

NOTICE CONCERNING COPYRIGHT RESTRICTIONS

This document may contain copyrighted materials. These materials have been made available for use in research, teaching, and private study, but may not be used for any commercial purpose. Users may not otherwise copy, reproduce, retransmit, distribute, publish, commercially exploit or otherwise transfer any material.

The copyright law of the United States (Title 17, United States Code) governs the making of photocopies or other reproductions of copyrighted material.

Under certain conditions specified in the law, libraries and archives are authorized to furnish a photocopy or other reproduction. One of these specific conditions is that the photocopy or reproduction is not to be "used for any purpose other than private study, scholarship, or research." If a user makes a request for, or later uses, a photocopy or reproduction for purposes in excess of "fair use," that user may be liable for copyright infringement.

This institution reserves the right to refuse to accept a copying order if, in its judgment, fulfillment of the order would involve violation of copyright law.

1997-2006: A Decade of Geothermal Power Generation in Mexico

Luis C.A. Gutiérrez-Negrín

Comisión Federal de Electricidad, Morelia, Mich., Mexico

E-mail: luis.gutierrez03@cfe.gob.mx

Keywords

Geothermal field management, steam production, geothermal electricity generation, geothermal indexes, future outlook, Mexico

ABSTRACT

Geothermal electricity generation in Mexico has grown significantly during the last decade. The number of geothermal fields in production, the installed capacity, the production of steam and the power generation increased between one fifth and one third between 1997 and 2006. Some indicators defined in this paper, like the Efficiency and the Production-Per-Well indices, show slight improvements, and yet there was some decrease in the Steam Specific Consumption and Capacity Factor indices. Geothermal development plans in Mexico include the Cerro Prieto V (100 MW), Los Humeros II (46 MW) and Cerritos Colorados (75 MW) projects, and an eighth 5-MW, back-pressure unit that is being installed at Los Humeros. Exploration of the Acoculco, Domo San Pedro, and La Soledad geothermal areas is in the planning stage.

Introduction

The electricity sector in Mexico remains in the hands of the Federal Government through two public utilities in charge of generation, transmission, distribution and commercialization. They are the Comisión Federal de Electricidad (CFE), and Luz y Fuerza del Centro (LFC), which offer the so-called “public electricity service”.

Luz y Fuerza del Centro is mainly an electricity distribution and commercialization company that is in control of only 1.5% of the national installed capacity, and yet has around 5 million of customers in an area that covers about 20,500 km² in Mexico City and parts of the surrounding central Mexican states of Mexico, Hidalgo, Morelos and Puebla (LFC, 2007).

Comisión Federal de Electricidad is in charge of the remaining 98.5% of the national installed electric capacity, as

well as the operation and maintenance of the entire electrical grid and the national center of energy control and dispatch (Centro Nacional de Control de Energía; CENACE). CFE has nearly 24 million of customers, and had sales for the equivalent of almost 14 billion dollars in 2005 (CFE, 2007b). The utility owns and operates with its own personnel 529 power units of different capacities and types (hydro, steam, gas, combined cycle, internal combustion, coal, nuclear, geothermal, and wind); CFE’s total installed capacity was 37,553 MW as of December 2006 (CFE, 2007a).

The Comisión also receives, transmits, distributes and commercializes the electricity produced by independent power producers (IPP). In 2006 there were 65 power units in Mexico with a total installed capacity of 10,387 MW, all of combined cycle type, owned and operated by private companies (CFE, 2007b). These companies sell their electricity production to CFE through long-term power purchasing agreements (PPA); at present they are not allowed to negotiate and contract with private costumers.

Moreover, there are around 465 power plants, with total installed capacity of 7016 MW (CRE, 2007), which were constructed and are presently owned and operated by private investors to satisfy their own power demand (“self-generation”). These plants were built to take advantage of existing industrial processes to co-generate electricity, or with the sole purpose to supply the owners’ electricity needs. It is worth mentioning that a previous estimate of 14,834 MW as self-generation capacity in Mexico (Gutiérrez-Negrín and Quijano-León, 2005)

Table 1. 2006 installed geothermal power generating capacity in Mexico. (Based on data from CFE, 2007a; CFE, 2007b; CRE, 2007).

