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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 (MWe). 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 MWe, 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 km^2 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). Direct uses of geothermics are under developed and limited mainly to bathing and swimming facilities.

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 MWe 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.

2. ELECTRICITY IN MEXICO

As of December 2003 the installed electric capacity in Mexico was 43,727 MWe (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 MWe 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 MWe. 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.

From that total of 43,727 MWe for public service, CFE owns and operates 36,971 MWe (84.5%), LFC 834 MWe (1.9%) (CFE, 2004b), and IPPs own and operate 5,922 MWe (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 MWe 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 MWe more (CFE, 2003; Table 1). For geothermal plants there are only plans for 135 MWe more (Los Humeros and La Primavera), and for wind-electric plants the only project is La Venta II (100 MWe).

Thus, the additional capacity to be commissioned between 2005 and 2010 equals 14,474 MWe, considering plants already in construction or planned (Table 1). However, CFE has plans to dismantle some old plants, losing 2,957 MWe 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 MWe. Thus the total projected use by 2010 would be: 58,201 – 2,957 + 7,003 = 62,247 MWe, out of which 55,244 MWe will be operating for public service, instead of those 58,201 MWe reported in Table 1.

Figure 1: Location of Mexican geothermal fields

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 the period of 2001-2003.

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

3. GEOTHERMAL-ELECTRIC PRODUCTION

Total geothermal-electric installed capacity in Mexico is 953 MWe, 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 stand-by, even though a potential of 75 MWe was assessed a long time ago (Fig. 1). The work for installing 50 MWe 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 MWe, composed of four plants of 110 MWe each, four of 37.5 MWe, four of 25 and one of 30 MWe, all of them the condensing type (Table 2). All of the units and the whole field is managed and operated by CFE.

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 km^2 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 MWe) in operation, with an installed capacity of 188 MWe (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 MWe with seven back-pressure units of 5 MWe net each. Some time ago all these units were being operated at 6 MWe, which was reported five years ago (Quijano-León and Gutiérrez-Negrín, 2000), yet their nominal net capacity is 5 MWe.

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 MWe more, with two units of 25 MWe 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 MWe 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: 197
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.

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.

Table 4 summarizes the direct use of geothermics grouped into 11 concepts, plus the geothermal heat pumps application. That installed capacity of 164.6 MWt would be used at an average capacity factor of 0.757 to utilize 3,931.8 TJ per year. Out of this total, 99.6% is represented by bathing and swimming developments.

5. DRILLING

Fifty-nine geothermal wells were drilled in Mexico between 2000 and 2003 (Table 5), 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.

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 MWe) 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 5). 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 follows:

Field	No. of wells		Total Depth (km)	
	1999	2003	1999	2003
Cerro Prieto	268	315	596.4	725.5
Los Azufres	72	82	112.6	129.1
Los Humeros	40	40	87.4	87.4
Las Tres Vírgenes	7	9	13.5	17.8
La Primavera	13	13	23.1	23.1
Other zones	35	35	46.7	46.7
Total	422	481	879.7	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.

6. HUMAN AND FINANCIAL RESOURCES

Personnel working in geothermal activities and holding a university degree is reported in Table 6 for the last five years. Column 1 (government) reports professionals working for the Secretary of Energy, whose activities involve geothermics. Column 2 (public utilities) covers on the CFE personnel, which increased in 16% between 2000 and 2004. Column 3 reports mostly researchers in the Instituto de Investigaciones Eléctricas (IIE), geophysical and geologic institutes of the UNAM, the Centro de Investigación Científica y Estudios Superiores de Ensenada (CICESE), and the Baja California university. The number of personnel shows a small increase of 13%. There were no paid foreign consultants in the period, and column 5 includes some foreign researchers paid by international programs working in institutes. Column 6 informs about personnel from drilling and consulting companies.

Figures presented in Table 6 are not consistent with those shown five years ago (Quijano-León and Gutiérrez-Negrín, 2000), particularly with the CFE personnel. Based on our present investigation, it becomes evident that figures for the period 1995-1999 were overestimated.

Investments for geothermal development are shown in Table 7. Figures for the periods 1990-1994 and 1995-1999 are the same as reported five years ago (Quijano-León and Gutiérrez-Negrín, 2000), and, as stated on that occasion, there are no public data on private investments in projects of direct use. Of course, all investments on electric uses of geothermics have been made by CFE, which means by public investment. Probably the most remarkable aspect of Table 7 is the reduction of investments for exploration and research, which drops from 33 million dollars in 1990-94 to a third in 1995-99 and to practically zero in the last five years. This trend will have to be reversed if CFE wants geothermal development in Mexico to continue.

