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Current Status of Geothermics in Mexico

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ABSTRACT

Geothermal energy in Mexico is almost entirely used to produce electricity, since its direct uses are still under development and currently remain restricted to bathing and swimming. The installed geothermal-electric capacity in Mexico as of December 2008 is 958 megawatts (MW). This capacity is currently operating into four geothermal fields, namely: Cerro Prieto (720 MW), Los Azufres (188 MW), Los Humeros (40 MW) and Las Tres Vírgenes (10 MW). All of the geothermal fields and power plants are owned and operated by the governmental agency CFE (Comisión Federal de Electricidad). One additional geothermal project is under construction (Los Humeros II, 25 MW) and other is under international bidding (Cerro Prieto V, 100 MW), which will add a net geothermal-electric capacity of 50 MW when commissioned. During 2008, thirty-seven power plants of condensing, back-pressure and binary cycle were in operation into those fields. The annual geothermal production (2008) was 65.9 million metric tons of steam at an annual average rate of 7,504 tons per hour (t/h). Steam was delivered by an average of 229 production wells, and was accompanied by 69.7 metric tons of brine that was disposed through 23 injection wells and a solar-evaporation pond operating in Cerro Prieto. Geothermal power plants at the fields produced 7,047 gigawatts-hour (GWh) of electric energy in 2008, which represented 3.0% of the whole electric generation in Mexico in that year. Around 3,594 kg/s (12,939 t/h) of geothermal fluids are utilized for direct uses, with an installed capacity of 155.8 MWt and a mean capacity factor of 0.82, 99.9% of which are bathing, swimming and balneology.

1. INTRODUCTION

In Mexico, geothermal resources remain to be mainly utilized to produce electricity. There has been a little development in direct uses of geothermics, and they are basically limited to bathing and swimming. So, this paper is focused on the status of geothermal-electricity in Mexico, yet also presents some available data on direct uses.

The public service of electricity in Mexico is provided by the Federal Government. Two public facilities, the Comisión Federal de Electricidad (CFE) and Luz y Fuerza del Centro (LFC), owned and operated by the government, are in charge of generation, transmission, distribution and commercialization of electric energy. Electric uses of geothermics are planned, developed and operated by the Gerencia de Proyectos Geotermoeléctricos –the geothermal division of the CFE.

2. THE ELECTRIC INDUSTRY

As of December 2008 the total installed electric capacity in Mexico was 51,105 MWe (Table 1). This total includes 20 independent power producers (IPP) amounting 11,457 MWe, whose power plants were constructed and are operated and owned by private companies (CFE, 2009; Sener, 2009). By law, the IPPs sell all their electric generation to the CFE through long-term power purchasing contracts, since they are not allowed to negotiate and contract with private costumers.

Additionally to the installed capacity for public service of electricity, as of December 2008 there were in Mexico 7,166 MWe in power plants operated by private companies for self-supplying, cogeneration, small production and continuous own uses, whose electric generation is entitled to satisfy their own needs. There were also 1,330 MWe in power plants for exportation of electricity to the USA and to Belize, located in the bordering states of Baja California (north of Mexico) and Yucatán (southeast of Mexico) (CRE, 2009). All of these power plants for self-supplying, cogeneration, small production, continuous own uses and exportation are not considered as public service of electricity. Then, taking into account this additional capacity, the total installed electric capacity in Mexico, including public and private service, was 59,601 MWe in December 2008.

From that total of 59,601 MWe, the CFE run and operates with their own personnel 38,474 MWe (64.4%), LFC 1,174 MWe (2%), IPPs 11,457 MWe (19.2%), other private companies 7,166 MWe (12%) to satisfy their own electric demand, and 1,330 MWe (2.2%) to export electric energy produced in Mexico. It is worth mention that the national installed capacity for public service in 2003 was 43,272 MWe, and it was expected 55,244 MWe by 2010 (Gutiérrez-Negrín and Quijano-León, 2005).

As indicated in Table 1, almost three quarters of the installed capacity for public service in Mexico (73.1%) is based on fossil-fueled power plants (hydrocarbons and coal), and more than one fifth (22.2%) on hydroelectric plants. Geothermal electric capacity represents 1.9% and wind only 0.1%. The rest (2.7%) is represented by nuclear power plants (Fig. 1).

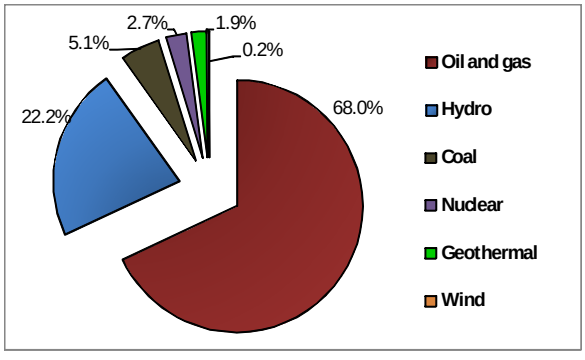

Figure 1: Breakdown (%) of the total electric installed capacity in Mexico as of December 2008.