	MW	% of Total	Power Units
Comisión Federal de Electricidad (CFE)	37,553	67.3	529
Luz y Fuerza del Centro (LFC)	864	1.5	53
Independent Power Producers (IPP)	10,387	18.6	65
- Total for Public Service	48,804	87.4	647
Self-generation and co-generation	7016	12.6	465
Total Installed Capacity	55,820	100.0	1112

was too large, since that number included the capacity of the IPP. One should add that self-generators can sell their excess power to CFE.

In summary, the total installed electricity generating capacity in Mexico was 55,820 MW in December 2006 (Table 1). Ten years ago, that capacity was 34,815 MW (Hiriart-Le Bert and Gutiérrez-Negrín, 1998). At that time all the power plants were run by CFE and LFC, since there were no IPP. Therefore, in the last ten years the installed capacity in Mexico increased by 60.3%, at an average 6% growth per year.

According to CFE (2007a, 2007b) the total electricity generated for public service in Mexico during 2006 was 223,018 GWh (Table 2). The power plants of CFE produced 162,472 GWh (72.8%); those operated by IPP, 58,884 GWh (26.4%), and the LFC plants, 1,663 GWh (less than 1%). In 1997 that total amounted to 161,386 GWh (Hiriart-Le Bert and Gutiérrez-Negrín, 1998), thus there has been an increase of 38.2% during the last decade (i.e. at an average annual growth of 3.8%).

The breakdown of the installed capacity and power generated by public service plants is given in Table 2. It shows that in 2006 the power plants fed by geothermal fluids had an installed capacity of 953 MW (2.0% of Mexico's total) and had generated 6685 GWh (3.0 % of the total).

Table 2. December 2006 breakdown of Mexico's public electricity service.

Energy source	Installed capacity		Electricity generated	
	MW	%	GWh	%
Oil and gas*	33,250	68.1	157,187	70.5
Water (Hydro)	10,551	21.6	30,305	13.6
Coal	2600	5.3	17,931	8.0
Nuclear	1365	2.8	10,866	4.9
Geothermal	953	2.0	6685	3.0
Wind ⁺	86	0.2	44	~ 0
Total	48,805	100	223,018	100

*Oil derivatives and natural gas; ⁺The main wind project at La Venta (State of Oaxaca) was commissioned in December 2006.

Geothermal Electricity Development in Mexico

As of December 1997 there were three geothermal fields under production in Mexico, i.e. Cerro Prieto, Los Azufres and Los Humeros. The geothermal division of CFE (the "Gerencia de Proyectos Geotermoelectrónicos") had been recently moved from the construction ("Subdirección de Construcción") to the operation area ("Subdirección de Generación"), which meant a series of management changes (Hiriart-Le Bert and Gutiérrez-Negrín, 1998).

In 2006 there were four fields under exploitation; added was Las Tres Vírgenes where the first two units were commissioned in July 2001. A fifth field, Cerritos Colorados (formerly La Primavera) remains on stand-by (Figure 1).

The main data regarding the geothermal power development in Mexico between 1997 and 2006 are presented in Table 3. It shows that during this period, (1) the number of



Figure 1. Location of the main geothermal fields in Mexico.

production wells increased from 168 to 219, (2) steam production went from 53.3 to 72.5 million tons, (3) the added installed geothermal electrical capacity was 203 MW (27% change), and (4) the amount of electricity generated increased by 1207 GWh (22% growth).

By "available steam" we mean the amount of steam that was used to generate electricity. The difference between the amounts of produced and available steam is what has been released to the atmosphere without going through the turbines, and what was lost in the steam transmission system between the wells and the power plants. The available steam showed an increase of 38% during this ten-year period (Table 3).

