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GEOTHERMAL ACTIVITY AND DEVELOPMENT IN MEXICO – KEEPING THE PRODUCTION GOING

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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 net installed geothermal-electric capacity in Mexico as of 2013 is 823.4 megawatts (MW). This capacity is currently operating in four geothermal fields: Cerro Prieto (570 MW), Los Azufres (191.6 MW), Los Humeros (51.8 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). During 2013, thirty eight power plants of condensing, back-pressure and binary cycle types were in operation in those fields. The annual geothermal production (2013) was 55.6 million metric tons of steam at an annual average rate of 6,353 tons per hour (t/h). Steam was delivered by an average of 225 production wells, and was accompanied by 67.4 million metric tons of brine that was disposed of through 26 injection wells and a solar-evaporation pond operating in Cerro Prieto. Geothermal power plants in the fields produced 5,769 gigawatts-hour (GWh) of electric energy in 2013, 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 (Gutiérrez-Negrín et al., 2010).

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 36, 4 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 224 generating plants, having an installed capacity of 51,780 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 (IPP).

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, (Gutiérrez-Negrín, 2007). In order to take the power from its generating plants to the household of each one of its customers, the CFE has more than 817,458 km of power lines that transmit and distribute electric power. Electricity reaches almost 190,000 communities (of these, 190,732 are small villages). Also, 97.9% of the population has access to electric service.

As of December 2013 the total installed electric capacity in Mexico was 52,695 MW (Table 1). This total includes 22 independent power producers (IPP) amounting 12,850 MW, whose power plants were constructed and are operated and owned by private companies (CFE, 2013). 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**	**2012**	**2013**
Capacity (MW)	CFE	36,855	36,971	38,422	37,325	37,470	38,397	38,474	38,927	39,704	39,270	39,362	39,845
	IPP	3,495	6,756	7,265	8,251	10,387	11,457	11,457	11,457	11,907	11,907	12,418	12,850
	Total	40,350	43,727	45,687	45,576	47,857	49,854	49,931	50,384	51,611	51,177	51,780	52,695
Generation (TWh)	CFE	177.05	169.32	159.53	170.07	162.47	157.51	157.16	154.14	160.37	170.42	175.8	161.59
	IPP	21.83	31.62	45.85	45.56	59.43	70.98	74.23	76.5	78.44	84.26	81.73	83.99
	Total	198.88	200.94	205.39	215.63	221.9	228.49	231.4	230.64	238.81	254.68	257.53	245.58

As indicated in Table 2, almost three quarters of the installed capacity for public service in Mexico (74%) is based on fossil-fuel power plants (hydrocarbons and coal), and more than one fifth (21%) on hydroelectric plants. Geothermal electric capacity represents 1.6% and wind only 0.2%. The rest (2.7%) is represented by nuclear power plants and photovoltaic (Figure 1).

TABLE 2: Gross installed capacity by generation type (December 2013)

Generation Type	**Effective capacity MW**	**Percentage**
Oil and Gas	26,263.02	45%
Hydroelectric	11,266	21.4%
Coal	2,600	4.9%
Geothermal	823.4	1.6%
Wind	86.75	0.2%
Nuclear	1,400	2.7%
Photovoltaic	7,68	0.011
Oil and Gas (private)	12,852.4	24.4%
Total	**52,695.75**	**100%**

The electric generation for public service in Mexico in 2013 was 245,588 GWh, as reported in the same Table 1. More than three quarters (82%) of the electric energy for public service in Mexico in 2013 was generated by power plants fuelled by hydrocarbons and coal, only 10% was produced by hydroelectric plants, 4% by nuclear power plants, 2.3% by geothermal-electric plants and 0.1% by wind power plants, as implicated in Table 3 (Figure 2).

