

Update of Geothermics in Mexico

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Abstract

Four geothermal fields are currently operating in Mexico (Cerro Prieto, Los Azufres, Los Humeros and Las Tres Vírgenes), with a total installed geothermal-electric capacity of 953 megawatts (MW). This means the country is located in third place, worldwide, just behind the USA and the Philippines. Thirty-six power plants of several types (condensing, back pressure and binary cycle), between 1.5 and 110 MW, operate in the fields, fed by 197 wells with a combined production of 7,700 metric tons of steam per hour (t/h). These production wells have depths between 600 and 4,400 meters. Steam comes with 8,750 t/h of brine that is injected through 19 injection wells or treated in a solar evaporation pond of 14 km² in Cerro Prieto. During 2003, steam produced in those fields equaled 67.5 million metric tons, and the power plants generated 6,282 gigawatt-hours (GWh), which represented 3.1% of the electric energy produced in Mexico. All the power plants and the geothermal fields are operated by the public utility, the Comisión Federal de Electricidad (CFE).

Keywords: Mexico, geothermal fields in operation, steam production, power capacity and generation, direct uses.

Actualización de la geotermia en México

Resumen

Actualmente se operan en México cuatro campos geotérmicos (Cerro Prieto, Los Azufres, Los Humeros y Las Tres Vírgenes), con una capacidad geotermoeléctrica total de 953 megawatts (MW). Esto coloca al país en el tercer lugar mundial, detrás de Estados Unidos y Filipinas. En esos campos operan treinta y seis unidades de tipos diversos (a condensación, a contrapresión y de ciclo binario), entre 1.5 y 110 MW, alimentadas por 197 pozos con una producción combinada de 7,700 toneladas de vapor por hora (t/h). Estos pozos productores tienen profundidades entre 600 y 4,400 metros. El vapor sale acompañado por 8,750 t/h de salmuera, que se inyecta en 19 pozos inyectoros o se trata en una laguna de evaporación solar de 14 km² en Cerro Prieto. Durante 2003 el vapor producido en los campos sumó 67.5 millones de toneladas y las unidades generaron 6,282 gigawatts-hora (GWh), lo que representó el 3.1% de la energía eléctrica producida en México. La empresa pública Comisión Federal de Electricidad (CFE) opera todas las plantas y campos geotérmicos.

Palabras clave: México, campos geotérmicos en operación, producción de vapor, capacidad instalada y generación, usos directos.

1. Introduction

Geothermics is used in Mexico mostly to generate electric energy, with some isolated direct uses restricted to small pilot projects in the Los Azufres and Los Humeros geothermal fields. There are also many places

where hot or warm waters are used for recreation and therapeutic purposes, but there are no coordinated efforts to promote it, and no available information on investments.

Mexico has two public utilities in charge of production, transmission, distribution and commercialization of electric energy: Comisión Federal de Electricidad (CFE) and Luz y Fuerza del Centro (LFC). Also, almost 6,000 MW of gas-fired, combined-cycle plants were constructed in the last few years and are being operated by independent power producers (IPP), who sell all their electric production to CFE through long-term power purchasing agreements (PPA). All of the geothermal power plants and fields are operated by CFE.

This paper presents the status of geothermics in Mexico, and the developments and achievements that occurred in the last five years, and is adapted from the official paper to be presented in the next World Geothermal Congress.

2. Electricity in Mexico

As of December 2003 the installed electric capacity in Mexico was 43,727 MW (Table 1). This figure includes only the so-called electricity for public service, that is to say, electric energy distributed and sold by CFE and LFC. However, there were at that time 5,492 MW of additional electric capacity installed in power plants constructed and operated by private companies for self-supplying or as a result of co-generation industrial processes (CFE, 2004). Thus, total electric capacity in Mexico, including self-suppliers and co-generators, was 49,219 MW. It is important to mention that self-suppliers and co-generators are allowed to sell their excess energy to CFE, and of course they can get energy from the public grid to compensate any deficit and fulfill their needs.

Table 1. Present and planned production of electricity.

