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GEOTHERMAL TRAINING PROGRAMME



GEOTHERMAL ACTIVITY AND DEVELOPMENT IN MEXICO – KEEPING THE PRODUCTION GOING

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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 net installed geothermal-electric capacity in Mexico as of December 2010 is 958 megawatts (MW). This capacity is currently operating in four geothermal fields: Cerro Prieto (720 MW), Los Azufres (188 MW), Los Humeros (40 MW) and Las Tres Vírgenes (10 MW). However, the running capacity is less than that, because of production decline mainly at Cerro Prieto geothermal field, one of the largest geothermal fields in the world. 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, 2 x 25 MW) which will add a net additional capacity of 35 MW when commissioned. This project is scheduled to be on line during the first semester of 2012. During 2011, thirty-seven power plants of condensing, back-pressure and binary cycle were in operation in those fields. The annual geothermal production (2011) was 60.4 million metric tons of steam at an annual average rate of 6,903 tons per hour (t/h). Steam was delivered by an average of 240 production wells, and was accompanied by 71.7 million metric tons of brine that was disposed through 28 injection wells and a solar-evaporation pond operating in Cerro Prieto. Geothermal power plants at the fields produced 6,191 gigawatt-hour (GWh) of electric energy in 2011, which represented 2.3% of the whole electric generation in Mexico in that year. Exploration of the Acoculco, Baja California Norte, El Chichonal, and Cuitzeo Lake geothermal areas is in the execution stage.

1. INTRODUCTION

In Mexico, geothermal resources remain to be mainly utilized to produce electricity. The public service of electricity in Mexico is provided by the Federal Government. Until October 10, 2009, two public facilities, the Comisión Federal de Electricidad (CFE) and Luz y Fuerza del Centro (LFC), owned and operated by the government, were in charge of generation, transmission, distribution and commercialization of electric energy. Since that date, only CFE has this responsibility. Electric uses of geothermal are planned, developed and operated by the Gerencia de Proyectos Geotermoeléctricos – the geothermal division of the CFE.

2. THE ELECTRIC INDUSTRY

The Federal Electricity Commission (CFE) is a company created and owned by the Mexican government. It generates, distributes and markets electric power for almost 35, 3 million customers.

This figure represents almost 100 million people. The CFE incorporates more than a million new customers every year. The infrastructure to generate electric power is made up of 209 generating plants, having an installed capacity of 52,515 megawatts (MW). 22.67% of its installed capacity stems from around 22 plants which were built using private capital and are currently operated by independent power producers (Productores Independientes de Energía or PIE).

The CFE generates power using various technologies and primary energy sources. It has thermoelectric, hydroelectric, coal-fired, geothermal and wind powered plants and facilities, as well as one nuclear power plant. In order to take the power from its generating plants to the household of each one of its customers, the CFE has more than 756,000 km of power lines that transmit and distribute electric power. Electricity reaches almost 190,000 communities (of these, 190,732 are small villages). Also, 97.6 % of the population has access to electric service.

As of December 2011 the total installed electric capacity in Mexico was 51,177 MW (Table 1). This total includes 22 independent power producers (IPP) amounting 11,907 MW, whose power plants were constructed and are operated and owned by private companies (CFE, 2011). 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.

TABLE 1: Mexico development of installed capacity and generation

		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011*
Capacity (MW)	CFE	36,855	36,971	38,422	37,325	37,470	38,397	38,474	38,927	39,704	39,270
	PIE's	3,495	6,756	7,265	8,251	10,387	11,457	11,457	11,457	11,907	11,907
	Total	40,350	43,727	45,687	45,576	47,857	49,854	49,931	50,384	51,611	51,177
Generation (TWh)	CFE	177.05	169.32	159.53	170.07	162.47	157.51	157.16	154.14	160.37	170.42
	PIE's	21.83	31.62	45.85	45.56	59.43	70.98	74.23	76.5	78.44	84.26
	Total	198.88	200.94	205.39	215.63	221.9	228.49	231.4	230.64	238.81	254.68

*Data as December 2011

As indicated in Table 2, almost three quarters of the installed capacity for public service in Mexico (68%) is based on fossil-fuelled power plants (hydrocarbons and coal), and more than one fifth (22%) on hydroelectric plants. Geothermal electric capacity represents 2% and wind only 0.1%. The rest (1.9%) is represented by nuclear power plants (Figure 1).

