 |

Source: CEPAL on oficial data bases
Preliminar data

**Table 2: Gross Generation Evolution GWh.**

GROSS GENERATION EVOLUTION GWh

| YEAR | TOTAL | HIDRO | GEO | VAPOR | DIESEL | GAS | COAL | COGENE RATION |
|---|---|---|---|---|---|---|---|---|
| 1990 | 2,318.4 | 2,140.6 | 0.0 | 81.2 | 1.5 | 95.1 | 0.0 | 0.0 |
| 1995 | 3,479.4 | 1,903.8 | 0.0 | 192.4 | 776.8 | 491.7 | 0.0 | 114.6 |
| 2000 | 6,047.8 | 2,673.9 | 202.2 | 73.3 | 1,617.6 | 253.7 | 558.4 | 668.6 |
| 2001 | 5,772.2 | 2,264.3 | 193.7 | 1.9 | 1,780.9 | 106.8 | 848.0 | 576.7 |
| 2002 | 6,191.1 | 2,013.5 | 130.0 | 23.9 | 2,312.3 | 147.0 | 943.3 | 621.1 |
| 2003 | 6,574.9 | 2,188.4 | 195.0 | 19.6 | 2,607.2 | 84.9 | 892.1 | 587.7 |
| 2004 | 6,999.0 | 2,655.9 | 194.2 | 76.7 | 2,433.3 | 3.4 | 1,030.0 | 605.5 |
| 2005 | 7,220.6 | 2,927.9 | 145.0 | 79.8 | 2,346.4 | 19.2 | 978.5 | 723.7 |
| 2006 | 7,434.3 | 3,248.4 | 142.5 | 0.0 | 2,210.6 | 15.3 | 1,010.5 | 807.0 |
| 2007 | 7,940.4 | 3,006.2 | 232.9 | 0.0 | 2,693.1 | 19.2 | 1,037.5 | 951.4 |
| 2008 | 7,917.4 | 3,581.3 | 289.2 | 20.0 | 2,083.9 | 25.4 | 1,047.6 | 870.0 |

Source: CEPAL on oficial data bases
Preliminar data

## 2. EXPLORATION BACKGROUND

The Guatemalan central government began to identify and explore these resources in 1972 through the government owned electric developer (INDE) with initial finance from several world development organizations (Roldan, 2005). In 1981, a regional reconnaissance study was carried out in order to identify and prioritize all of the geothermal resources in Guatemala. The results of the survey identified 13 geothermal areas, of which 7 areas were selected as the most promising for electrical generation with temperatures ranging from 230-300°C. Listed in order of decreasing priority they are Amatitlán, Tecuamburro, Zunil I, Zunil II, San Marcos, Moyuta, and Totonicapán (Figure 1). Second priority areas with low temperature resources are Los Achiotes, Palencia, Retana, Ayarza, Atitlán, Motagua and Ipala.

