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STRATEGIES AND ECONOMICS OF GEOTHERMAL POWER DEVELOPMENT IN MEXICO

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ABSTRACT

This paper presents a summary of the geothermal energy costs in Mexico. The values range between 3.29 and 3.46 cents US per kilowatt-hour (kWh) for plants already in operation. The cost of the new Cerro Prieto IV project is 2.81 cents US per kWh, value comparable with the cost of highly efficient gas fired plants. The Las Tres Vírgenes project, made up of two 5 MW condensing plants will have a higher cost, of the order of 4.11 cents US per kWh, due to the size of the turbines and the rather isolated situation of the site. The Comision Federal de Electricidad (CFE) will issue an international bid for an EPC (Engineering, Procurement and Construction) contract to build four units of 25 MW each at the Los Azufres geothermal field. The estimated cost of production is 3.18 cents US per KWh. Mexico is currently engaged in the operation of competitive geothermal facilities and in the expansion of the installed capacity in old fields as well as in the new Las Tres Vírgenes field.

1. INTRODUCTION

Mexico has more than 25 years of experience producing electric energy from geothermal origin. Exploration to find geothermal resources capable for use in electrical projects is currently ongoing since the fifties. In fact, the first geothermal electric power plant commercially operating in the American Continent was placed in Pathé, State of Hidalgo, in the central portion of Mexico. These facts are more or less known among the geothermal community in the world.

However, public information about the economics of the Mexican geothermal fields and new projects is scarce, and particularly about the costs of generation of the geothermal plants.

The main components of the generation costs in the geothermal fields in operation in Mexico are presented in this paper. Calculated costs for the new geothermal electric projects, presently under construction or in planning, are also presented.

Since the geothermal plants in Mexico are owned and operated by the CFE, the power costs are lower than the compareable costs in privately owned and operated projects. In the CFE case the following costs are actually eliminated:

- No high risk investment returns are charged into exploration and steam supply development,
- No developers fees or profits are charged into the project capital costs,
- No equity investor returns are charged into the financing costs,
- The capital amortization is based on CFE's cost of borrowing,
- CFE, as a government entity, pays no geothermal royalties, and
- Operations and maintenance are performed at CFE's costs, without additional fees or profit.

These factors, which are part of CFE's geothermal strategy, result in geothermal power costs to CFE, which are competitive with other power technologies.

2. THE CERRO PRIETO IV PROJECT

The Cerro Prieto geothermal field is located in the northwestern part of Mexico, very close to the border with the United States of America. Presently there are nine geothermal electric plants operating on it, which are part of an electric system isolated from the national grid (the National Electric System).

The isolated electric system, the Baja California System, covers the northern portion of the Baja California Peninsula, and has two interconnection points to the grid of California, USA, that can handle 400 MW. The Baja California System has experienced an annual growth close to 7%.

The first geothermal power units of Cerro Prieto started commercial operation in April 1973. In 1979 two more power units were commissioned, and in 1982 a fifth unit was installed. All of them use the steam coming from the portion of the field known as Cerro Prieto I (CP-I). Additional exploration activities led to the discovery of portions known as CP-II and CP-III, so in 1986 and 1987 another four power units, of 110 MW each, were commissioned. Present installed capacity in the field is 620 MW and supplies 75% of the energy consumed in the Baja California grid.

In 1998 129 geothermal wells produced almost 45 million metric tons of steam in Cerro Prieto, which were used to generate 4,845 gigawatts-hour (GWh) (Quijano-León and Gutiérrez-Negrín, 2000), with a power average of 553 MW. The steam was accompanied by 66 million tons of saline water, almost the half of which (31 million) was injected through seven injection wells. The rest was conducted to an evaporation pond, thus avoiding any contamination to ground water.

During 26 years of commercial exploitation, the main parameters of the Cerro Prieto geothermal reservoir, such as pressure, temperature and enthalpy, have shown an evolution very close to that predicted.

On the other hand, the generation cost has been below 3.46 US cents per kilowatt-hour, which is competitive with the generation costs of electricity produced in Mexico by means

of other technologies. That cost is made up of the following items (figures in US cents per kWh):

Power plant investment	1.63
Operation and Maintenance (plant)	0.36
Steam supplying	1.17
Operation and Maintenance (field)	0.30
Total	3.46

As a result of recent exploration and modeling studies carried out in Cerro Prieto, the CFE decided to increase the installed capacity by 100 MW, by means of four condensing power plants of 25 MW each. This is the project named CP-IV. The bid for the construction and installation of the units was launched in December 1996. The chosen financial scheme was a Build, Lease and Transfer (BLT) contract, in which the contractor must provide the financial resources, and the power plants will be operated by the CFE. The criterion for the evaluation of the offers was the levelized generation price.