TABLE 2: Gross installed capacity by generation type (December 2011)

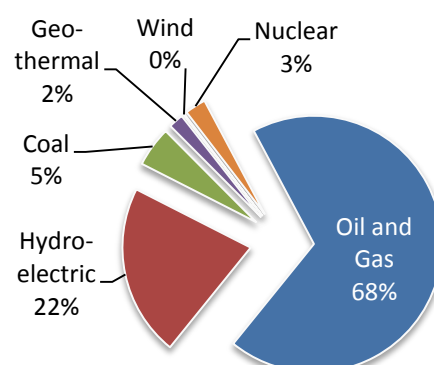
Generation Type	Effective capacity (MW)	Percentage
Oil and Gas	23,121.17	46%
Hydroelectric	11,210.90	22%
Coal	2,600.00	5%
Geothermal	886.60	2%
Wind	86.75	0%
Nuclear	1,364.88	3%
Oil and Gas (private)	11,906.90	23%
Total	51,177.20	100%

The electric generation for public service in Mexico in 2011 was 254,680 GWh, as reported in Table 1. More than three quarters (81%) of the electric energy for public service in Mexico in 2011 was generated by power plants fuelled by hydrocarbons and coal, only 13% was produced by hydroelectric plants, 4% by nuclear power plants, 2.3% by geothermal-electric plants and 0.04% by wind power plants, as implicated in Table 2 (Figure 2; Table 3).

3. GEOTHERMAL ELECTRICITY

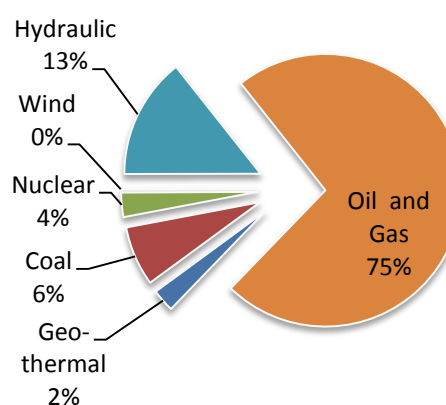
The net geothermal-electric capacity in Mexico is 958 MW (964.5 gross MW) as shown in Figure 3, installed into four geothermal fields (Cerro Prieto, Los Azufres, Los Hornos and Las Tres Vírgenes). Table 4 shows the running capacity for each field, the projects under construction and future increases on capacity. The fifth field, La Primavera (Cerritos Colorados project), remains on stand-by, even though a potential of 75 MW was assessed long time ago. Installation of the first units in this field is expected to start soon, since the Environmental Impact Assessment has been approved for a 25 MW power station. However some social opposition is still in the surrounding cities and has to be solved in order to be able to construct the power station there.

Present geothermal-electric capacity represents 2.3% of the total electric capacity for public service in the country. Thirty seven power plants of several types (condensing, back pressure and binary cycle), between 1.5 and 110 MW, operate in those fields, fed by 240 geothermal wells with a combined production of 6,903 metric tons of steam per hour (t/h). The production wells have depths between 600 and 4,400 meters. Steam comes with almost 9,000 t/h of brine that is injected through 28 injection wells, or treated in a solar evaporation pond of 14 km² in Cerro Prieto. During 2011, steam produced in



Effective capacity MW

FIGURE 1: Breakdown (%) of the total electric installed capacity in Mexico as of December 2011



Generation type

FIGURE 2: Total generation of electricity in Mexico in 2011 by type of power plant and fuel used

TABLE 3: Generation of electricity by source

Generation type	Percentage
Geothermal	2.30%
Coal	6.23%
Nuclear	3.58%
Wind	0.04%
Oil and Gas (Private Producers)	31.24%
Hydraulic	12.84%
Oil and Gas	43.77%

those fields amounted 60.4 million of metric tons, and the power plants generated 6,504 gigawatt-hour (GWh), which represented 2.3% of the electric energy produced in Mexico.



FIGURE 3: Location of Mexican Geothermal Fields under exploitation (Cerritos Colorados, formerly known as La Primavera, remains in stand-by)

TABLE 4: Geothermal capacity in Mexico

Geothermal Field	Start up year	Running Capacity MW	Under Construction MW	New Projects MW
Cerro Prieto, BC	1973	720		
Los Azufres, Mich	1982	188		50
Los Humeros, Pue	1990	40	2 x 25	2 x 25
Las Tres Vírgenes, BCS	2001	10		
Cerritos Colorados, Jal				25

The national capacity factor in 2011 was 84.1% or 0.84 in average. All the fields and power units are managed and operated by personnel of the CFE.