The electric generation for public service in Mexico in 2008 was 234,096 GWh, as reported in the same Table 1. To this total must be added 35,642 GWh generated by private companies for self-supplying, cogeneration, small production and continuous own uses, and 11,251 GWh produced for exportation (CFE, 2009; CRE, 2009; Sener, 2009). Thus, total electric generation in Mexico, including public and private service, was 280,989 GWh in 2008, out of which 157,160 GWh (55.9%) were generated by CFE, 2,704 GWh (1%) by LFC, 74,232 GWh (26.4%) by IPPs, and 35,642 GWh (12.7%) by other private companies for their own needs. The remaining 11,251 GWh (4%) was exported.

More than three quarters (76%) of the electric energy for public service in Mexico in 2008 was generated by power plants fueled by hydrocarbons and coal, only 16.6% was produced by hydroelectric plants, 4.2% by nuclear power plants, 3% by geothermal-electric plants and 0.1% by eolic power plants, as implicated in Table 1 (Fig. 2). Five years ago, the electric energy generated for public service in Mexico in 2003 was 200,939 GWh (Gutiérrez-Negrín and Quijano-León, 2005).

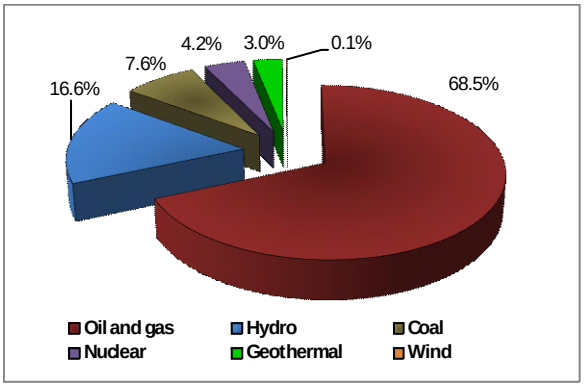

Figure 2: Total generation of electricity in Mexico during 2008, regarding the type of power plant and fuel used.

According to the CFE (CFE, 2008), by December 2008 six power projects were under construction to be commissioned in 2009 through 2015, with an installed capacity of 2,454 MWe, as reported in Table 1. Out of those projects, three are of combined cycle, one hydro, one coal and one gas, with no geothermal-electric projects in construction. There were also funds committed for other 1,053 MWe, including two wind-electric power plants (202 MWe), several fossil-fueled power units (705 MW), and two geothermal-electric projects: Cerro Prieto V (100 MWe) and Los Humeros II (25 MW). The project Cerro Prieto V is composed of two condensing units of 50 MWe each, and includes the decommissioning of two old units (U-1 and U-2) of Cerro Prieto I, each of 37.5 MWe; so, the additional capacity in this geothermal field will be 25 MWe, scheduled for 2011. The project Los Humeros II is composed of one condensing unit of 25 MWe to be commissioned in 2011. There are plans for project Los Humeros III, with another 25-MWe unit (see also Table 2).

Total projected use by 2015 (Table 1) results 55,688 MWe for public service of electricity (i.e. excluding self-supplying, cogeneration, exportation, small production and continuous own uses). This amount includes 5,075 MWe for several power plants based on fossil fuels, 242 MWe for two small hydroelectric plants, 304 MWe for three wind-electric plants and 100 MWe for two geothermal-electric projects (other than already in construction or with committed funds). It also considers the decommissioning of several power plants based on fossil fuels amounting 3,190 MWe (CFE, 2008). The geothermal projects are the first stage of Los Azufres III and Cerritos Colorados. The complete project of Los Azufres III consists of one 25-MWe unit and one 50-MWe unit, being the first one the initial stage, which considers dismantle three 5-MWe back-pressure units currently in operation (units number 2, 6 and 10). Therefore, the net additional capacity in this field will be 10 MWe. The Cerritos Colorados project (formerly reported as La Primavera) is composed of three 25-MWe condensing units, and it is expected to be commissioned between 2013 and 2014 (see also Table 2).

3. GEOTHERMAL ELECTRICITY

There are currently in Mexico four geothermal fields in production, Cerro Prieto, Los Azufres, Los Humeros and Las Tres Vírgenes (Fig. 3), with an operating net capacity of 958 MWe composed of 37 power units of different type (condensing of single and double flash types, back-pressure and binary cycle) and capacity (from 1.5 to 110 MW) that produced 7,047 GWh of electric energy in 2008 (Table 2). This represents an average annual plant factor of 83.7% or 0.84, which results 7.3% better than five years ago (according to data presented by Gutiérrez-Negrín and Quijano-León, 2005), and yet is 4.3% lower than obtained in 2005 (Gutiérrez-Negrín, 2007). All the fields and power units are managed and operated by personnel of the CFE.

Figure 3: Geothermal fields under exploitation in Mexico. (Cerritos Colorados, formerly known as La Primavera, remains in stand-by.)