By July 1997 the CFE received five offers. The offers were technically and economically evaluated, and the winner presented the following parameters:

Gross capacity	107.6 MW
Net capacity	100.0 MW
Cost of the installed kW	797.0 USD
Cost/kWh	2.81 US cents

This cost includes the steam supply and Operation and Maintenance (O&M). It was the lowest levelized generation price, and is lower than the average generation cost of geothermal electricity in Mexico, which is 3.46 US cents, as mentioned.

The construction of the project started in April 1998, and the scheduled commission date is July 2000. On the other hand, drilling of the production wells for this project started in May 1999, by means of a contract of 20 million US dollar.

THE LOS AZUFRES II PROJECT

The Los Azufres geothermal field is located in the State of Michoacán, at the central part of Mexico. The field covers an area of 60 km^2 in a volcanic complex that belongs to the Mexican Volcanic Belt, at 2,800 meters above sea level.

In 1982 the first five power units were installed in Los Azufres. They were backpressure units of 5 MW each. In 1986 another 5 MW unit started operation, and in 1988 one condensing power plant of 50 MW was commissioned. This is the seventh unit, called the Tejamaniles Unit. Between 1989 and 1992 another three backpressure power units (numbers 8, 9 and 10) started operation. In 1993 two more power units were installed, each of binary cycle type and 1.5 MW of capacity.

Presently the field has an installed capacity of 93 MW, excluding unit 1, which is operating in the Amatitlán, Guatemala, geothermal field. This unit, the first geothermal electric power unit in Guatemala, is being used to assess the reservoir under exploitation conditions, and is part of an international service contract that involves the CFE.

The power units operating in Los Azufres produced 457.4 GWh during 1998 (Quijano-León and Gutiérrez-Negrín, 2000). However, this figure is not representative, because unit 7 presented several problems in that year. Regular production in the field is around 700 GWh (Hiriart-Le Bert and Gutiérrez-Negrín, 1998).

In 1998, 17 production wells were in operation in Los Azufres, with an average production of 40.6 t/h per well. Thus, 5.9 million tons of steam were produced during the year, at an annual average of 678 t/h (Quijano-León and Gutiérrez-Negrín, 2000). The separated water was of 3.5 million tons, and was returned to the reservoir through 6 injection wells.

In Los Azufres the generation cost is 3.29 US cents per kWh, and is composed of:

Power plant investment	1.54
Operation and Maintenance (plant)	0.34
Steam supply	0.91
Operation and Maintenance (field)	0.50
Total	3.29

This cost is lower than in the Cerro Prieto field (3.46), because the power plant investment and the steam supply costs in Los Azufres are also lower than in Cerro Prieto, even though the O&M costs are slightly higher.

In the field there are some 30 production wells, so the production capacity is around 1,200 t/h. Therefore, there is an excess of capacity of approximately 600 t/h of steam, which can be used to supply new power plants.

Taking into account that availability of steam, and considering that the reservoir has been exploited during 17 years with almost no declination in the steam production, the CFE decided to increase the installed capacity by 100 MW. As a matter of fact, the mathematical modeling of the geothermal system suggests the reservoir in Los Azufres can support another 260 MW: 170 MW in the northern zone and 90 in the southern zone (Hiriart-Le Bert and Gutiérrez-Negrín, 1996).

Therefore, the CFE is preparing the technical and economic documents to issue an international bid for and EPC (Engineering, Procurement and Construction) contract to install four 25 MW each power units in Los Azufres, project named Los Azufres II. The financial scheme for this project will probably involve private financing from the contractor during the construction period. The CFE would pay the total amount to the contractor, once this delivers the units, by issuing international debt bonds. The CFE is considering also a bid for the drilling of the necessary production wells for the units and the construction of the surface steam gathering system (separators, silencers, steam ducts) under the same financing scheme.

The Los Azufres II project is very close to the regions with the highest demand of electrical energy, whose growth in the following ten years is estimated at 7% per year. Four condensing units of 25 net MW each, located at different parts of the field, with four machine halls comprising the project. Sites where the units will be located are zones of the field where the reservoir has been exploited during 15 or more years by means of backpressure turbine units. Thus, some of

these backpressure units will be moved to new zones of the field to prove the reservoir conditions.