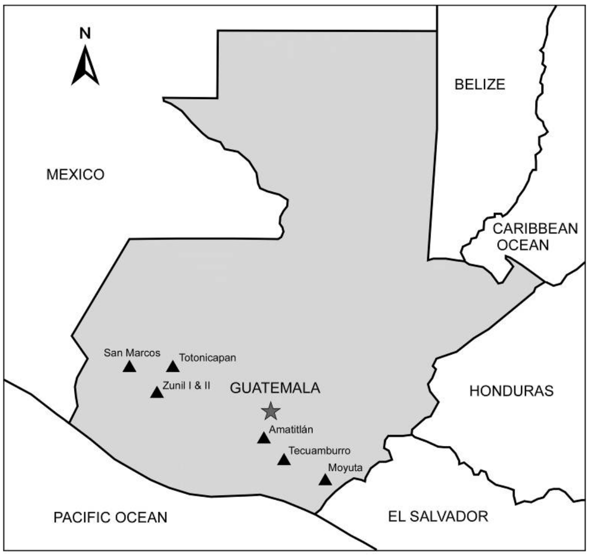


**Figure 1: Location map of high temperature geothermal areas in Guatemala.**

## 3. PRE-FEASIBILITY STUDIES IN GUATEMALA

### 3.1 Moyuta

Moyuta was the first geothermal area to be studied. It is located in the department of Jutiapa on the southeaster part of Guatemala. Surface exploration studies were carried out in 1975 over an area of 330 km². INDE along with Italian consultant company Electroconsult (ELC) carried out complete geological, geochemical, and geophysical studies to determine Moyuta's economic and technical geothermal potential. The results of the pre-feasibility study concluded that a shallow reservoir was located on the northern flank of the Moyuta volcanic complex with an estimated reservoir temperature of 180°C. In 1976, INDE drilled 2 deep exploration wells to a depth of 1000 m but the results were not favorable and the project was later abandoned.

The Moyuta area was reevaluated in 1990 by INDE with the cooperation from Los Alamos National Laboratory (LANL) and the USGS. Analysis of chemical and isotopic data from sampled gas and water were used to estimate the areas geothermal potential and recommend new sites for exploration drilling. The distribution of thermal features indicates that deep reservoir fluid rise convectively near the axis of the volcanism and is structurally controlled by north trending faults. An updated conceptual model illustrates the reservoir is recharged locally and fluids are heated to reservoir temperatures near the axis of Quaternary andesitic vents forming the east-west trending dome and flow complex (Goff et al. 1991). Two convective sub systems and lateral outflows make up the overall reservoir with temperatures of 210°C for the northern system and 170°C for the southern system (Figure 2). The study suggested that future drilling should be done closer to the intersections of the north trending faults and the Quaternary volcanic axis.

### 3.2 Tecuamburro

The Tecuamburro geothermal area is located 50 km southeast of Guatemala City. In 1981, the Tecuamburro area was selected as one of the most promising areas for electrical generation. Geothermal manifestations include fumaroles, boiling springs, mud pots, and a large acid sulfate lagoon formed by a phreatic explosion 2,900 year ago called Laguna Ixpaco. The geothermal area is located on the northern flank of the Tecuamburro Volcano, a large andesitic composite cone with a complex geological history. From 1988 to 1991, INDE with technical assistance from Los Alamos National Laboratory (LANL) carried out a surface exploration study to estimate the areas geothermal potential. The studies included field mapping, vulcanological studies, an extensive geochemical sampling and analysis of geothermal springs and fumaroles. In 1991, an exploratory core hole was drilled to a total depht of 800 m. Although drilling did not confirm the existence of a geothermal reservoir, a bottom hole temperature of 235°C was reached (Goff, 1992). Core samples revealed an alternating sequence of basaltic andesitic lava flows and pyroclastic deposits with hydrothermal alteration consistent with bottom hole temperatures. The borehole had drilled into a section of impermeable cap rock. No permeable zones were identified.