Cerro Prieto is the oldest and largest Mexican geothermal field in operation. It is located in the northern part of Mexico (Fig. 1), and its first power units were commissioned in 1973. There are currently 13 operating units of condensing type: four 110-MWe double-flash, four single-flash of 37.5 MWe each, four single-flash of 25 MWe each and one 30-MWe single-flash, low pressure, amounting 720 MWe. These power units produced 5,176 GWh in 2008 (sum of the generation of each unit in Table 2) at an annual capacity factor of 81.8% (0.82).

This geothermal field lies in a pull-apart basin produced between two active strike-slip faults (the Cerro Prieto and Imperial faults) belonging to the San Andreas Fault System. Thinning of the continental crust in the basin has produced a thermal anomaly that is the ultimate cause of the heat source of the geothermal system. The geothermal fluids are contained in sedimentary rocks (lenticular sandstones intercalated in series of shales) with a mean thickness of 2,400 meters.

More than 350 geothermal wells have been drilled in 35 years in Cerro Prieto, with depths up to 4,400 m. 167 production wells were in operation during 2008 producing 45.9 million tons of separated steam at an annual average rate of 5,224 tons per hour (t/h). The annual average production rate per well was 31.3 t/h, being 25% lower than the annual rate in 2003, which was 39.3 t/h per well (Gutiérrez-Negrín and Quijano-León, 2005). There were also 13 injection wells in operation that returned to the reservoir 19.6 million tons, out of 63.0 million tons of total separated brine. The rest was disposed in the solar evaporation pond of 14.3 km^2 in surface.

Taking into account the steam produced in 2008 in Cerro Prieto, the gross steam specific consumption results in an annual average of 8.82 tons per MWh. The production of steam in this field in 2008 was 8% lower than five years ago, but generation of electricity was 1% higher, according with data reported for 2003 (Gutiérrez-Negrín and Quijano-León, 2005).

Los Azufres is the second geothermal field operating in Mexico. It is located in the central part of the country, 250 km away from Mexico City, and lies within the physiographic province of the Mexican Volcanic Belt in a pine-forest at 2,800 masl. The first power units were commissioned in 1982, and presently there are 14 power units in operation: one condensing of 50 MWe, four condensing of 25 MWe each, seven 5-MWe back-pressure and two 1.5-MWe binary cycle. The total installed capacity is 188 MWe (Table 2). Generation of electricity in 2008 was 1,517 GWh, at an annual capacity factor of 91.8% (0.92).

Los Azufres is a volcanic field whose geothermal fluids are hosted by andesites affected by three fault systems produced by local and regional tectonic activity. The most important of such systems presents an E-W trend and controls the movement of the subsurface fluids. The heat source of the system seems to be related to the magma chamber of the nearby San Andrés volcano that is the highest peak in the area.

Along 2008, 39 production wells were in operation in Los Azufres, which produced 14.6 million tons of steam, at an annual average rate of 1,668 t/h. The annual mean production per well was 42.8 t/h, resulting 4% lower than the average in 2003 (44.6 t/h, as reported by Gutiérrez-Negrín and Quijano-León, 2005). The produced steam was accompanied by 4.53 million tons of brine that was fully injected into the reservoir through 6 injection wells.

The gross specific consumption in Los Azufres in 2008 was 9.66 tons of steam per MWh, which is one of the historically lowest in this field yet still higher than in Cerro Prieto. The steam production in 2008 is 30% higher than five years ago, when 11.3 million tons were produced. The electric energy generated in 2008 is 78% higher than in 2003, when only 851.7 GWh were generated (Gutiérrez-Negrín and Quijano León, 2005). However, the highest electricity generation in Los Azufres was achieved in 2006, with 1,522 GWh (Gutiérrez-Negrín, 2007).

The geothermal field of Los Humeros is also of volcanic type. It is located in the eastern-central part of Mexico, at the eastern end of the Mexican Volcanic Belt. Its power units number 1 and 2 started to commercially operate in 1990, and currently there are eight back-pressure units of 5 MWe each with a total operating capacity of 40 MWe. The more recent unit (Unit 8) was commissioned in April 2008 (Table 2).

Los Humeros lies inside a Quaternary caldera (Caldera de Los Humeros) at 2,600 masl. The geothermal fluids are also contained in andesites overlying a complex basement composed of metamorphic, sedimentary and intrusive rocks. The heat source is the magma chamber that produced two collapses and formed the Los Humeros and Los Potreros calderas, being the latter nested in the first one. Los Potreros collapse occurred 100,000 years ago, and the last volcanic activity has been dated in 20,000 years.

There were 20 production wells operating in Los Humeros during 2008. They produced 4.83 million tons of steam at an annual mean rate of 550 t/h, resulting in an average production per well of 27.5 t/h. This average is 9% lower than in 2003, when 30.3 t/h of steam per well was obtained (Gutiérrez-Negrín and Quijano-León, 2005). The wells in Los Humeros produce usually low brine, and so occurred in 2008 when 0.46 million tons of brine was obtained. The brine was returned to the reservoir by three injection wells.