	Geothermal		Fossil Fuels		Hydro		Nuclear		Wind		Total	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
In operation in December 2003*	953	6,282	31,792	164,397	9,615	19,753	1,365	10,502	2	5	43,727	200,939
Under construction in December 2003	0		6,366		1,374		0		0		7,740	
Funds committed but not yet under construction in December 2003	125		6,499		0		0		100		6,724	
Total projected use by 2010**	1,078		44,657		10,989		1,365		102		58,191	

* Figures do not include 5,492 MW of installed capacity for co-generation and self-supplying, mostly from fossil fuels.

** For total effective projected use, consider that CFE plans to dismantle old power plants (fossil fuels) for a total of 2,957 MW between 2004 and 2010.

(1) Capacity in MW(e)

(2) Gross Production in GWh/year

From that total of 43,727 MW for public service, CFE owns and operates 36,971 MW (84.5%), LFC 834 MW (1.9%) (CFE, 2004b), and IPPs own and operate 5,922 MW (13.5%).

As shown in Table 1, 72.7% of the installed capacity is based on fossil-fueled power plants (gas and liquid hydrocarbons, and coal), 22% is hydroelectric power, 3.1% is nuclear-electric and 2.2% is geothermal-electric. Wind is less than 0.01%.

Generation of electricity in Mexico during 2003 was 200,939 GWh (Table 1). Out of that, 168,515 GWh were generated by the power plants operated by CFE (83.9%), 1,629 GWh (0.8%) by LFC (CFE, 2004b) and 30,795 GWh (15.3%) by IPPs.

In 2003, 164,397 GWh of energy were generated by fossil-fueled power plants (Table 1), or 81.8% of the total, while hydroelectric plants contributed only 9.8%, nuclear 5.2%, and geothermics 3.1%. Wind-electricity was insignificant.

By December 2003, several fossil-fueled power plants (including one coal-electric) with 6,366 MW of additional capacity were under construction to be commissioned between 2005 and 2010. Two hydro-electric plants (El Cajón and the third stage of Chicoasén) were also under construction, for 1,374 MW more (CFE, 2003; Table 1). For geothermal plants there are only plans for 135 MW more (Los Humeros and La Primavera), and for wind-electric plants the only project is La Venta II (100 MW).

Thus, the additional capacity to be commissioned between 2005 and 2010 equals 14,474 MW, considering plants already in construction or planned (Table 1). However, CFE has plans to dismantle some old plants, losing 2,957 MW between 2004 and 2010 (CFE, 2003). It is estimated, on the other hand, that the installed capacity for self-supplying and co-generation plants will be 7,003 MW. Thus the total projected use by 2010 would be: $58,201 - 2,957 + 7,003 = 62,247$ MW, out of which 55,244 MW will be operating for public service, instead of those 58,201 MW reported in Table 1.

Development plans for electric capacity between 2003 and 2012 have been made by CFE based on an estimate of economic growth at an average annual rate of 4.7% for the gross internal product, which implies an average annual rate of growth of 5.6% for the electric demand (CFE, 2003). Those estimates could be high, since the average annual rate of economic growth in Mexico has been 0.6% for 2001-2003.

Previous estimates for 2005 (Quijano-León and Gutiérrez-Negrín, 2000) were 1,080 MW for geothermal-electric installed capacity and 48,300 MW for total electric installed capacity. Estimates for geothermics were a little high compared with the present 953 MW (13% over-estimation), while total estimates were a little low (2%) compared with the present 49,219 MW, including self-suppliers and co-generators.



Fig. 1. Location of Mexican geothermal fields

3. Geothermal-electric production

Total geothermal-electric installed capacity in Mexico is 953 MW, as shown in tables 1 and 2. There are four geothermal fields in production: Cerro Prieto, Los Azufres, Los Humeros and Las Tres Vírgenes. The fifth field, La Primavera (Cerritos Colorados project), remains on standby, even though a potential of 75 MW was assessed a long time ago (Fig. 1). The work for installing 50 MW in this field is expected to start in the next few years, as reported in Table 2.