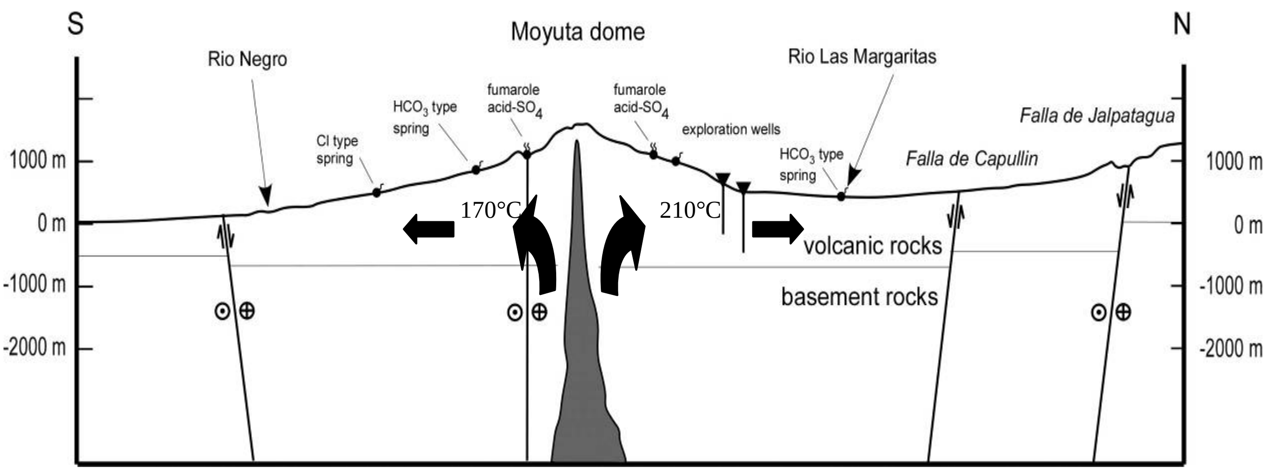


**Figure 2: Schematic Cross Section of the Moyuta geothermal system showing configuration of reservoir relative to the axis of Quaternary magma conduits (Modified from Goff et al., 1991).**

Based on the prefeasibilty results, Figure 3 illustrates the conceptual model, showing two separate geothermal reservoirs, one located on the northern flank of Tecuamburro Volcano with temperatures close to 300°C and a second reservoir that is geochemically distinct fluids and with estimated temperatures of 165 °C located approximately 10 km north of the Tecuamburro Volcano (Janik et al. 1992).

In 2005, the private firm WJEC conducted a reevaluation the geothermal potential of the Tecuamburro area as part of a regional initiative by the Japanese government to support the development of renewable resources in the Plan Puebla Panama (PPP) region. The project was aimed at promoting investment in geothermal projects by elevating the project status to advanced prefactibility. The study consisted of a recompilation and analysis of the available technical data, an evaluation of the local power sector, environmental aspects, and implementation of project development. To confirm the previous conceptual model, an MT survey was carried out over an area of 9 km² and centered on Laguna Ixpaco. This provided useful information for a volumetric estimate of the resource and drilling well targets for future drilling. The recalculated potential was estimated at 50 MWe for 30 years with a cumulative probability of 75% (WestJec, 2006).

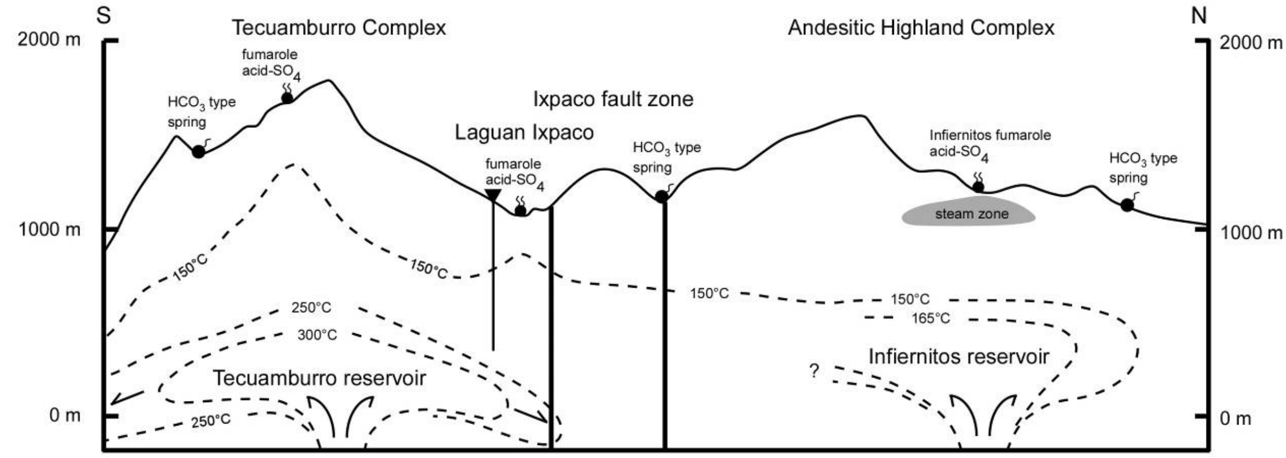


**Figure 3: Conceptual Model of the Tecuamburro Geothermal area. (Modified from Janik).**

## 4. GEOTHERMAL RESOURCE DEVELOPMENT

### 4.1 Zunil I Geothermal Field

In 1977, after the Moyuta project was abandoned, INDE decided to carry out surface exploration studies in the Zunil area, located in the eastern department of Quetzaltenango. The studies covered an area of 310 km2 and based on the initial results, the Zunil area was divided into two areas, Zunil I and II (Figure 4).