4. KEEPING THE PRODUCTION GOING

4.1 Cerro Prieto Geothermal Field

Cerro Prieto is the oldest and largest Mexican geothermal field in operation. It is located in the northern part of Mexico (Figure 3), and its first power units were commissioned in 1973. Commercial exploitation started in 1973, so this reservoir has been under extraction conditions for around than 40 years. There are currently installed 13 units of condensing type: four 110-MW double-flash, four single-flash of 37.5 MW each, four single-flash of 25 MW each and one 30-MW single-flash, low pressure, amounting 720 MWe (Figure 4). These power units produced 4,547 GWh in 2011 at an annual capacity factor of 72% (0.72). The decrease in annual capacity factor is due to the production decline of steam in the wells. 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 400 geothermal wells have been drilled in 38 years in Cerro Prieto, with depths up to 4,400 m. 174 production wells were in operation during 2011 producing 39.96 million tons of separated steam at an annual average rate of 4561 tons per hour (t/h). The annual average production rate per well was 26 t/h. There were also 18 injection wells in operation that returned to the reservoir around 64.17 million tons of total separated brine. The rest was disposed in the solar evaporation pond of 14.3 km² in surface. Taking into account the steam produced in 2011 in Cerro Prieto, the gross steam specific consumption results in an annual average of 8.5 tons per MWh.

CURRENT SITUATION	CPI					CPII		CPIII		CPIV				TOTAL
	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	U13	
Installed Capacity MW	37.5	37.5	37.5	37.5	30	110	110	110	110	26.95	26.95	26.95	26.95	727.8
Specific Consumption t/MWh	10.6	10.6	10.6	10.6		8.09	8.09	8.18	8.18	6.81	6.81	6.81	6.81	
Steam Required th	398	398	398	398		890	890	900	900	184	184	184	184	5908
Year of commissioning Operation	Apr-73	Oct-73	Feb-79	Apr-79	Jan-82	Jan-86	Apr-84	Jan-86	Agu-86	Apr-00	May-00	Jun-00	Jul-00	
Years in Operation	37	37	32	32	29	25	27	25	25	11	11	11	11	

FIGURE 4: Cerro Prieto Geothermal Field January 2012

Figure 5 shows the historic production in this geothermal field, including the annual number of wells repair and drill annually. As it is shown in this figure, production is no longer able to be sustaining under the actual injection and extraction conditions. Therefore, there is an exploration campaign going on and projects to efficient the use of the steam in order to compensate the production decline and being able to reach a sustainable level of production and generation in the field. According to numerical models, the sustainable level of Cerro Prieto will be of around 3000 t/h of steam. Several studies are under execution in order to review and change production and extraction strategies to reduce annual production decline.

4.2 Los Azufres Geothermal Field

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 MW, four condensing of 25 MW each, seven 5-MW back-pressure and two 1.5-MW binary cycles. The total installed capacity is 188