The Cerro Prieto geothermal field is located in the northern part of Mexico (Fig. 1), near the border with the US. The first plants in the field started to operate in 1973, and today there is an installed capacity of 720 MW, composed of four

plants of 110 MW each, four of 37.5 MW, four of 25 and one of 30 MW, all of them the condensing type (Table 2). All of the units and the whole field is managed and operated by CFE.

Table 2. Utilization of geothermal energy for electric power generation as of December, 2004.

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status ¹⁾	Type of Unit ²⁾	Total Installed Capacity (MWe)	Annual Energy Produced in 2003 (GWh/yr)	Total Under Construction or Planned (MWe)	
Cerro Prieto	U-1	1973	1		1F	37.5	279.12		
	U-2	1973	1		1F	37.5	274.07		
	CP-I	U-3	1979	1		1F	37.5	300.55	
		U-4	1979	1		1F	37.5	296.47	
	U-5	1982	1		2F	30.0	34.49		
	CP-II	U-1	1986	1		2F	110.0	760.13	
		U-2	1987	1		2F	110.0	751.21	
	CP-III	U-1	1986	1		2F	110.0	729.27	
		U-2	1987	1		2F	110.0	863.92	
	CP-IV	U-1	2000	1		1F	25.0	183.96	
		U-2	2000	1		1F	25.0	202.50	
		U-3	2000	1		1F	25.0	203.19	
		U-4	2000	1		1F	25.0	232.83	
	Los Azufres	U-2	1982	1		O	5.0	43.90	
U-3		1982	1		O	5.0	38.77		
U-4		1982	1		O	5.0	43.70		
U-5		1982	1		O	5.0	28.75		
U-6		1986	1		O	5.0	43.79		
U-7		1988	1		1F	50.0	253.66		
U-9		1990	1		O	5.0	39.61		
U-10		1992	1		O	5.0	44.13		
U-11		1993	1		B	1.5	4.55		
U-12		1993	1		B	1.5	0.00		
U-13		2003	1		1F	25.0	82.12		
U-14		2003	1		1F	25.0	39.87		
U-15		2003	1		1F	25.0	94.40		
U-16		2003	1		1F	25.0	94.48		
Los Humeros	U-8	1989	1		O	5.0	42.60		
	U-2	1990	1		O	5.0	43.92		
	U-3	1991	1		O	5.0	45.57		
	U-4	1991	1		O	5.0	23.96		
	U-5	1992	1		O	5.0	44.05		
	U-6	1994	1		O	5.0	43.74		
	U-7	1993	1		O	5.0	41.57		
	U-8, U-9	2008	2	N	1F		0.00	50.0	
Las Tres Virgenes	U-1	2002	1		1F	5.0	25.13		
	U-2	2002	1		1F	5.0	7.70		
La Primavera	U-1, U-2	2006	2	N	1F		0.00	50.0	
	U-3	2008	1	N	1F		0.00	25.0	
Total			43			953.0	6,281.66	125.0	

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

2) 1F = Single Flash, B = Binary (Rankine Cycle), 2F = Double Flash, O = Other (Back-pressure)

During 2003, there were 149 production wells in operation in Cerro Prieto, which produced 51.3 million tons of separated steam at an annual average rate of 5,855 tons per hour (t/h). This is the highest historic production of steam in Cerro Prieto, 8% higher than steam produced in 2002 (Gutiérrez-Negrín and Quijano-León, 2003) and 15% higher than production of steam five years ago (Quijano-León and Gutiérrez-Negrín, 2000). Annual average production rate per well resulted in 39.3 t/h. The steam was accompanied by 70.6 million tons of brine, which was disposed of in the solar evaporation pond of 14 km² of surface, and by injection through 9 injection wells over the year.