Deep exploration in the Zunil I geothermal field began in 1981 initially with 6 deep exploration wells. Production was achieved from a two phase liquid dominated reservoir with a temperature of 280°C. In 1991, 3 new wells were drilled targeting the deeper part field. Production was achieved by the first 2 wells becoming the highest producers in the field. Drilling into the deeper part of the reservoir had confirmed the existence of a single phase reservoir with higher permeability below a depth of 1000 m with temperatures close to 300°C (Asturias, 2003). The field was estimated to produce sustainable steam and brine to supply a 24 MWe binary power plant for 25 years. In 1999, though a Power Purchase Agreement (PPA) between INDE and Ormat Inc., a 28 MWe (installed capacity) geothermal power plant was commissioned (Orzunil). Under the terms of the contract, INDE manages the production of steam and brine to the power plant and purchases the energy generated by Orzunil. Currently Orzunil generates 16 MWe.

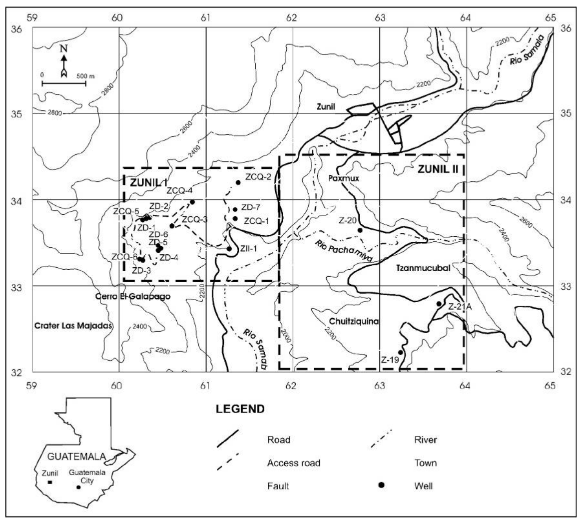


**Figure 4: Zunil I and II Geothermal Fields showing well locations.**

Shortly after Orzunil began operations, the production of geothermal water in relation to steam began to drop, in part due to the overall low permeability of the shallow reservoir and also due to the fact that the reinjection of steam condensate and brine from the plant was not providing pressure support to the reservoir. Reservoir simulations indicated that a poor hydrogeological connection exists between the reinjection zone and the production zone and as much as 86% of the reinjected total is discharging with the lateral outflow to the east of the production zone (Asturias, 2005). Declining reservoir pressures has prevented plant operation at full capacity. In 2005, two make up wells were drilled to depths of 1500 m in the eastern and western portions of the geothermal field, both wells suffered from low permeability and only one well was able to maintain flowing conditions. Both wells will need to be properly tested before they can be connected to the power plant or if INDE plans to use them to supply steam to the portable 5 MWe backpressure unit.

### 4.2 Amatitlán Geothermal Field

Amatitlán geothermal area is located 40 km south of Guatemala City. In 1972 INDE began the reconnaissance of the area and by 1989 the consulting firm Electroconsult was contracted to carry out surface exploration studies over an area of approximately 170 km². Deep exploration of the resource soon followed and in 1993 the consulting firm West Japan Engineering Consultants (WJEC) was contracted to supervise drilling and testing operations of 4 deep exploration wells. The results confirmed the existence of a deep chloride rich geothermal system with a temperature of 285°C. (Figure 5).

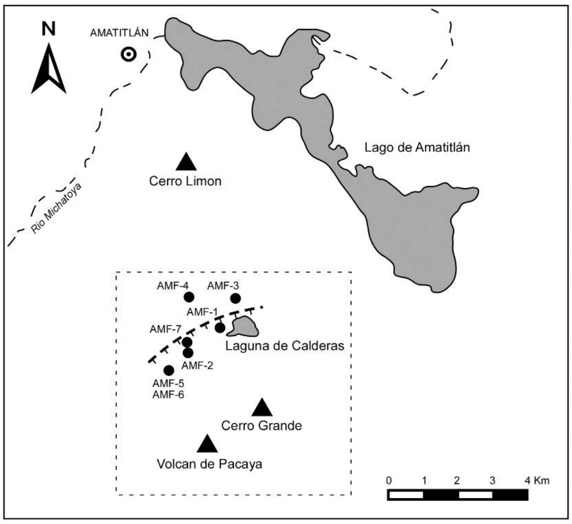


**Figure 5: Amatitlán Geothermal field showing well locations and outflow of geothermal system (Modified after Lima 1996).**