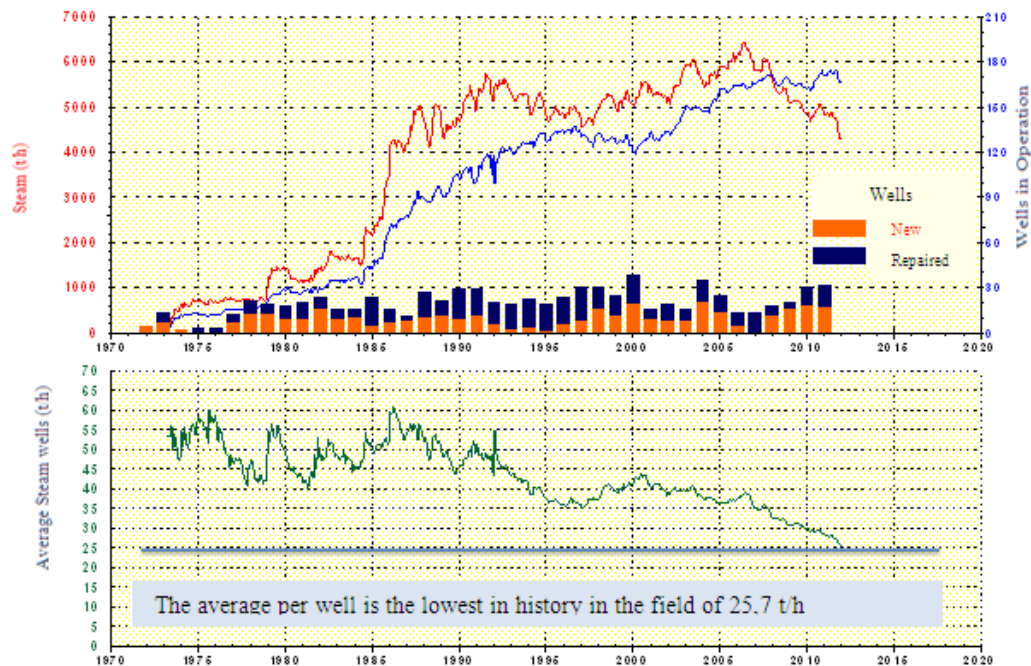


FIGURE 5: Historic production of Cerro Prieto Geothermal Field

MW (Table 4). Generation of electricity in 2011 was 1,575 GWh, at an annual capacity factor of 95% (0.95). 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 2011, 40 production wells were in operation in Los Azufres, which produced 14.7 million tons of steam, at an annual average rate of 1687 t/h. The annual mean production per well was 42 t/h. The produced steam was accompanied by 4.9 million tons of brine that was fully injected into the reservoir through 6 injection wells. The gross specific consumption in Los Azufres in 2011 was 9.33 tons of steam per MWh, which is one of the historically lowest in this field yet still higher than in Cerro Prieto.

Figure 6 shows the historical annual production of steam at Los Azufres. As it can be seen, production has been maintained and the geothermal power plant ranks in the first 15 places of best operational conditions in the country competing with 144 power plants in Mexico (SGD-index)

Late 2011, an international bid has been sent in order to install a new project in the north part of the field. This project is named Azufres III and consists of 50 MW net capacity project.

4.3 Los Humeros Geothermal Field

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 24 production wells operating in Los Humeros during 2011. They

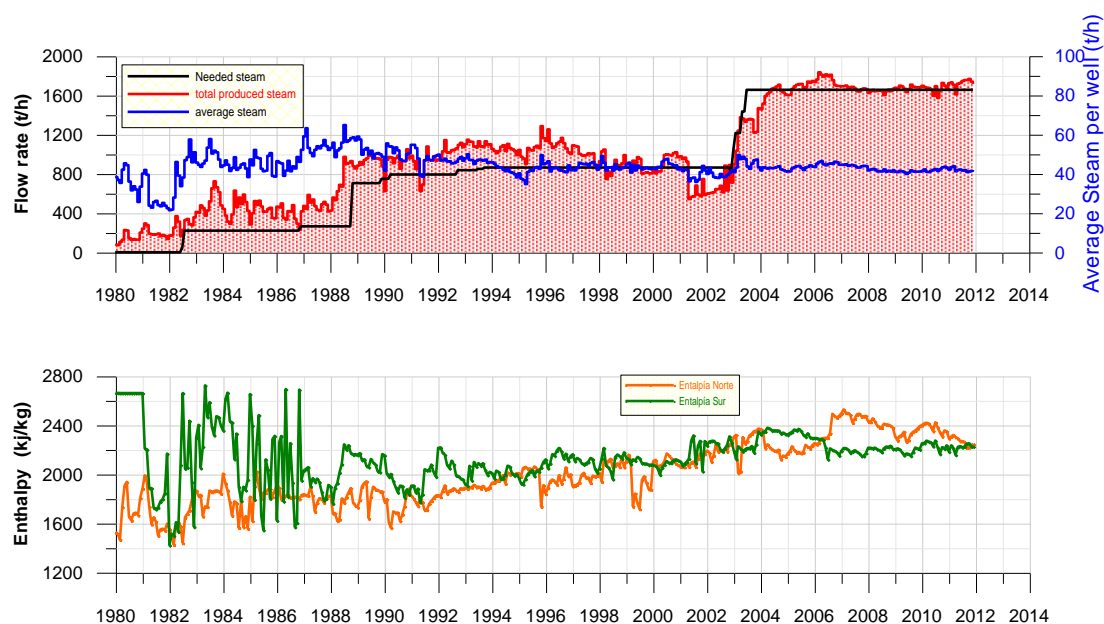


FIGURE 6: Historic production of Los Azufres Geothermal Field

produced 5.09 million tons of steam at an annual mean rate of 581 t/h, resulting in an average production per well of 24 t/h. The wells in Los Humeros produce usually low brine, and so occurred in 2011 when 0.56 million tons of brine was obtained. The brine was returned to the reservoir by three injection wells. Generation of electricity in Los Humeros was 335.64 GWh. The capacity factor in 2011 was 95% (0.95), but the gross specific consumption was 15.16 tons of steam per MWh.