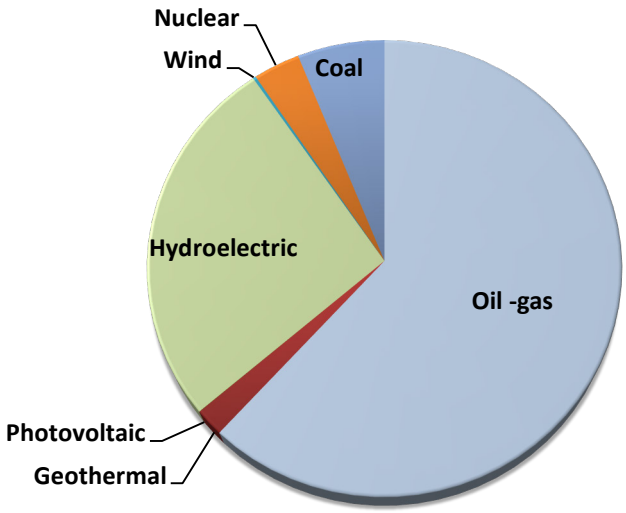

FIGURE 1: Breakdown of the total CFE electric installed capacity in Mexico as of December 2013

TABLE 3: Generation of electricity by source

Generation type	Percentage
Geothermal	2.3%
Coal	6%
Nuclear	4.6%
Wind	0.1%
Photovoltaic	0.01%
Hydraulic	10.7%
Oil and Gas	42%
Oil and Gas (Private Producers)	34.2%

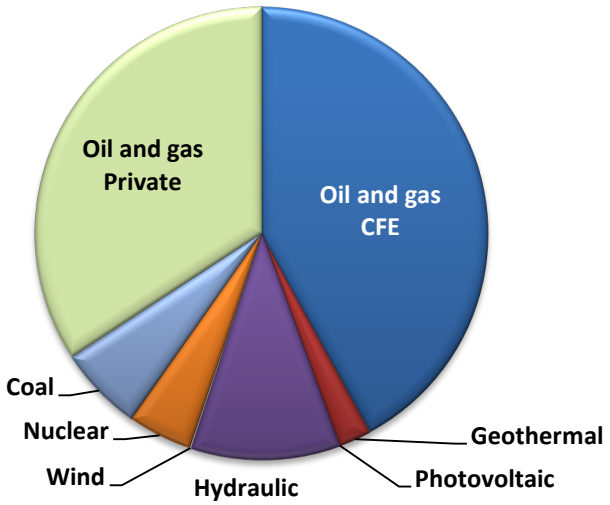

FIGURE 2: Total generation of electricity in Mexico in 2013, by type of power plant and fuel used

3. GEOTHERMAL ELECTRICITY

The net geothermal-electric capacity in Mexico is 833.4 MW as shown in Figure 3, installed into four geothermal fields (Cerro Prieto, Los Azufres, Los Humeros 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, (CFE, 2011). 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.

FIGURE 3: Locations of Mexican geothermal fields under exploitation (Cerritos Colorados, formerly known as La Primavera, remains in stand-by). The national capacity factor in 2013 was 80.6% or 0.8 on average. All the fields and power units are managed and operated by personnel of the CFE.

That present geothermal-electric capacity represents 2.3% of the total electric capacity for public service in the country. Thirty eigth power plants of several types (condensing, back pressure and binary cycle), between 1.5 and 110 MW, operate in those fields, fed by 225 geothermal wells with a combined production of 6,355 metric tons of steam per hour (t/h). The production wells have depths between 600 and 4,400 meters. Steam comes with almost 7,700 t/h of brine that is injected through 26 injection wells, or treated in a solar evaporation pond of 14 km^2 in Cerro Prieto. During 2013, steam produced in those fields amounted 55.6 million of metric tons, and the power plants generated 5,768 gigawatts-hour (GWh), which represented 2.3% of the electric energy produced in Mexico.

TABLE 4: Geothermal capacity in Mexico

Geothermal Field	Start up year	Running Capacity MW	Under Construction MW	New Projects MW
Cerro Prieto, BC	1973	570		
Los Azufres, Mich	1982	191.6	1 x 50	1 x 25
Los Humeros, Pue	1990	51.8		2 x 25
Las Tres Vírgenes, BCS	2001	10		2
Cerritos Colorados, Jal				25

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 40 years. There are currently installed 11 units of condensing type: four 110 MW double-flash, four single-flash of 25 MW each and one 30 MW single-flash, low pressure, amounting 570 MWe (Table 5). These power units produced 3,996 GWh in 2013 at an annual capacity factor of 78% (0.78). 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 40 years in Cerro Prieto, with depths up to 4,400 m. 159 production wells were in operation during 2013 producing 34.54 million tons of separated steam at an annual average rate of 3,942 tons per hour (t/h). The annual average production rate per well was 24.7 t/h. There were also 17 injection wells in operation that returned to the reservoir around 59.82 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 2013 in Cerro Prieto, the gross steam specific consumption results in an annual average of 8.5 tons per MWh.