Electric energy produced in Cerro Prieto in 2003 is 5,111.7 GWh (sum of the generation of each unit in Table 2). This is also the highest energy produced in the history of this field, and 3.6% higher than electricity generated in 2002 (Gutiérrez-Negrín and Quijano-León, 2003). Considering steam produced, it is possible to get a gross specific consumption of 10 tons of steam per MWh produced (t/MWh) for the whole field. Net specific consumption, taking into account only the steam passed through turbines, is of course lower: 8.14 t/MWh. This average is from a range that varies from 6.94 t/MWh for Unit 1 of CP-IV to 13.74 t/MWh for the most inefficient unit, CP-I.

The Los Azufres geothermal field is located in central Mexico, 250 km to the west of Mexico City and within the Mexican Volcanic Belt, a physiographic province composed of Plio-Quaternary volcanoes and volcanic products (Fig. 1). There are 14 power units of diverse types (condensing, back-pressure, binary cycle) and capacities (1.5 to 50 MW) in operation, with an installed capacity of 188 MW (Table 2). Unit 1 was definitively installed in the Amatitlán, Guatemala, geothermal field, where it is currently in operation. Unit 8 was moved and is operating in the Los Humeros field. Units 13 through 16 constitute the project Los Azufres II, reported as planned in 2000 (Quijano-León and Gutiérrez-Negrín, 2000) and which started operation in the third quarter of 2003; that is why their production of energy was relatively low in 2003 (Table 2). Power units and the whole geothermal field are managed and operated by CFE.

An average of 29 production wells were in operation in Los Azufres during 2003. They produced 11.3 million tons of steam at an annual average rate of 1,285 t/h. Of course this production represents an historic record for the field, 82% higher than production of the previous year (Gutiérrez-Negrín and Quijano-León, 2003), 67% higher than steam produced five years ago (Quijano-León and Gutiérrez-Negrín, 2000), and 31% higher than the previous record in 1996 –when 8.6 million tons were produced in the field. The average production rate per operating well was 44.6 t/h. Separated brine in 2003 was 5.15 million tons for the year, which was completely injected back to the reservoir through 6 injection wells.

Generation of electricity in Los Azufres in 2003 was 851,730 MWh (851.7 GWh: the sum of produced energy of each unit in Table 2, CFE, 2004b), which is almost three times the electricity generated in 2002 (Gutiérrez-Negrín and Quijano-León, 2003) and 42% higher than the generation in 1999 (Quijano-León and Gutiérrez-Negrín, 2000). This is the highest generation in the history of Los Azufres. Net specific consumption of steam for all the units in operation resulted in an average of 10.77 t/MWh, varying from 12.88 t/MWh for the old (1990), back-pressure Unit 11, to 6.67 t/MWh for the recent, condensing Unit 15.

Los Humeros is another volcanic geothermal field, located in the eastern-central part of Mexico, also inside the Mexican Volcanic Belt (Fig. 1). The field lies within a Quaternary caldera (Caldera de Los Humeros) and has an installed capacity of 35 MW with seven back-pressure units of 5 MW net each. Some time ago all these units were being operated at 6 MW, which was reported five years ago (Quijano-León and Gutiérrez-Negrín, 2000), yet their nominal net capacity is 5 MW.

During 2003, CFE operated an average of 17 production wells in Los Humeros. They produced 4.61 million tons of steam at an annual average rate of 526 t/h. This production is rather better than that obtained in 2002,

which was 2.43 million (Gutiérrez-Negrín and Quijano León, 2003) and similar to that reported five years ago (4.76 million; Quijano-León and Gutiérrez-Negrín, 2000). Annual average production rate per well was 30.3 t/h, the highest in the history of Los Humeros. Separated brine was 0.89 million, completely injected into the reservoir with two injection wells.

Those seven power units produced 285,400 MWh (285.4 GWh, which is the sum of individual generation reported in Table 2). This energy is almost double that produced in 2002 (Gutiérrez-Negrín and Quijano-León, 2003), although 19% lower than reported for 1999 (Quijano-León and Gutiérrez-Negrín, 2000). Net specific consumption of steam, in annual average, was 12.65 t/MWh, with little variation from the other units (12.52 to 12.82 t/MWh). There are plans in Los Humeros for installing 50 MW more, with two units of 25 MW net each. See Table 2.