Figure 7 shows the historical annual production of steam at Los Humeros. As it can be seen, production has been maintained and this geothermal power plants together with Los Azufres ranks in the first 15 places of best operational conditions in the country competing with 144 power plants in Mexico.

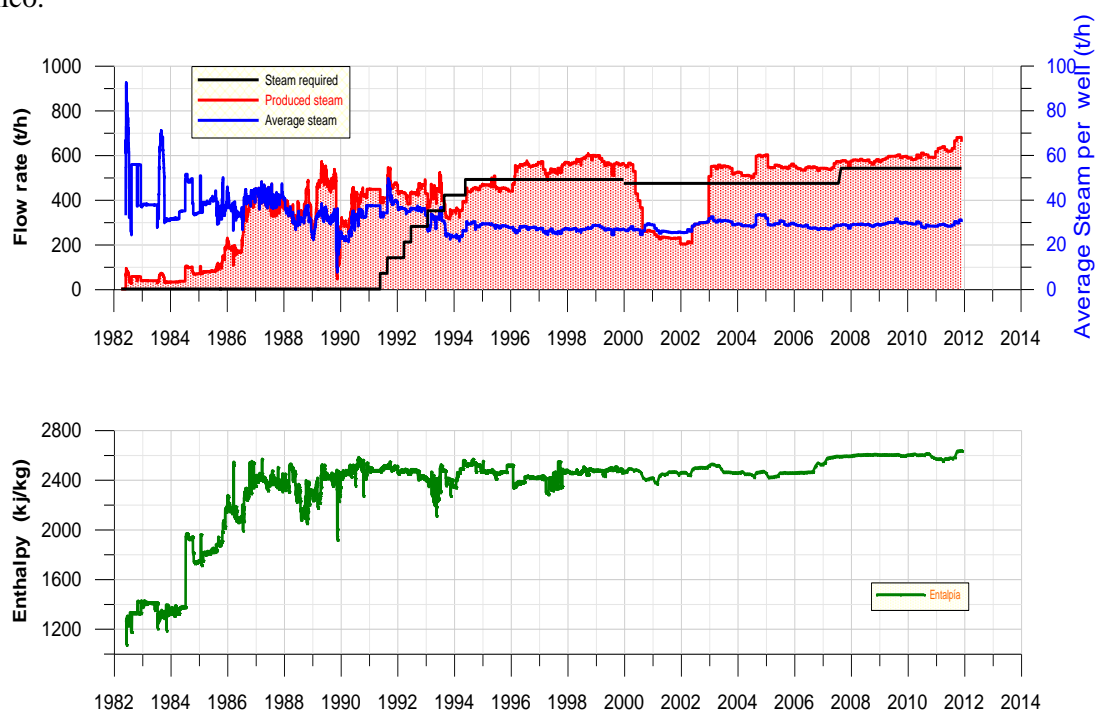


FIGURE 7: Historic production of Los Humeros Geothermal Field

As part of the development of this geothermal field, there is right now under construction Los Humeros II this project consisting of substitution of 4 units of 5 MW each in order to installed two new 25MW each one. After commissioning these power stations total install capacity in the field will be 70 MW, meaning a 75% of increment. Additional plans are discussed in section 5 of this paper.

4.4 Las Tres Virgenes Geothermal Field

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-MW power units in operation that were officially commissioned in 2002. Generation of electricity in 2011 was 46.5 GWh, at an annual mean capacity factor of 50% (0.50). 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 2011 there were four production wells in operation that produced 0.623 million tons of steam at an annual mean rate of 71 t/h (Figure 8). The annual average production per well was 18t/h. Unlike Los Humeros, wells of Las Tres Virgenes produce much brine: in 2011 the associated brine was 2.01 million tons. All this brine was fully injected through one injection well. In this moment the option of installing a binary cycle power plant is under economic analysis. The gross specific consumption in Las Tres Virgenes was 13.39 tons of steam per MWh in 2011, which is considerably higher than reported five years ago (Gutiérrez-Negrín; Quijano-León, 2005), and yet is lower than obtained in Los Humeros. The steam produced and the electricity generated in Las Tres Virgenes in 2011 represents the highest ones since the field started to be exploited, even though they are still far away from the optimum. Because of that during 2011, the mean capacity factor has been increased to 10% compared with 2010, thus contributing with almost 65% of the total isolated generation system in that part of the country. In 2012 it is expected to increase the capacity factor in this field to be comparable to Los Azufres and Los Humeros.