In Table 3 four indices are presented. The first one is the ratio between the available and the produced steam, expressed as percentage. It indicates how effectively the produced steam was used to generate electricity and can be considered as a sort of efficiency index (EI). It slightly increased (less than 2%) between 1997 and 2006.

Table 3. Data and indices on geothermal power development in Mexico.

Data		1997*	2006	Difference
(a)	Number of wells under production	168	219	30.2%
(b)	Steam production (million tons)	53.3	72.5	36.1%
(c)	Steam production rate (t/h)	6084	8278	36.1%
(d)	Available steam (million tons)	50.9	70.3	38.2%
(e)	Installed capacity (MW)	750	953	27.1%
(f)	Electricity generation (GWh)	5478	6685	22.0%
Indices				
(EI)	Efficiency index [(d)/(b)*100] (%)	95.50	97.01	1.6%
(PPW)	Production per well [(c)/(a)] (t/h)	36.22	37.84	4.5%
(SSC)	Steam specific consumption [(d)/(f)] (t/MWh)	9.29	10.52	13.3%
(CF)	Capacity factor (%)	83.38	80.08	-4.0%

*Data from Hiriart-Le Bert and Gutiérrez-Negrín (1998)

The average production per well (PPW) index, given in tons of steam per hour and well, is the result of dividing the average total production rate by the number of extraction wells in operation. In 2006 the PPW was 4.5% higher than in 1997 (Table 3). The highest PPW was reached in 2000 with a value of 41.5 t/h per well, when only 157 production wells were in operation (Gutiérrez-Negrín and Quijano-León, 1995).

The third index in Table 3 is the specific steam consumption (SSC), which corresponds to the amount of steam utilized to generate one megawatt-hour, and is obtained by dividing the available steam by the amount of electricity generated; it is expressed as tons of steam per megawatt-hour. The smaller this index SSC the better, since it indicates that one generates electricity using less steam. In 1997 the SSC was lower than in 2006, because last year the maintenance of some Cerro Prieto units took more time than originally planned.

The last index is the capacity factor (CF) that relates the actual and theoretical amounts of electricity generation. A CF of 100% indicates that the power units operated uninterruptedly during the whole period (a year, in this case), which usually is impossible since the units must be off line during a certain period of time for maintenance. The index was also better in

1997 than in 2006, due to last year's long maintenance period at Cerro Prieto. The highest CF in the past decade, however, was accomplished in 2005 (i.e. 87.4%).

The number of production wells in operation in Mexico has varied during the last ten years (Figure 2). It dropped from 168 in 1997 to 157 in 2000 because of delays in the bidding process to drill new wells, particularly at Cerro Prieto. After that problem was solved, the number of wells climbed to 199 in 2005 and 206 in 2006.

Figure 3 depicts changes in total annual steam production. There was a significant increase in 2003, due to a larger number of production wells in operation. That year, several new wells came on line at Cerro Prieto and Los Azufres, and the Los Azufres II (4 x 25 MW) project was commissioned. It is important to point out that steam production in 2000 was even better than in 1999 and 2001, in spite of the lower number of production wells (Figures 2 and 3).

The history of the installed geothermal electrical capacity and generation in Mexico during the 1997-2006 period is shown in Figure 4. The main increases in installed capacity occurred in 2000 and 2003, when the Cerro Prieto IV (4 x 25 MW) and Los Azufres II (4 x 25 MW) projects started operation, respectively. The largest amount of total annual geothermal power generation was attained in 2005; it decreased in 2006 because of the maintenance of the Cerro Prieto power units (see above).

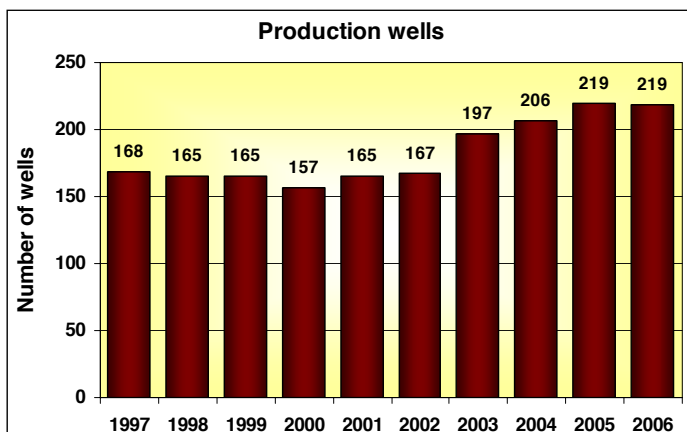


Figure 2. Number of geothermal production wells on line in Mexico during the 1997-2006 period.