Generation of electricity in Los Humeros was 313.4 GWh (sum of individual generation reported in Table 2). This energy is almost 10% higher than generated five years ago and the highest since 1999, when the power units then installed were operated at 6 MWe (Gutiérrez-Negrín and Quijano-León, 2005). The capacity factor in 2008 was 92% (0.92), slightly higher than in Los Azufres and the better in Mexico. The gross specific consumption was 15.4 tons of steam per MWh.

Las Tres Vírgenes is the most recent field in operation in Mexico. It is located in the middle of the Baja California peninsula, at the north of the state of Baja California Sur and inside the buffer zone of the El Vizcaíno Biosphere Reserve. There are only two condensing 5-MWe power units in operation that were officially commissioned in 2002. Generation of electricity in 2008 was 41.2 GWh, at an annual mean capacity factor of 47% (0.47).

Las Tres Vírgenes is inside a Quaternary volcanic complex composed of three N-S aligned volcanoes, from which the name of the field becomes. The geothermal fluids are hosted by intrusive rocks (chiefly granodiorite) and the heat source of the system is related to the magma chamber of the La Virgen volcano, the youngest and most southern of the volcanic complex.

During 2008 there were three production wells in operation that produced 0.55 million tons of steam at an annual mean rate of 62.7 t/h. The annual average production per well was 20.9 t/h, almost 19% higher than in 2003, when 17.6 t/h was obtained as average production (Gutiérrez-Negrín and Quijano-León, 2005). Nevertheless, the best figure was got in 2006, with 28.8 t/h per well (Gutiérrez-Negrín, 2007). Unlike Los Humeros, wells of Las Tres Vírgenes produce much brine: in 2008 the associated brine was 1.77 million tons. All this brine was fully injected through one injection well.

The gross specific consumption in Las Tres Vírgenes was 13.4 tons of steam per MWh in 2008, which is considerably higher than reported five years ago (Gutiérrez-Negrín and Quijano-León, 2005), and yet is lower than obtained in Los Humeros. The steam produced and the electricity generated in Las Tres Vírgenes in 2008 represents the highest ones since the field started to be exploited, even though they are still far away from the optimum.

Total geothermal production data in Mexico for 2008 are presented in Table 3, where they are compared with data for 2003.

It can be noted that despite the number of production wells increased in 16% in the last five years, the production of steam decreased in 2.4%. This means, of course, that in general the average production per well has dropped in the same 16% along the period, as shown in the same table, which forced CFE to drill more wells in order to sustain the steam supplying. However, despite the lower production of steam, generation of electricity jumped 12% meanwhile the installed capacity increased only 0.5%. This means that the available steam has been used more efficiently to produce electricity, which is reflected by the index of gross specific consumption of steam, which improved in the period to be almost 13% lower. Thus, in 2003 the geothermal-electric plants in Mexico required to produce an average of 10.7 tons of steam to generate 1 MWh, but in 2008 this amount dropped to 9.35.

Table 3: Main data on geothermal-electric production in Mexico in 2003 and 2008.

Data	2003	2008
Production wells (number)	197	229
Injection wells (number)	19	23
Steam produced (10^6 ton)	67.5	65.9
Steam produced (t/h)	7,702	7,504
Steam per well (t/h)	39.1	32.8
Brine disposed (10^6 ton)	76.7	69.7
Installed capacity (MWe)	953	958
Electricity (GWh)	6,282	7,047
GSC* of steam (t/MWh)	10.7	9.35

** Gross specific consumption*

4. DRILLING OF GEOTHERMAL WELLS

There were 62 geothermal wells drilled in Mexico for geothermal-electric purposes in the period 2004-2008, all of which were constructed by drilling companies contracted by CFE (Table 4). The annual average results in ~12 wells, yet actually 21 wells were drilled in 2004, 18 in 2005, 7 in 2006, just one in 2007 and 15 in 2008 (Otero-Solís, 2009). It can be assumed there were no wells drilled for direct uses in the period, because most of bathing facilities use thermal water from hot springs and only exceptionally from hot-water wells constructed with other purposes.

Only one exploration well was drilled in those years: the well EAC-2 constructed in 2008 in the geothermal zone of Acoculco, Pue., at 1,900 m depth. Considering there were no exploration wells in the previous period reported (2000-2003, according to Gutiérrez-Negrín and Quijano-León, 2005), the well EAC-2 was the first exploration well drilled in Mexico in the last nine years.

Five injection wells were drilled between 2004 and 2008, with a total length of 8,427 m (Table 4). Four of them were constructed at the Cerro Prieto field in 2004 (6,677 m) and one in the Los Azufres field in 2005 at 1,750 m depth (Otero-Solís, 2009).