Flow testing of the first two production wells yielded a combined capacity of 12 MWe (Lima, 2003) and in 1999, two more production wells were drilled targeting zones on the western side of the geothermal field with higher temperature and permeability. Resource assessment concluded that the Amatitlán reservoir has an estimated production capacity of 50 MWe for 30 years.

A 5 MW backpressure unit was purchased from Mexico's Comision Federal de Electricidad (CFE) and was commissioned by INDE on November 1998. Steam was supplied by two production wells and all mass extracted was reinjected back into the reservoir at 100 percent. The plant was decommissioned in 2007 after operation of the field was handed over to a private developer. In the near future, INDE plans to relocate the backpressure unit to the Zunil II geothermal area.

In 2001 Ormat Inc. was awarded the concession of the Amatitlán geothermal field and has agreed to install 50 MWe by the year 2011. In 2006 the company began phase one of construction with a binary power plant with and installed capacity of 24 MWe. The plant was officially commissioned in August of 2007 and currently produces a total of 340 T/hr of steam and brine from 4 production wells and reinjects at 100 percent of all residual water and condensate.

## 5. DIRECT USE OF GEOTHERMAL ENERGY

The Direct use geothermal energy in Guatemala in the past has been used for its medicinal purposes, agriculture, and domestic use. The areas of Totonicapan, Quetzaltenango, and Amatitlán are popular tourist attractions know for their thermal bath houses and spas. The construction company Bloteca, was the first to successfully apply a direct use of geothermal energy using steam in the curing process of concrete products (Merida, 1999). In 1993, a low temperature resource was discovered by accident 20 km west of the Amatitlán geothermal field after drilling for water to supply the plant. An in 1994, a well was drilled to a depth of 213 m with a bottom hole temperature of 185°C. More wells were drilled, and the company began to explore other uses for the geothermal energy.

In 1999, a fruit dehydration plant, Agroindustrias La Laguan, was build to use hot water from one of geothermal wells in the drying process. A downhole heat exchanger was installed in the well, along with an enhancer tube in order to increase the performance of the heat exchanger. A schematic diagram shows how hot water is used for the drying process (Figure 6). Water from a tank is first pumped into the well where it is heated. The hot water then flow through a pipe to a radiator. A ventilator blows cool air through the radiators were it heats up. After the water in the radiator cools, it flows to a tank where it is pumped back into the well. The company produces dehydrated pineapple, mango, banana, apple, and chili peppers. The project proved that direct use of geothermal energy is economically attractive and environmentally friendly by eliminating the need for fossil fuels in the industrial process.

## 6. CONCLUSIONS

- Guatemala needs to change the energy matrix, using renewable energy, in order to be independent from fossil fuels.

- There are 14 identified areas with geothermal resources, 7 of which are high temperature areas. Developing geothermal energy has been a slow process in the past, but new legislation promoting development of renewable resources is providing an incentive for private developers to invest in geothermal.

- Tecuamburro and Moyuta are promising geothermal areas that have studies at the prefeasibility level. Development of these new resources will depend on the rising cost of deep exploration.

- The Zunil I field has seen a decline in production due to declining reservoir pressure. In the future more make up wells will need to be drilled in order to raise the production of the field. The reinjection zone must also be relocated so that the reinjected fluid can provide pressure support to the reservoir. Make up wells drilled in 2005 have not been properly tested, but initial tests were not favorable. Nevertheless, INDE in the future plans to evaluate these wells before a decision is made to use their production to supply a 5 MW backpressure unit or to connect them to the existing Orzunil plant.