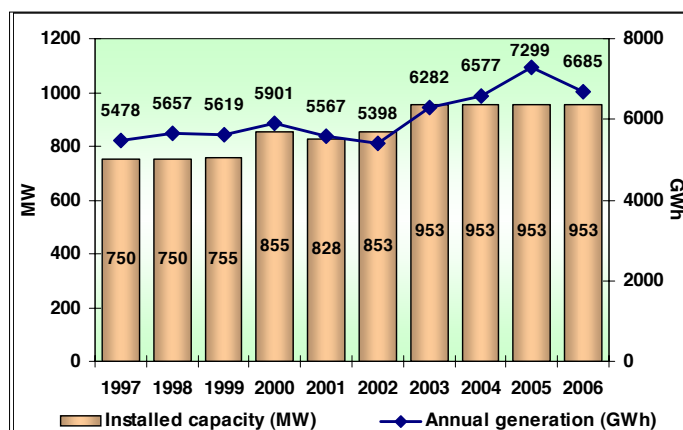


Figure 4. Total installed geothermal electricity capacity and power generation in Mexico during the 1997-2006 period.

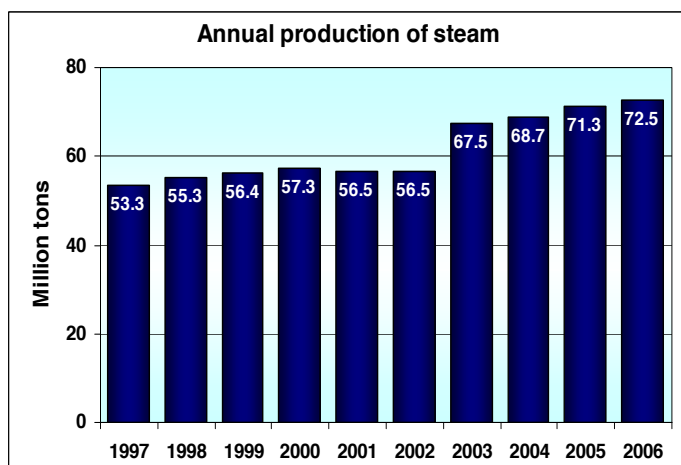


Figure 3. Total annual geothermal steam production in Mexico during the 1997-2006 period.

Summary of Developments Between 1997 and 2006

Data for 1997 and 2006 on the four producing geothermal fields in Mexico are given in Table 4 and Figs. 5 and 6. Next we will present some relevant information on the electrical development of these areas.

The first power plant at Cerro Prieto, the most important geothermal field in Mexico that is located in the northwestern part of the country (Figure 1), came on line in 1973. Presently there are four 110-MW, four 37.5-MW, four 25-MW and one 30-MW units, all of condensing type; the total installed capacity is 720 MW.

The first units at the Los Azufres field of central Mexico (Figure 1), were of the backpressure type; five 5-MW units

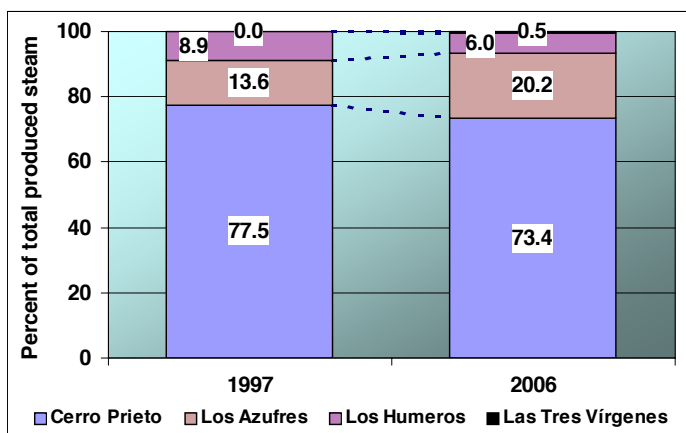


Figure 5. Contribution (in percent) of each Mexican field to the total annual geothermal steam produced in 1997 and 2006.