The Las Tres Vírgenes geothermal field is located in the middle of the Baja California peninsula, in the northern part of the Mexican State of Baja California Sur (Fig. 1). It is inside a Quaternary volcanic complex composed of three N-S aligned volcanoes, and has been developed in the buffer area of the El Vizcaíno Biosphere Reserve.

The heat source of the system seems to be related to the magma chamber of the La Virgen volcano, the youngest and most southern part of the volcanic complex. Geothermal fluids are contained in granodiorites with low secondary permeability.

The exploration surveys started in 1982. The first exploration well was drilled in 1986. Up to now, there are two condensing units of 5 MW each, which started operating in July 2001. During 2003 CFE operated two production wells with a combined production of 0.31 million tons of steam, at an annual average rate of 35 t/h, which was a little higher than the amount of steam produced in 2002 (0.28 million; Gutiérrez-Negrín and Quijano-León, 2003). The average annual production per well was 17.58 t/h, the lowest of the Mexican geothermal fields, although 41% higher than the average obtained in the previous year.

Production of electric energy from these units was 32,827 MWh (32.8 GWh, as reported in Table 2), though Unit 1 was out of the system the first semester of 2003. This production is 69% higher than in the previous year (Gutiérrez-Negrín and Quijano-León, 2003) and was distributed to the nearby towns of Santa Rosalía and others, which are isolated from the national electric grid. Annual net specific consumption of steam averaged 9.38 t/MWh. Plans for installing one more unit of 15 MW in this field, reported five years ago (Quijano-León and Gutiérrez-Negrín, 2000), were abandoned because of the low growth of electricity demand.

Total geothermal production in Mexico during 2003 is the sum of results in Cerro Prieto, Los Azufres, Los Humeros and Las Tres Vírgenes, and can be summarized as follows (annual averages):

Production wells in operation:	97
Injection wells in operation:	19
Production of steam:	67.5 million tons
Production rate of steam:	7,700 t/h
Average production per well:	39.1 t/h
Separated brine disposed:	76.7 million tons
Generation of electricity:	6,282 GWh
Gross specific consumption of steam:	10.38 t/MWh

The number of production wells, steam produced and electric energy generated in the geothermal field, are the highest figures in 30 years of geothermal-electric production in Mexico. Previous records were: 177 wells

in operation (in the year 1996), 57.28 million tons of steam (year 2000), and 5,737 GWh (also in 1996). However, CFE had a better average production per well in 1999, 2000 and 2001, with 39.2, 41.64 and 40.8 t/MWh, respectively.

4. Direct use

Direct use of geothermics in Mexico is limited to bathing and swimming facilities—mostly with recreational purposes and some with therapeutic uses. However, CFE has developed some pilot projects to promote the use of geothermal resources in agricultural and industrial applications in the fields of Los Azufres and Los Humeros. Two major projects to use residual geothermal brines in Cerro Prieto, one for mineral concentration and exploitation in a solar evaporation pond and the other for industrial laundry, had to be cancelled and remain on stand-by.

Table 3. Utilization of geothermal energy of direct heat as of December, 2004.

¹⁾ Types:

A = Agricultural drying (grain, fruit, vegetables)

G = Greenhouse and soil heating

O = Other (Mushroom breeding)

B = Bathing and swimming (including balneology)

H = Individual space heating (other than heat pumps)

²⁾ Enthalpy information is given only if there is steam or two-phase flow.