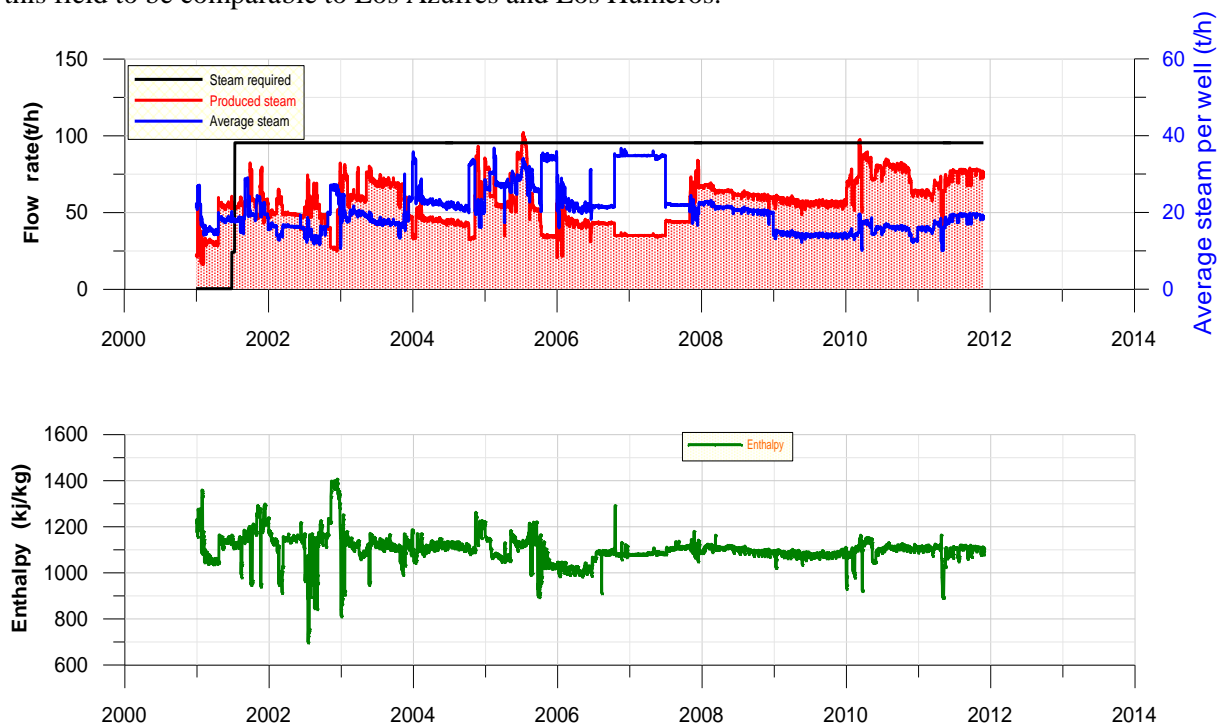


FIGURE 8: Historic production of Las Tres Virgenes Geothermal Field

5. NEW GEOTHERMAL DEVELOPMENTS

The National Development Plan 2007-2012 states that environmental sustainability is a central public policy of Mexico. This implies the country should take into consideration the environment as one of the elements of competitiveness and economic and social development. Using renewable sources of energy can simultaneously reduce the dependence on fossil fuels, reduce the emissions of greenhouse gases and increase the added value of economic activities. Mexico has great potential in renewable energy, especially geothermal and provides ample opportunities to be exploited, and meet the challenges of global warming. According to this public policy, geothermal projects for the near term are shown in Table 5.

TABLE 5: Mexican geothermal projects in the near term.

Projects	2012	2013	2014	2015
Los Humeros II Phase A	25			
Los Humeros II Phase B	25			
Los Azufres III			50	
Los Humeros III				25
Total				125

The project Los Humeros II phases A and B is composed of two condensing units of 25 MW each to be commissioned in 2011(phase A) and 2012 (phase B). Phase B includes the replacement of 3 x 5 MW backpressure units, using the same amount of steam to generate 10 MW of additional power. Thus, the net additional capacity of the Los Humeros II project will be 35 MW.