Fifty six production wells were constructed in Mexico in the last five years, all with temperatures higher than 150 °C, with a combined depth of 148,035 meters (Table 4). 50 of those wells were drilled in Cerro Prieto (89%), 17 in 2004 and 2005, 5 in 2006 and 11 in 2008. Two production wells were constructed in Los Azufres in 2006 representing 3.6% of the total, 3 in Los Humeros in 2008 (5.3% of the total) and one in Las Tres Vírgenes in 2007 (1.8% of the total) (Otero-Solís, 2009). The average depth for production wells in Cerro Prieto was 2,725 m, 1,550 m in Los Azufres, and 2,200 m in Los Humeros. The only well in Las Tres Vírgenes was drilled at 2,102 m depth.

As usual, the geothermal-drilling activity in Mexico was concentrated in Cerro Prieto, where 54 out of 62 wells were constructed (87%) and 90.2% of the total length was drilled. Most production wells constructed in Cerro Prieto had the purpose of replace old wells, because the productive lifespan of a well in this field is typically 10 years, usually requiring a work-over by the fourth or fifth year. Production wells in the Los Azufres and Los Humeros have a longer production span and normally do not require work-over.

Taking into account the drilling data reported five years ago (Gutiérrez-Negrín and Quijano-León, 2005), the accumulative total number and depth of geothermal wells constructed in Mexico can be updated as presented in Table 5. Therefore, between 1963 and December 2008 in Mexico 556 geothermal wells, including exploration, production and injection, have been drilled with a combined depth of 1,188 km and an average depth of 2,137 m per well. 66% of the wells and 73% of the combined length have been constructed in the Cerro Prieto field, which currently counts for 75% of the geothermal-electric installed capacity and 73% of electric generation.

Table 5: Geothermal wells drilled in Mexico between 1963 and December 2008.

Geothermal field	Wells (no.)	Depth (km)	
		Total	Average
Cerro Prieto	369	868.4	2.353
Los Azufres	85	133.9	1.575
Los Humeros	43	94.0	2.185
Las Tres Vírgenes	10	19.9	1.993
Cerritos Colorados	13	23.1	1.778
Other zones	36	48.6	1.351
Total	**556**	**1,187.9**	**2.137**

It is worth to note the average depth of geothermal wells, which is similar in the fields of Cerro Prieto and Los Humeros, and even in Las Tres Vírgenes, but is quite short in Los Azufres. The average depth of exploration wells in other geothermal zones is even shallower (1,351 m). These zones include: San Marcos, Jal., Volcán Ceboruco, Nay., Laguna Salada, BC, Acoculco and Las Derrumbadas, Pue., Los Negritos, Mich., San Antonio El Bravo and Maguarichic, Chih., Aguacaliente, El Centavito and Santispac, BCS, Santiago Papasquiaro, Dgo., and one recent (1995) exploration well in Pathé, Hgo.

5. DIRECT USES OF GEOTHERMAL RESOURCES

Direct uses of geothermal resources in Mexico are mainly bathing and swimming facilities with recreational purposes and some of them with therapeutic uses. Table 6 presents the updated estimations on geothermal baths and swimming facilities in Mexico. Almost all of these resorts have been developed and are operated by private investors, yet there are isolated facilities operated by federal, state or municipal governments, through their tourism offices or, in some

cases, through federal institutions like the national social security institute (IMSS: Instituto Mexicano del Seguro Social).

Data included in the Table 6 were originally estimated in 2000 (Quijano-León and Gutiérrez-Negrín, 2000), based on the regional reconnaissance of geothermal resources in Mexico made by the CFE approximately between 1980 and 1990. The geothermal resources used for bathing, swimming and balneology were grouped for states since so were explored by the CFE. Now, some data, particularly the annual average flow, have been updated with recent information.

CFE has developed some direct uses of geothermal resources at the Los Azufres geothermal field, including a wood-dryer, a fruits and vegetables dehydrator, a greenhouse and a system for heating of its offices and facilities in this field (Hiriart, 2004). These projects represent an installed capacity of 0.47 MWt and an annual energy use of 4.5 TJ/year (Table 6). One additional project formerly reported at the Los Humeros geothermal field (Gutiérrez-Negrín and Quijano-León, 2005), for breeding eatable mushrooms of the species *Pleurotus ostreatus*, had to be adjourned.

Figure 4: Fruits and vegetables dehydrator prototype constructed by CFE in Los Azufres.

The geothermal heat pumps are still scarcely known in Mexico and practically undeveloped, except for some isolated cases with no available information. In general, district and individual space heating is not used in Mexico because of the mild temperatures along the year in almost all the territory.

Thus, it can be considered that Mexico has around 4,369 kg/s (15,727 t/h) of geothermal resources with an average temperature of 47 °C, out of which 3,594 kg/s (12,939 t/h) are utilized for direct uses, with an installed capacity of 155.8 MWt, with a mean capacity factor of 0.82 and an annual utilization of 4,023 TJ/year (Tables 6 and 7).