(No. 1 to 5) were commissioned in 1982. The installed capacity in this field grew more than 100% in the last decade (Table 4). At present it is 188 MW (i.e. one 50-MW condensing, four 25-MW condensing, seven 5-MW backpressure, and two 1.5-MW binary cycle units).

Geothermal steam production at Los Azufres was a fifth of Mexico's total last year, rising from 13.6% in 1997 (Figure 5). The electric generation in the field rose from 11% to almost 23% between 1997 and 2006 (Figure 6).

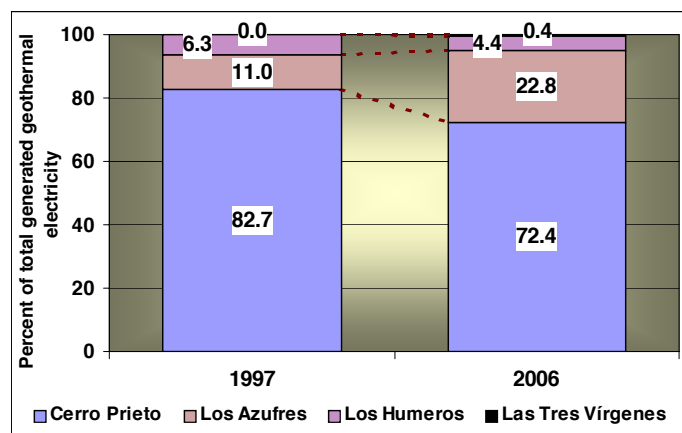


Figure 6. Contribution (in percent) of each Mexican field to the total annual geothermal power generation in 1997 and 2006.

An eighth 5-MW backpressure unit is being installed at Los Humeros field, and is expected to be operating during the second half of 2007. This unit was moved from the Cerro Prieto field.

The most recent Mexican geothermal field that came under production was that at Las Tres Vírgenes, in the Baja California peninsula (Figure 1). Two 5-MW condensing power units were commissioned in 2001; the power being generated is being sent to local electrical grid.

Table 4. Electricity developments in each of the geothermal fields of Mexico during the 1997-2006 period.

Data	Cerro Prieto		Los Azufres		Los Humeros		Tres Vírgenes	
	1997*	2006	1997*	2006	1997*	2006	1997*	2006
Number of wells under production	129	165	19	36	20	17	0	1
Steam production (million tons)	41.3	53.2	7.3	14.6	4.7	4.3	0	0.3
Steam production rate (t/h)	4712	6073	830	1672	539	496	0	38
Available steam (million tons)	39.2	51.4	7.1	14.5	4.6	4.2	0	0.3
Installed capacity (MW)	620	720	88	188	42	35	0	10
Electricity generation (GWh)	4529	4843	605	1522	343	295	0	25
Indices								
Efficiency index (EI) (%)	94.92	96.59	97.25	98.76	97.46	96.08	0	99.22
Production per well (PPW) (t/h)	36.53	36.80	43.68	46.44	26.95	29.19	0	28.83
Steam specific consumption (SSC) (t/MWh)	8.66	10.61	11.69	9.50	13.40	14.15	0	13.08
Capacity factor (CF) (%)	83.39	76.79	78.47	92.42	93.32	96.29	0	28.40

*Data from Hiriart-Le Bert and Gutiérrez-Negrín (1998)

The generation of electricity at the Los Humeros geothermal field, located in the central-east part of the country (Figure 1), began when two 5 MW backpressure units were commissioned in 1990. Since then, other five of these units came on line; at present the total installed capacity in the field is 35 MW. One should note that these units were generating 6 MW, 120% of their nominal capacity, during the 1996-2000 period; that is why the 1997 installed capacity is shown as 42 MW in Table 4. The running of the units above their nominal capacity may have caused the failure of several of them in the year 2000.