Los Azufres III project is scheduled for 2014. This project consists of one 50-MW unit, which considers dismantling four 5-MW backpressure units currently in operation. Therefore, the net additional capacity in this field will be 30 MWe.

Late 2012, a new international bid will be deployed in order to install a new 25 MW project in the north part of the field. This project is named Humeros III Fase A, this project will substitute 3 back pressure units of 5 MW each, so therefore the net increment of installed capacity will be 10 MW. Los Humeros III Fase B, with a second unit of 25 MW each (Table 5), dismantling the last five 5-MWe back pressure units is scheduled to start operations mid-2017. Thus, this project will bring a net additional capacity of 25 MW.

6. EXPLORATION

Exploratory studies of geology, geochemistry and geophysics have made it possible to identify areas of high, medium and low enthalpy geothermal potential interest of approximately 500 MW. The most likely areas are showed in Figure 9 and Table 6.

6.1 El Chichonal Volcano

Studies to evaluate the geothermal potential of the Chichonal Volcano area started since the 80's with geological surveys, identification of thermal manifestations and geochemical evaluation, concluding that this area presents the best conditions for the existence of high enthalpy resource in the state of Chiapas.

In 1982 Chichonal Volcano erupted causing a disaster in the region. After the eruption, the volcano has been studied by numerous scholars and academic institutions, from the point of view of volcanic hazards; recently CFE has started exploration studies to locate exploration wells. Geothermometry estimates temperatures around 220 °C.