Bathing, swimming and balneology are by far the main direct uses of geothermal resources, since 3,593 kg/s (12,934 t/h) are used for these purposes (99.9% of the total), and only 1.5 kg/s (5.2 t/h) are utilized for other direct uses in Los Azufres (less than 0.1%) (Table 6). The installed capacity for bathing uses is 155.3 MWt (99.7% of the total) and the annual utilization is 4,022.8 TJ/year (99.9% of the total), being the rest for the other direct uses (Table 7).

The total available flow of geothermal water of low temperature in the country (15,727 t/h) is equivalent to the total geothermal flow, including steam and brine, produced by all the production wells operating in Mexico in 2008 that was 15,444 t/h as annual average.

6. HUMAN AND FINANCIAL RESOURCES

Personnel with a university degree allocated to geothermal activities are reported in Table 8 for the last five years. Professionals working for the government are mainly in the federal Secretary of Energy; they are not involved only in geothermal activities, but in renewable energy sources. Under public utilities is reported the CFE personnel working in its geothermal division (Gerencia de Proyectos Geotermoeléctricos). Total manpower of this division averaged 900 persons in the last five years (data for 2009 are as of April), but most of them lacks of university degree. Figures include professionals based on the headquarters in Morelia City and on the geothermal fields of Cerro Prieto, Los Azufres, Los Humeros, Las Tres Vírgenes and Cerritos Colorados (formerly La Primavera).

It can be noted in Table 8 a decrease of 16% in the amount between 2005 and 2009 (101 in 2005 and only 85 in 2009), which is even higher if we consider the previous period (2000-2004). During 2004 it was reported 120 professionals working for the CFE (Gutiérrez-Negrín and Quijano-León, 2005), and so the decrease between 2004 and 2009 is 29%. This situation seems to happen mainly due to the retirement of many specialists and the difficulty to be replaced, yet also the total manpower of the Gerencia de Proyectos Geotermoeléctricos dropped from 1,036 to 900 between both periods (2000-2004 and 2005-2009).

The column 3 in Table 8 reports the amount of professionals working in the electric research institute (IIE, Instituto de Investigaciones Eléctricas), in the geophysical and geologic institutes of the national university (UNAM), in the center of scientific research and high studies of Ensenada (Cicese, Centro de Investigación Científica y Estudios Superiores de Ensenada), and the Baja California university. Even though the IIE is not a university but a research center financed mostly by the CFE, its personnel was reported in this column. The IIE includes a geothermal division whose personnel are devoted to geothermal activities. Around 72% of the total of persons reported in this column works in the IIE, and the rest in the universities. The amount has remained quite steady in the last five years.

There were not paid foreign consultants between 2005 and 2009, but a couple of foreign researchers paid by international programs working in institutes in 2005 (Table 8, columns 4 and 5). Professional personnel working for private companies are mainly specialists related to drilling activities in geothermal fields.

Table 9 shows the estimated investments for geothermal development over the periods 1995-1999, 2000-2004 and 2005-2009. Figures for the first two periods are different to those reported five years ago (Gutiérrez-Negrín and Quijano León, 2005), because of the following considerations. For research and development it was reported 11.5 million USD for 1995-1999; this amount in Mexican currency remains the same, but it was updated considering the exchange-rate variation and the depreciation of the US currency in the last years, and so becomes approximately 7.21 million USD at present value (2009). For the period 2000-2004 it was reported no investment in research and development, but it had not been

considered investments made by the IIE. Thus, the correct figure is 111 million Mexican pesos (Arellano, 2009) that represent 11.28 million USD at present (2009) value.

For field development it was reported 385.8 and 415 million USD for the periods 1995-1999 and 2000-2004, respectively (Gutiérrez-Negrín and Quijano León, 2005). Both figures in Mexican currency are the same, yet taking into account the exchange rate variation and the depreciation of the USD in those periods, the updated figures become approximately 239.7 and 306.3 million USD, respectively, as now reported in the Table 9.

Figures reported in the Table 9 for the last period (2005-2009) include in research and development the investment actually made by the IIE geothermal department in 2005 through 2008 and the budget programmed for 2009 (Arellano, 2009); they also include the cost of the only exploration well (EAC-2) drilled in the period by CFE. For field development, figure was obtained from the investment actually made by the geothermal division of CFE in 2005-2008 and the budget expected to be exerted in 2009. All the figures were updated at present (2009) USD value.

Having said that, it is remarkable the decrease in the investment for field development in the period 2005-2009 compared to the immediately previous –a decrease of 24.5%. In fact, total investment in the last period is practically equal to that for the period 1995-1999 at constant dollars (Table 9). There are no available data on investment in direct uses, and then all the investments reported in this table come from public funds.