³⁾ Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184

or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

⁴⁾ Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319

or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

⁵⁾ Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171

Note: The capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Locality	Type ¹⁾	Maximum Utilization					Capacity ³⁾ (MWt)	Annual Utilization		
		Flow Rate (kg/s)	Temperature (°C)		Enthalpy ²⁾ (kJ/kg)			Average Flow (kg/s)	Energy ⁴⁾ (TJ/yr)	Capacity Factor ⁵⁾
			Inlet	Outlet	Inlet	Outlet				
Los Azufres, Mich.	A	0.100	77.0	60.0			0.007	0.080	0.179	0.801
Los Azufres, Mich.	B	38.000	72.0	55.0			2.703	31.000	69.511	0.815
Los Azufres, Mich.	G	0.050	60.0	40.0			0.004	0.040	0.105	0.793
Los Azufres, Pue.	H	4.583	110.0	86.0			0.460	4.167	13.191	0.909
Los Humeros, Pue.	O	2.778	75.0	60.0			0.174	2.500	4.946	0.901
La Primavera, Jal.	B	63.000	48.0	31.0			4.481	59.000	132.296	0.936
Aguascalientes*	B	265.000	43.0	30.0			14.414	150.000	257.205	0.566
Chiapas*	B	1,000.000	36.0	29.0			29.288	800.000	738.640	0.800
Chihuahua*	B	38.000	39.3	25.0			2.274	28.000	52.813	0.736
Coahuila*	B	56.000	32.0	25.0			1.640	30.000	27.699	0.536
Durango*	B	34.000	52.5	38.0			2.063	15.000	28.688	0.441
Guanajuato*	B	293.000	40.8	29.0			14.466	225.000	350.195	0.768
Hidalgo*	B	271.000	41.5	32.0			10.772	228.000	285.695	0.841
Jalisco*	B	368.000	37.8	30.0			12.010	285.000	293.214	0.774
México*	B	103.000	35.1	25.0			4.363	80.000	106.575	0.775
Michoacán*	B	161.000	44.5	33.0			7.721	135.000	204.775	0.841
Morelos*	B	95.000	45.0	30.0			14.466	225.000	350.195	0.768
Nuevo León*	B	295.000	38.0	30.0			9.874	218.000	230.034	0.739
Querétaro*	B	770.000	31.8	26.5			17.259	585.000	408.956	0.751
San Luis Potosí*	B	292.000	36.8	31.0			7.054	198.000	151.474	0.681
Sinaloa*	B	7.000	72.5	61.0			0.337	4.300	6.522	0.614
Tlaxcala*	B	10.000	35.0	28.0			0.293	7.500	6.925	0.749
Veracruz*	B	42.000	65.0	48.0			2.987	35.000	78.481	0.833
Zacatecas*	B	163.000	36.6	28.5			5.532	125.000	133.549	0.766
TOTAL		4,371.511	50.2	38.0			164.642	3,470.587	3,931.863	0.757

* It is included the estimated total flow rate of all the bathing sites in the state, and the average inlet & outlet temperature.

Geothermal heat pumps is a technology still scarcely known in Mexico and practically undeveloped, except for some private and isolated cases with no available information.

Table 3 presents, however, our estimations on geothermal baths and swimming facilities in Mexico. Most of these resorts were developed and are operated by private investors, although some of them are developments of federal, state or municipal governments through their tourism offices or, in some cases, through federal institutions like the social security institute (IMSS).

Data included in Table 3 for Los Azufres and Los Humeros are rather precise, since most of them are projects developed and/or operated by CFE. Data grouped for states of Mexico are estimates. They are based on results of the regional reconnaissance of geothermal resources in the country concluded by CFE several years ago. Therefore, figures can be outdated.

Data of Table 3 are the same as presented five years ago (Quijano-León and Gutiérrez-Negrín, 2000), except for the space-heating development in Los Azufres (Sánchez, 2003), whose characteristics were improved from those presented before.

As shown in Table 3, Mexico has an installed capacity of 164.6 MWt for direct use of geothermics (mostly bathing and swimming facilities) distributed in more than 160 sites in 19 states of the country. These facilities use around 12,500 t/h of hot water, at an average of 50°C. This flow of water is equivalent to 76% of the total geothermal flow (steam and brine) currently obtained by all the production wells in the four geothermal fields of Mexico.