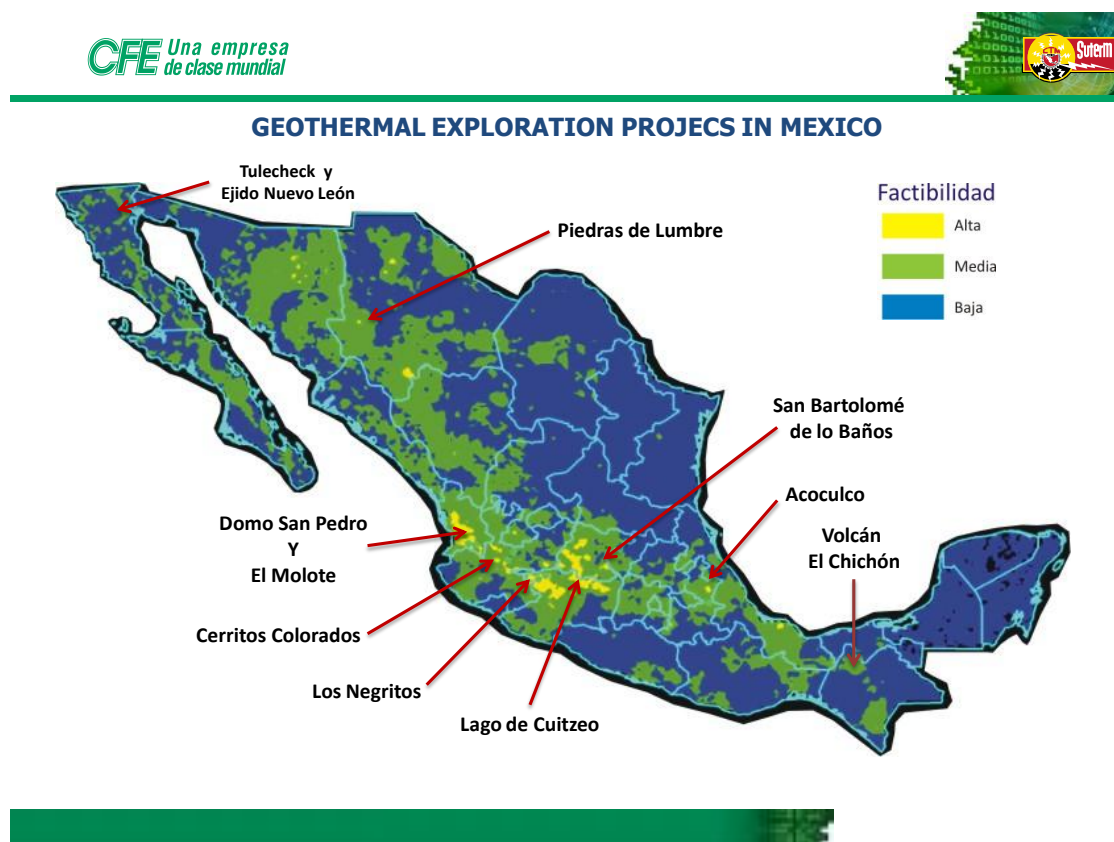


FIGURE 9: Main geothermal areas on exploration stage

TABLE 6: Geothermal exploration projects

Project	Objective	Current Status
Cerritos Colorados, Jal.	Install 25 MW, condensing type unit	EIA approved, but social issues still in progress
Nuevo Leon y Saltillo	Evaluate potential and install 100 MW	Exploration drilling 2013-2015.
Acoculco, Puebla.	Assessment as a EGS project.	2 depth wells drilled with high temperature but negligible permeability.
Tulecheck, BC.	Binary Cycle project	2 exploration wells drilled in 2010.
El Chichonal, Chis.	Exploration for high temperature resources	Exploration studies in progress 3 exploration wells to be drilled 2013-2014
Tacanán, Chis.	Exploration for high temperature resources	Exploration studies in progress
Cuitzeo Lake	Binary Cycle project	Exploration studies in progress 3 exploration wells to be drilled 2013-2014

6.2 Piedras de Lumbre, Chich.

The geothermal area of Piedras de Lumbre is located 220 km in a straight line southwest of Chihuahua City and 60 km southwest of San Juanito, Chihuahua railroad station-Pacific, within the municipality of Maguarichi.

In the past, this geothermal area had a 300-kW binary cycle power plant, fed by a shallow low-enthalpy reservoir. This unit supplied energy to a nearby, small village then isolated from the grid. The unit was dismantled when the grid reached the village, but recently the CFE reassumed exploration surveys looking for a high temperature, deeper reservoir.

6.3 Tulecheck

This geothermal area is located in the Mexicali Valley around 15 km south of the city of Mexicali, about 20 km northwest of Cerro Prieto, and between 6 and 8 km east of the Sierra Cucapa. A low enthalpy resource is expected to be developed there, since geothermometry studies indicate temperatures of 180-200 °C.

6.4 Acoculco

The Acoculco geothermal zone, Pue., is a volcanic complex located in the eastern Mexican Volcanic Belt and the Sierra Madre Oriental provinces. Currently two exploratory wells have been drilled by the CFE in the area, with temperatures above 300 °C and low permeability. With the known information is not still possible determine the feasibility of a geothermal-electric project, and further studies are required. However, given the most recent results this project is a candidate to be developed as an enhanced (or engineered) geothermal system in the future.

6.6. Cuitzeo Lake

Some geothermal manifestations occur at the shores of this lake, located in the state of Michoacán, presenting geothermometry temperatures of around 200 °C. A low enthalpy resource is expected to be developed here. Geophysical, geological and geochemical exploration surveys were finished in 2010, and exploration wells are to be sited in order to continue with the assessment of the project.

6.7 Nuevo Leon Ejido

Geological and thermal information was obtained from eight exploratory wells drilled in the 80's. Temperatures above 250 C in a deep reservoir were identified. Therefore the east of Cerro Prieto has been selected for new power stations in order to compensate the production and generation reduction in the actual geothermal field. This project will be called Ejido Nuevo León and development wells will be drilled in order to extract the enough steam for the new projects. A geothermal capacity of around 100 MW is calculated.

7. CONCLUSIONS

Mexico is a very rich country in renewable sources of energy, and then it is possible reduce simultaneously the dependence on fossil fuels, reduce GHG emissions and increase the added value of economic activities. Mexico has great potential in renewable energy, especially geothermal, and provides ample opportunities to be exploited, to meet the challenges of global warming.

There are four geothermal fields in commercial operation. Cerro Prieto has been in operation for more than 37 years and currently presents a large production decline requiring changes in the exploitation and injection strategy.

Mexico occupies the fourth geothermal installed capacity place worldwide. However its growing has been slow compared with other countries such as the US and Indonesia. For 2015 it is expected the installed capacity to grow to ~1050 MW, with projects Los Humeros II and III and Los Azufres III

Besides that, large exploration campaigns are running in order to find new geothermal areas that can be commercially exploited using both high and medium enthalpy systems. The most important places are El Chichonal volcano, Cuitzeo Lake, Acoculco and Cerritos Colorados.

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