Future Outlook and Final Remarks

The last decade has been fruitful for geothermal power development in Mexico. The number of geothermal fields under exploitation and of production wells in operation, as well as the installed capacity, steam production and the electricity generation increased between 22 and 36% during that period. The Efficiency (EI) and the Production Per Well (PPW) indices showed slight improvements (1.6 and 4.5%, respectively). On the other hand, the Steam Specific Consumption (SSC) and the Capacity Factor (CF) indexes decreased (13.3% and

4%, respectively), but that was because of maintenance problems at Cerro Prieto in 2006.

Cerro Prieto continues to be the main Mexican geothermal field under production, but its relative importance in the country's geothermal scene has decreased. That is, it generated 83% of the total geothermal power in 1997, but 72% in 2006 (Figure 6). Contrarily, the contribution of the Los Azufres field to the national total of geothermal electricity generation jumped from 11 to almost 23%.

Future geothermal development plans include the Cerro Prieto V, Los Humeros II and Cerritos Colorados projects. The

first one is composed of two 50-MW condensing units (100 net MW or 107 gross MW); probably it will be financed using a BLT (build, leasing, transfer) scheme. The international bid is scheduled to be announced during the second half of 2007, with construction starting in the second quarter of 2008 and commissioning planned for April 2010.

Los Humeros II project has two phases and would add 46 MW (net) to the installed capacity at this field. Phase A includes the construction and installation of one 25-MW condensing unit (26.6 gross MW), and Phase B, the construction and installation of seven 3-MW low-pressure units to be placed at the end of each of the present seven backpressure units and run using the steam presently being discharged to the atmosphere. Bidding dates are September and November 2007 for these two phases, respectively; the corresponding planned construction periods starting in April and June 2008. Both projects are expected to be completed by April 2010.

The Cerritos Colorados project consists of one 25-MW unit followed by one of 50-MW, both of condensing type; these would be the first power units installed in this field. The project includes the construction of a 14.5-km long, 69 kV transmission line. Bidding dates have not been decided yet since the project has to be approved by the environmental authorities first.

Regarding to exploration plans, the drilling of a deep well in the Aocolco geothermal zone is planned for the second half of 2007. Aocolco is located in the State of Puebla, in the same region as the Los Humeros field, and has already been explored by the CFE; it included an exploration well

that showed relative high temperatures. Other geological and geophysical studies will be carried out in the Domo San Pedro (State of Nayarit) and La Soledad (State of Jalisco) geothermal areas during 2007.

Acknowledgement

Author likes to thank Marcelo Lippmann for his patient and careful review of the original manuscript.

References

- CFE, 2007a. Informe mensual de operación - Diciembre de 2006. Comisión Federal de Electricidad, Subdirección de Distribución, Unidad de Supervisión, Control y Gestión. Unpublished internal report, 21 pp.
- CFE, 2007b. Data from the website of the Comisión Federal de Electricidad: <http://www.cfe.gob.mx>.
- CRE, 2007. Tabla de permisos de generación e importación y de energía eléctrica vigentes. Comisión Reguladora de Energía website: <http://www.cre.gob.mx>.
- Gutiérrez-Negrín, L.C.A., and J.L. Quijano-León, 2005. Results of geothermal exploitation in Mexico in 2004. *GRC Transactions*, Vol. 29, pp. 229-233.
- Hiriart-Le Bert, G., and L.C.A. Gutiérrez-Negrín, 1998. Results of the geothermal exploitation in Mexico in 1997. *Geotermia*, Vol. 14, No. 2, pp.71-77.
- LFC, 2007. Data from the website of Luz y Fuerza del Centro: <http://www.lfc.gob.mx>.