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(Other tables in the next five pages)

	Geothermal		Fossil Fuels		Hydro		Nuclear		Wind		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in December 2008	958	7,047	37,354	178,098	11,343	38,892	1,365	9,804	85	255	51,105	234,096
Under construction in December 2008	25		1,704		750		0		0		2,479	
Funds committed, but not yet under construction in December 2008	125		705		0		0		202		1,032	
Total projected use by 2015	1,118		41,648		12,335		0		591		55,692	

Notes:

1. All data are for the so-called public service of electricity, excluding self-suppliers, co-generators, small producers and exporters.
2. Total projected use by 2015 for geothermics includes the projects: CP-V (100 MW) and Los Humeros (U-9 and U-10: 50 MW) with funds already committed, and projects Cerritos Colorados U-1 to U-3 (75 MW) and Los Azufres (U-17: 25 MW) at planning stage. It also implies dismantle U-1 and U-2 of CP-1 (-75 MW) and units 2, 6 and 10 of Los Azufres (-15 MW).
3. Total projected use by 2015 for fossil fuels includes the dismantling of 3,190 MW of current, old power plants.

Table 1. Present and planned production of electricity

Locality	Power Plant Name	Year Commissioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe	Total Annual		Total under Constr. or Planned MWe
							Running Capacity MWe	Energy Produced 2008[3)] GWh/yr	
Cerro Prieto	CP-I U-1	1973	1		1F	37.5	37.5	174.75	
	U-2	1973	1		1F	37.5	37.5	182.02	
	U-3	1979	1		1F	37.5	37.5	277.18	
	U-4	1979	1		1F	37.5	37.5	134.47	
	U-5	1982	1	N	2F	30.0	30.0	0.00	
	CP-II U-1	1986	1		2F	110.0	110.0	942.62	
	U-2	1987	1		2F	110.0	110.0	763.89	
	CP-III U-1	1986	1		2F	110.0	110.0	944.40	
	U-2	1987	1		2F	110.0	110.0	863.39	
	CP-IV U-1	2000	1		1F	25.0	25.0	207.57	
	U-2	2000	1		1F	25.0	25.0	217.24	
	U-3	2000	1		1F	25.0	25.0	233.12	
	U-4	2000	1		1F	25.0	25.0	235.48	
	CP-V	2011	2		1F	0.0	0.0	0.00	100.0
Los Azufres	U-2	1982	1		O	5.0	5.0	43.72	
	U-3	1982	1		O	5.0	5.0	44.12	
	U-4	1982	1		O	5.0	5.0	43.70	
	U-5	1982	1		O	5.0	5.0	41.29	
	U-6	1986	1		O	5.0	5.0	41.81	
	U-7	1988	1		1F	50.0	50.0	391.86	
	U-9	1990	1		O	5.0	5.0	36.44	
	U-10	1992	1		O	5.0	5.0	41.92	
	U-11	1993	1		B	1.5	1.5	2.76	
	U-12	1993	1		B	1.5	1.5	3.01	
	U-13	2003	1		1F	25.0	25.0	192.95	
	U-14	2003	1		1F	25.0	25.0	224.06	
	U-15	2003	1		1F	25.0	25.0	221.30	
	U-16	2003	1		1F	25.0	25.0	187.68	
	U-17	2015	1		1F	0.0	0.0	0.00	25.0
Los Humeros	U-1	1990	1		O	5.0	5.0	37.99	
	U-2	1990	1		O	5.0	5.0	31.08	
	U-3	1991	1		O	5.0	5.0	37.64	
	U-4	2003	1		O	5.0	5.0	42.81	
	U-5	1991	1		O	5.0	5.0	42.18	
	U-6	1992	1		O	5.0	5.0	44.85	
	U-7	1994	1		O	5.0	5.0	44.61	
	U-8	2008	1		O	5.0	5.0	32.25	
	U-9	2011	1		1F	0.0	0.0	0.00	25.0
	U-10	2013	1		1F	0.0	0.0	0.00	25.0
Las Tres Vírgenes	U-1	2002	1		1F	5.0	5.0	21.04	
	U-2	2002	1		1F	5.0	5.0	20.20	
Cerritos Colorados*	U-1	2013	1		1F	0.0	0.00	0.00	25.0
	U-2, U-3	2014	2		1F	0.0	0.00	0.00	50.0
Total			**45**			**958.0**	**958.0**	**7,047.39**	**250.0**

* Formerly La Primavera.

Note: Total under construction or planned implies dismantle Units 1 and 2 of Cerro Prieto I (-75 MW) and units 2, 6 and 10 of Los Azufres (-15 MW). So, the net additional planned capacity would be: 250-90 = 160 MW.

Table 2. Utilization of geothermal energy for electric power generation as of 31 December 2008

Notes:

1) N = Not operating (temporary), R = Retired. Blank if presently operating.

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

3) Data as for 31 December 2008.