The CFE calculates that it will be necessary to drill 11 new production and one injection well to complete the steam supply for the Los Azufres II units and for the backpressure units to be moved.

The main parameters of the project are as follows:

Gross capacity	107.6 MW
Net capacity	100.0 MW
Cost of the installed kW	815.0 USD
Cost/kWh	3.18 US cents

THE LOS HUMEROS GEOTHERMAL FIELD

This field is located at the eastern part of Mexico, just between the Mexican states of Puebla and Veracruz. It covers an area of 16 km^2 and is at 2,800 meters above sea level. The field is inside a Quaternary volcanic caldera that is part of the Mexican Volcanic Belt. The geothermal fluids are contained in hydrothermally altered andesitic rocks.

In 1968 the CFE started the first exploratory geological studies in Los Humeros, and in 1981 the first exploration wells were drilled. Two first power units of 5 MW each and of the backpressure type, were commissioned in 1990. In 1991 another two units were commissioned, and one more unit was added each year to complete seven power units in 1994. All of them are of the backpressure type and have a nominal capacity of 5 MW. However, the CFE has been operating the units at 6 MW since 1997, making for an installed capacity of 42 MW.

During 1998 those seven power units produced 357 GWh. They used the steam produced by 20 wells, at an average rate of 543 t/h (27.3 t/h per production well), totaling 4.75 million metric tons per year (Quijano-León and Gutiérrez-Negrín, 2000). The associated brine was around 1 million tons, which was returned to the reservoir by means of two injection wells.

In the Los Humeros field the generation cost is 3.45 US cents per kWh, and it is made up of:

Power plant investment	1.64
Operation and Maintenance (plant)	0.30
Steam supply	0.91
Operation and Maintenance (field)	0.60
Total	3.45

This cost is practically the same as the Cerro Prieto, and little higher than the generation cost obtained for the Los Azufres field.

There are no new geothermal projects programmed for the Los Humeros field, but the CFE is studying the possibility to install a condensing power unit of 50 MW by moving some of the backpressure units.

THE LAS TRES VÍRGENES FIELD

Las Tres Vírgenes is the newest geothermal field in Mexico, without power units as yet. The field is located at the middle portion of the Baja California Peninsula, within a volcanic Quaternary complex composed of three volcanoes aligned north-south.

That portion of the country is isolated from the National Electric System and, also, from the Baja California System. The electric energy is generated by means of thermal power plants of internal combustion type that use diesel fuel. The generation cost of this type of plants is very high, because of the cost of the fuel and its transportation.

Based on the assessment of the production wells drilled in the field, the CFE decided to construct and install two condensing type power units of 5 MW each. This is the Las Tres Vírgenes I project. Thus, in October 1997 an international bid for construction and installing of those units was issued, under a BLT financial scheme. The bidding process was concluded in December 1998 when the contract was awarded.

The main technical and economic parameters of the Las Tres Vírgenes I project are as follows:

Gross capacity	10.85 MW
Net capacity	10.00 MW
Cost of the installed kW	1,434.00 USD
Cost/kWh	4.11 US cents

The total cost includes steam supply and O&M. The costs are higher than those for the Cerro Prieto IV project, as expected, because of the size of the turbines and the low pressure of the steam, but also because the production and transmission of the geothermal fluids are more difficult and expensive than in the Cerro Prieto field. It is due to the low permeability of the production rocks at depth (granites and granodiorites) and the roughness of the terrain. In any case, the total unit cost of the energy (4.11 cents US/kWh) is lower than the present cost of the energy produced by means of diesel.

Construction of the project started in June 1999, and both units should be commissioned in February 2001. All the necessary production and injection wells have been already drilled.

CONCLUSIONS

Generation costs for geothermal power in Mexico are competitive with the cost of generation by means of fossil fuels. They range between 3.29 and 3.46 US cents per kilowatt-hour in the three geothermal fields in operation. Cost of generation for new geothermal electric projects are very attractive, ranging from 2.81 cents US for the Cerro Prieto IV project to 3.18 cents US for the Los Azufres II project (both of 100 MW net). An exception is the Las Tres Vírgenes project (4.11 cents), but even it is competitive with the local costs of generation, due to the isolation and inaccessibility of the region.

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