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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 2004*	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 2004	0		6,366		1,374		0		0		7,740	
Funds committed but not yet under construction in December 2004	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 MWe 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 MWe between 2004 and 2010.*

(1) Capacity in MWe.

(2) Gross Production in GWh/year.

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 (MW_e)
Cerro Prieto	CP-I U-1	1973	1		1F	37.5	279.12	
	U-2	1973	1		1F	37.5	274.07	
	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 Vírgenes	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)

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

[1)] Types:
A = Agricultural drying (grain, fruit, vegetables)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
H = Individual space heating (other than heat pumps)
O = Other (Mushroom breeding)

[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)]**	**Annual Utilization**		
		Flow Rate	Temperature (°C)		Enthalpy[2)] (kJ/kg)			Average Flow	Energy[4)]	Capacity Factor[5)]
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	
Los Azufres, Mich.	A	0.100	77.0	60.0			0.007	0.045	0.101	0.450
Los Azufres, Mich.	B	38.000	72.0	55.0			2.703	30.400	68.166	0.800
Los Azufres, Mich.	G	0.050	60.0	40.0			0.004	0.021	0.055	0.420
Los Azufres, Mich.	H	4.583	110.0	86.0			0.460	1.389	4.397	0.303
Los Humeros, Pue.	O	2.778	75.0	60.0			0.174	1.625	3.215	0.585
La Primavera, Jal.	B	63.000	48.0	31.0			4.481	51.000	114.357	0.809
Aguascalientes*	B	265.000	43.0	30.0			14.414	165.000	282.926	0.622
Chiapas*	B	1,000.000	36.0	29.0			29.288	725.000	669.393	0.725
Chihuahua*	B	38.000	39.3	25.0			2.274	28.000	52.813	0.737
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			4.353	80.000	106.575	0.776
Michoacán*	B	161.000	44.5	33.0			7.747	131.000	198.707	0.813
Morelos*	B	95.000	45.0	30.0			5.962	66.000	130.581	0.694
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			17.075	585.000	408.956	0.759
San Luis Potosí*	B	292.000	36.8	31.0			7.086	198.000	151.474	0.678
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	0.750
Veracruz*	B	42.000	65.0	48.0			2.987	33.000	73.996	0.785
Zacatecas*	B	163.000	36.6	28.5			5.524	125.000	133.549	0.767
TOTAL		**4,371.511**	**50.2**	**38.0**			**155.993**	**3,233.280**	**3,628.232**	**0.738**

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

Table 4. Summary table of geothermal direct uses as of December 2004.

[1)] Installed Capacity (thermal power) (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
[2)] Annual 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
[3)] Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
[4)] Other than heat pumps.
[5)] Includes drying or dehydration of grains, fruits and vegetables
[6)] Excludes agricultural drying and dehydration
[7)] Includes balneology

Use	Installed Capacity[1)] (MWt)	Annual Energy Use[2)] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3)]
Individual Space Heating[4)]	0.460	4.397	0.303
District Heating [4)]	0	0	0
Air Conditioning (Cooling)	0	0	0
Greenhouse Heating	0.004	0.055	0.420
Fish Farming	0	0	0
Animal Farming	0	0	0
Agricultural Drying[5)]	0.007	0.101	0.450
Industrial Process Heat[6)]	0	0	0
Snow Melting	0	0	0
Bathing and Swimming[7)]	155.347	3,620.464	0.739
Other Uses (Mushroom breeding)	0.174	3.215	0.585
Subtotal	155.993	3,628.232	0.738
Geothermal Heat Pumps	0	0	0
TOTAL	**155.993**	**3,628.232**	**0.738**

Table 5. 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.

Table 6. Allocation of professional personnel to geothermal activities.

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2000	3	103	39	0	0	80
2001	3	103	41	0	0	80
2002	3	110	42	0	0	80
2003	3	110	44	0	5	70
2004	3	120	44	0	10	50
Average	**3**	**109**	**42**	**0**	**3**	**72**

Notes Table 6:
Restricted to personnel with University degrees
(1) Government
(2) Public utilities
(3) Universities
(4) Paid foreign consultants
(5) Contributed through foreign aid programs
(6) Private industry

Table 7. Total investments in geothermics in US Dollars (2004).

Period	Research & Development, Including Surface Exploration and Exploration Drilling (Million US$)	Field Development, Including Production Drilling & Surface Equipment (Million US$)	Utilization (Million US$)		Funding Type (%)	
			Direct	Electrical	Private	Public
1990-1994	33.0	245.6	0.0	278.7	0	100
1995-1999	11.5	385.8	0.0	397.3	0	100
2000-2004	0.0	415.0	0.0	415.0	0	100