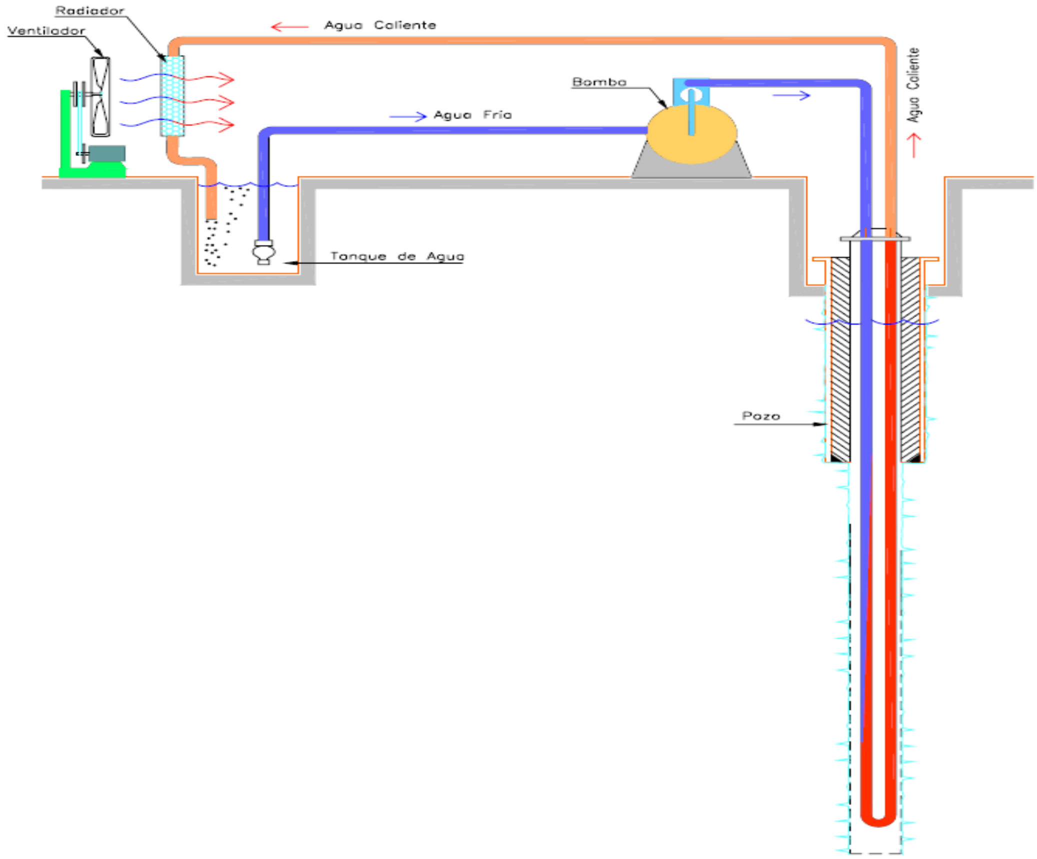


**Figure 6: Schematic diagram of Agroindustrias La Laguna dehydration plant in Amatitlán.**

- Ortitlán is scheduled to reach its design capacity towards the end of the second quarter of 2009, upon the connection of an additional well that was recently drilled, in order to comply with the terms of the contract to elevate the installed capacity in Amatitlán to 50 MWe by the year 2011.

- Bloteca and Agroindustrias La Laguna have applied direct use of geothermal energy in their industrial process such as curing construction blocks and dehydration of fruit. Both projects area environmentally friend, and economically attractive and can serve as examples that direct uses of geothermal energy can also be successfully applied in Guatemala and Central America.

REFERENCES

Asturias, F., 2005. Development of a Tridimensional Model of the Zunil I and II Geothermal Fields. Unpublished Report. Guatemala, 2005.

Asturias, F., 2003.Reservoir Assessment of the Zunil I and II Geothermal Fields, Guatemala. UNU Geothermal Training Programme Reports 2003. Reykyavik, Iceland, 2003.

Battocletti, L., Lawrence, R., 1999. Geothermal Resources in Latin America and the Carribbean. Sandia National Laboratories and US Department of Energy. February, 1999.

Boer, M., Grajeda, C., 2006. Lessons Learned from Geothermal Development in Guatemala. UNU/GTP and LaGeo Workshop for Decision Makers on Geothermal Projects in Central America, El Salvador, November, 2006.