TABLE 5: Source: Cerro Prieto Geothermal Field, December 2013

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	570
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 t/h	398	398	398	398		890	890	900	900	184	184	184	184	4,316
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 shows the historic production in this geothermal field, including the annual number of wells repaired and drilled annually. As it is shown in this figure, production is no longer sustainable under the actual injection and extraction conditions. Therefore, there is an exploration campaign going on and projects to make more efficient 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

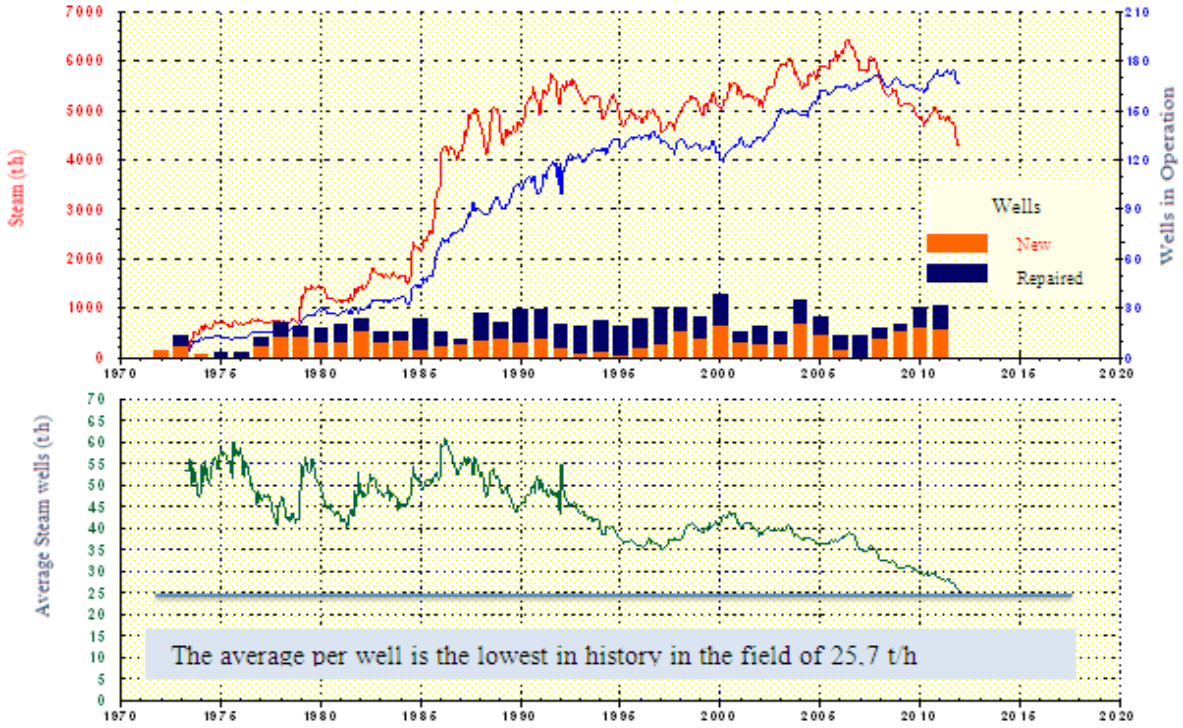

FIGURE 4: Historic production of Cerro Prieto Geothermal Field

Volcanic Belt in a pine-forest at 2,800 m a.s.l. The first power units were commissioned in 1982, and presently there are 12 power units in operation: one condensing of 50 MW, four condensing of 25 MW each and seven 5 MW back-pressure. The total installed capacity is 191.6 MW (Table 4). Generation of electricity in 2013 was 1,503GWh, 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 2013, 40 production wells were in operation in Los Azufres, which produced 14.8 million tons of steam, at an annual average rate of 1689 t/h. The annual mean production per well was 42 t/h. The produced steam was accompanied by 4.4 million tons of brine that was fully injected into the reservoir through 6 injection wells. The gross specific consumption in Los Azufres in 2013 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 5 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 (CFE, 2014).