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1)]	(all)	1	0	0	0	1.900
Production	>150° C	56	0	0	0	148.035
	150-100° C	0	0	0	0	0.000
	<100° C	0	0	0	0	0.000
Injection	(all)	5	0	0	0	8.427
Total		**62**	**0**	**0**	**0**	**158.362**

Table 4. Wells drilled for electrical, direct and combined use of geothermal resources from January 1, 2004 to December 31, 2008 (excluding heat pump wells)

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

Locality	Type[1)]	Maximum Utilization					Capacity[3)] (MWt)	Annual Utilization		
		Flow Rate (kg/s)	Temperature (°C)		Enthalpy[2)] (kJ/kg)			Ave. 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	0.045	0.101	0.450
Los Azufres, Mich.	B	38.000	72.0	55.0			2.703	34.960	78.391	0.920
Los Azufres, Mich.	G	0.050	60.0	40.0			0.004	0.022	0.059	0.449
Los Azufres, Mich.	H	4.583	110.0	86.0			0.460	1.389	4.397	0.303
La Primavera, Jal.	B	63.000	48.0	31.0			4.481	58.650	131.511	0.931
Aguascalientes*	B	265.000	43.0	30.0			14.414	183.150	314.047	0.691
Chiapas*	B	1,000.000	36.0	29.0			29.288	799.675	738.340	0.799
Chihuahua*	B	38.000	39.3	25.0			2.274	29.680	55.982	0.781
Coahuila*	B	56.000	32.0	25.0			1.640	31.500	29.084	0.562
Durango*	B	34.000	52.5	38.0			2.063	15.975	30.553	0.470
Guanajuato*	B	293.000	40.8	29.0			14.466	237.600	369.805	0.811
Hidalgo*	B	271.000	41.5	32.0			10.772	250.800	314.265	0.925
Jalisco*	B	368.000	37.8	30.0			12.010	316.350	325.467	0.859
México*	B	103.000	35.1	25.0			4.353	90.880	121.069	0.882
Michoacán*	B	161.000	44.5	33.0			7.747	142.790	216.591	0.887
Morelos*	B	95.000	45.0	30.0			5.962	74.580	147.557	0.785
Nuevo León*	B	295.000	38.0	30.0			9.874	250.700	264.539	0.850
Querétaro*	B	770.000	31.8	26.5			17.075	663.975	464.165	0.862
San Luis Potosí*	B	292.000	36.8	31.0			7.086	222.750	170.408	0.763
Sinaloa*	B	7.000	72.5	61.0			0.337	4.601	6.979	0.657
Tlaxcala*	B	10.000	35.0	28.0			0.293	7.913	7.306	0.791
Veracruz*	B	42.000	65.0	48.0			2.987	37.455	83.985	0.891
Zacatecas*	B	163.000	36.6	28.5			5.524	138.700	148.186	0.851
TOTAL		**4,368.733**	**47.1**	**35.5**			**155.819**	**3,594.140**	**4,022.787**	**0.819**

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

Table 6. Utilization of geothermal energy for direct heat as of 31 December 2009 (other than heat pumps)

Notes:

1) 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).

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.

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

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

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]	0.000	0.000	0.000
Air Conditioning (Cooling)	0.000	0.000	0.000
Greenhouse Heating	0.004	0.059	0.449
Fish Farming	0.000	0.000	0.000
Animal Farming	0.000	0.000	0.000
Agricultural Drying[5]	0.007	0.101	0.450
Industrial Process Heat[6]	0.000	0.000	0.000
Snow Melting	0.000	0.000	0.000
Bathing and Swimming[7]	155.347	4,018.229	0.820
Other Uses (specify)	0.000	0.000	0.000
Subtotal	**155.819**	**4,022.787**	**0.819**
Geothermal Heat Pumps	0.000	0.000	0.000
TOTAL	**155.819**	**4,022.787**	**0.819**

Table 7. Summary table of geothermal direct uses as of 31 December 2009

Notes:

1) Installed capacity (thermal power) (MWt) = Max. flow rate (kg/s) [inlet temp. (°C) - outlet temp. (°C)] x 0.004184.

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

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.

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	4	101	30	0	2	21
2006	5	97	32	0	0	23
2007	5	89	35	0	0	21
2008	4	86	36	0	0	21
2009	6	85	33	0	0	21
Total	24	458	166	0	2	107

Table 8. Allocation of professional personnel to geothermal activities (Restricted to personnel with University degrees)

Notes:

1) Government

2) Public Utilities

3) Universities

4) Paid Foreign Consultants.

5) Contributed Through Foreign Aid Programs.

6) Private Industry.

Period	Research & Development Incl. Surface Explor. & Exploration Drilling Million US$	Field Development Including Production Drilling & Surface Equipment Million US$	Utilization		Funding Type	
			Direct Million US$	Electrical Million US$	Private %	Public %
1995-1999	7.21	239.73	0	246.94	0	100
2000-2004	11.28	306.34	0	317.62	0	100
2005-2009	15.22	231.04	0	246.25	0	100

Note: Figures for 1995-1999 and 2000-2004 were updated taking into account the evolution of the Mexican Peso/USD exchange rate and the annual inflation rate of the USD.

Table 9. Total investment in geothermal in (2009) US$