5. Drilling

Fifty-nine geothermal wells were drilled in Mexico between 2000 and 2003 (Table 4), 21 in the year 2000, 13 in 2001, and 12 each in 2002 and 2003. All the wells were constructed by drilling companies contracted by CFE for geothermal-electric purposes. There is no information about geothermal wells drilled for direct use, and it is possible to assume no well was constructed with this purpose in the period, since bathing and swimming resorts use mostly water from hot springs.

Table 4. Wells drilled for electric, direct and combined use of geothermal resources, from January 1, 2000, to December 31, 2003 (excluding heat pump wells).

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other	
Exploration ¹⁾	(All)	0	0	0	0	0
Production	>150°C	56	0	0	0	145.5
	100-150°C	0	0	0	0	0
	<100°C	0	0	0	0	0
Injection	(All)	3	0	0	0	4.4
Total	(All)	59	0	0	0	149.9

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

There were no exploratory wells during the last five years because CFE did not explore any new zones. However, three of the 59 wells were injection wells constructed in 2000 in the Cerro Prieto field. All of the 56 production wells recorded temperatures higher than 150°C. Of these, 44 (78.6%) were drilled in Cerro Prieto, 10 (17.8%) in the Los Azufres field, and 2 (3.6%) in Las Tres Vírgenes. In this field, the most recent well was drilled in 2001. No wells were drilled in Los Humeros. Including the injection wells, Mexican

drilling activity was concentrated in Cerro Prieto, since four of each five geothermal wells were drilled in that field.

Maybe it is worth mentioning that production wells in Cerro Prieto were drilled mainly to replace exhausted, old wells. Productive life of a typical production well in this field is around 10 years, with a workover around the fourth or fifth year. In contrast, production wells constructed in Los Azufres were drilled to supply additional steam that the project Los Azufres II (100 MW) required. Few wells in Los Azufres are replacement wells (the productive life of a well is typically longer than in Cerro Prieto) and several Los Azufre wells have more than 20 years of operation with no workover.

Total length of these wells is 149,905 meters: 145,521 m for production wells and 4,384 m for injection wells (Table 4). Therefore, the average depth for each production well was 2,599 meters and 1,461 meters for each injection well. This is a national average, and it may be interesting to differentiate it for each field. Thus, the average depth for each production well constructed in the period in Cerro Prieto was 2,835 meters, while in Los Azufres it was 1,644 meters and in Las Tres Vírgenes 2,171 meters. It becomes evident that wells in Cerro Prieto are, on average, quite deeper than at Los Azufres.

Considering the data related to the number and total depth of wells drilled in Mexico reported in December 1999 (Quijano-León and Gutiérrez-Negrín, 2000), and making some corrections, it is possible summarize the present situation as shown in Table 5.

Table 5. Total geothermal wells and depths in Mexico in 1999 and 2003.

		Cerro Prieto	Los Azufres	Los Humeros	Las Tres Vírgenes	La Primavera	Other zones	Total
Number of Wells	1999	268	72	40	7	13	35	422
	2003	315	82	40	9	13	35	481
Total Depth (km)	1999	596.4	112.6	87.4	13.5	23.1	46.7	879.7
	2003	725.5	129.1	87.4	17.8	23.1	46.7	1,029.6

Thus, as of December 2003 in the Cerro Prieto field, CFE has drilled 315 wells with a combined depth of 725,500 meters; in Los Azufres 82 wells with 129,050 meters; in Los Humeros 40 wells with 87,352 meters; in Las Tres Vírgenes 9 wells with 17,826 meters; in La Primavera 13 wells with 23,117 meters; and in other geothermal zones around 35 wells with 46,737 meters. These other geothermal zones include: San Marcos, Jal., Volcán Ceboruco, Nay., Laguna Salada, BC, Acoculco y Las Derrumbadas, Pue., Los Negritos, Mich., San Antonio El Bravo y Maguarichic, Chih., Aguacaliente, El Centavito y Santispac, BCS, Santiago Papasquiaro, Dgo., and one recent (1995) exploratory well in Pathé, Hgo. Thus, the total number of geothermal wells drilled in Mexico between 1960 and 2003 is 481, with a combined total depth of 1,029,582, excluding temperature-gradient wells.

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