Cepal Statistics 2008. Central America Isthmus. Electricity Subsector Statistics 2008. United Nations..LC/Mex. L.905 pp. 16-17.

Goff et al., 1991. A Re-evaluation of the Moyuta Geothermal System, Southern Guatemala. Geothermal Resources Council Transactions, Vol. 5, Davis, California, October 1991, pp 3-10.

Goff et al., 1992. Tecuamburro Volcano, Guatemala: Exploration Geothermal Gradient Drilling and Results. Geothermics, Vol. 2, 1992, pp. 483-502.

Janik, et al., 1992. Hydrogeochemical Exploration of Geothermal Prospects in the Tecuamburro Volcano Region, Guatemala. Geothermics, v. 21, 1992, pp. 447-481.

Lima et al., 1996. A Hydrogeological and Geochemical Model of the High Temperature Geothermal System of Amatitlán, Guatemala. Geothermal Resources Council Transactions, Vol. 20, September, 1996.

Lima, E., Roldan, A., 2003. Geothermal Guatemala, Past, Present, and Future Development of Geothermal Energy in Guatemala. Geothermal Resources Council Bulletin, 2003.

Merida, L., 1999. Curing Blocks Drying Fruit in Guatemala. GHC Bulletin, December 1999.

WestJec, 2006. Feasibility Study of the Tecuamburro Geothermal Field, Santa Rosa State, Guatemala. METI/JETRO, March, 2006.

**TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2009**

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid (explain)
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Data for 2009 if available, otherwise for 2008. Please specify which.

| Locality | Power Plant Name | Year Com-missioned | No. of Units | Status[1)] | Type of Unit[2)] | Total Installed Capacity MWe | Annual Energy Produced 2008[3)] GWh/yr | Total under Constr. or Planned MWe |
|---|---|---|---|---|---|---|---|---|
| Zunil, Quetzaltenango | Orzunil | 1999 | 7 | | B | 24 | 135.48 | |
| San Vicente Pacaya, Escuintla | Ortitlán | 2007 | 1 | | B | 25.2 | 136.50 | 50 |
| Total | | | | | | | | |
| Total | | | | | | | **271.98** | |

Source: www.amm.org.gt (Statistics report 2008)
INDE internal report 2008

## TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2005 TO DECEMBER 31, 2009 (excluding heat pump wells)

1) Include thermal gradient wells, but not ones less than 100 m deep

| Purpose | Wellhead Temperature | Number of Wells Drilled | | | | Total Depth (km) |
|---|---|---|---|---|---|---|
| | | Electric Power | Direct Use | Combined | Other (specify) | |
| Exploration[1)] | (all) | 4 | | | | 4 |
| Production | >150° C | 4 | | | | 6 |
| | 150-100° C | | | | | |
| | <100° C | | | | | |
| Injection | (all) | | | | | |
| Total | | 8 | | | | 10 |

Source: Geothermal Unit INDE

**TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES** (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Progran
(6) Private Industry

| Year | Professional Person-Years of Effort | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| 2005 | 2 | 3 | | 2 | N.A | |
| 2006 | 2 | 3 | | 2 | N.A. | |
| 2007 | 2 | 3 | | 1 | N.A | 4 |
| 2008 | 2 | 3 | | 2 | N.A | 6 |
| 2009 | 2 | 3 | 2 | 2 | N.A. | 8 |
| Total | 10 | 15 | 2 | 9 | N.A | 18 |

N.A. Not Available

**TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) US$**

| Period | Research & Development Incl. Surface Explor. & Exploration Drilling | Field Development Including Production Drilling & Surface Equipment | Utilization | | Funding Type | |
|---|---|---|---|---|---|---|
| | | | Direct | Electrical | Private | Public |
| | Million US$ | Million US$ | Million US$ | Million US$ | % | % |
| 1995-1999 | 2 | 5 | | 40 | 80 | 20 |
| 2000-2004 | 4.5 | 7 | | 5 | | 100 |
| 2005-2009 | 2 | 12 | | 45 | 15 | 85 |

Source: Geothermal Unit INDE