Late 2013, 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 (Phase A) and consists of 50 MW and Azufres III (Phase B) consist of 25 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 five back-pressure units of 5 MWe each and one

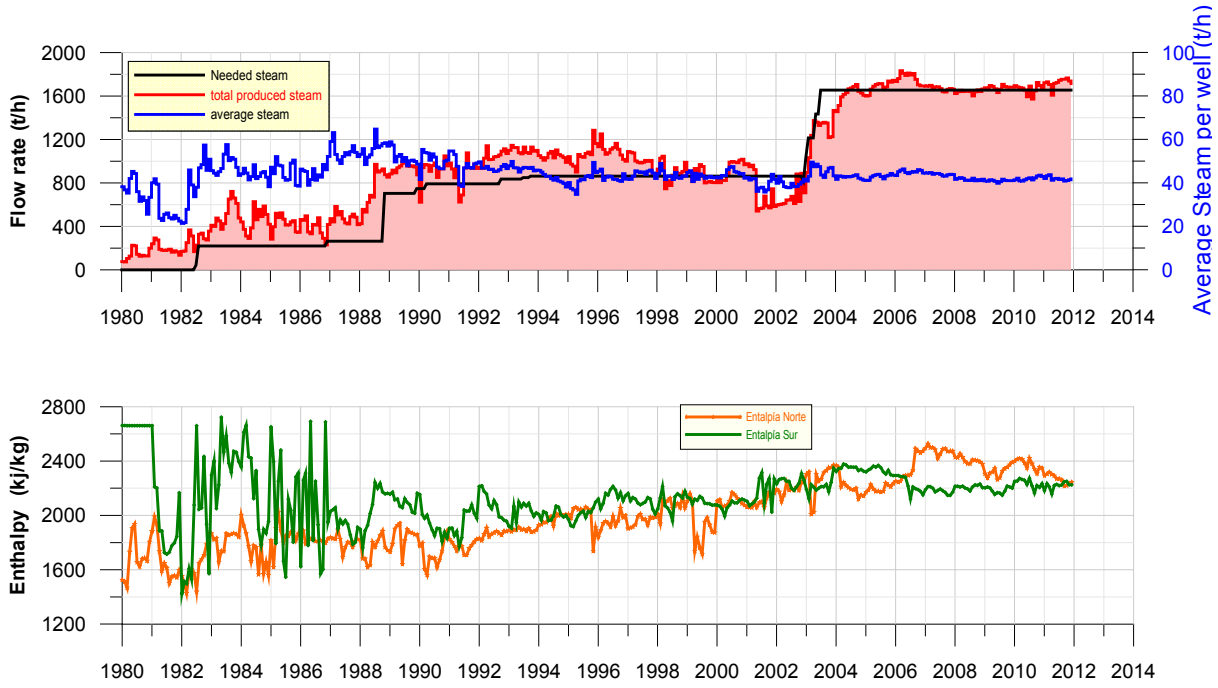

FIGURE 5: Historic production of Los Azufres Geothermal Field

unit of 26.8 MWe, with a total operating capacity of 51.8 MWe. Los Humeros lies inside a Quaternary caldera (Caldera de Los Humeros) at 2,600 m a.s.l. 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 23 production wells operating in Los Humeros during 2013. They produced 5.47 million tons of steam at an annual mean rate of 624 t/h, resulting in an average production per well of 27 t/h. The wells in Los Humeros produce usually low brine, and so occurred in 2013 when 0.73 million tons of brine was obtained. The brine was returned to the reservoir by three injection wells. Generation of electricity in Los Humeros was 335.76 GWh. The capacity factor in 2013 was 61% (0.61), but the gross specific consumption was 15.16 tons of steam per MWh.

Figure 6 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.

As part of the development of this geothermal field, there is right now under construction Los Humeros III 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 100 MW, meaning a 50% 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 2013 was 54.58 GWh, at an annual mean capacity factor of 56% (0.56). Las Tres Vírgenes is inside a Quaternary volcanic

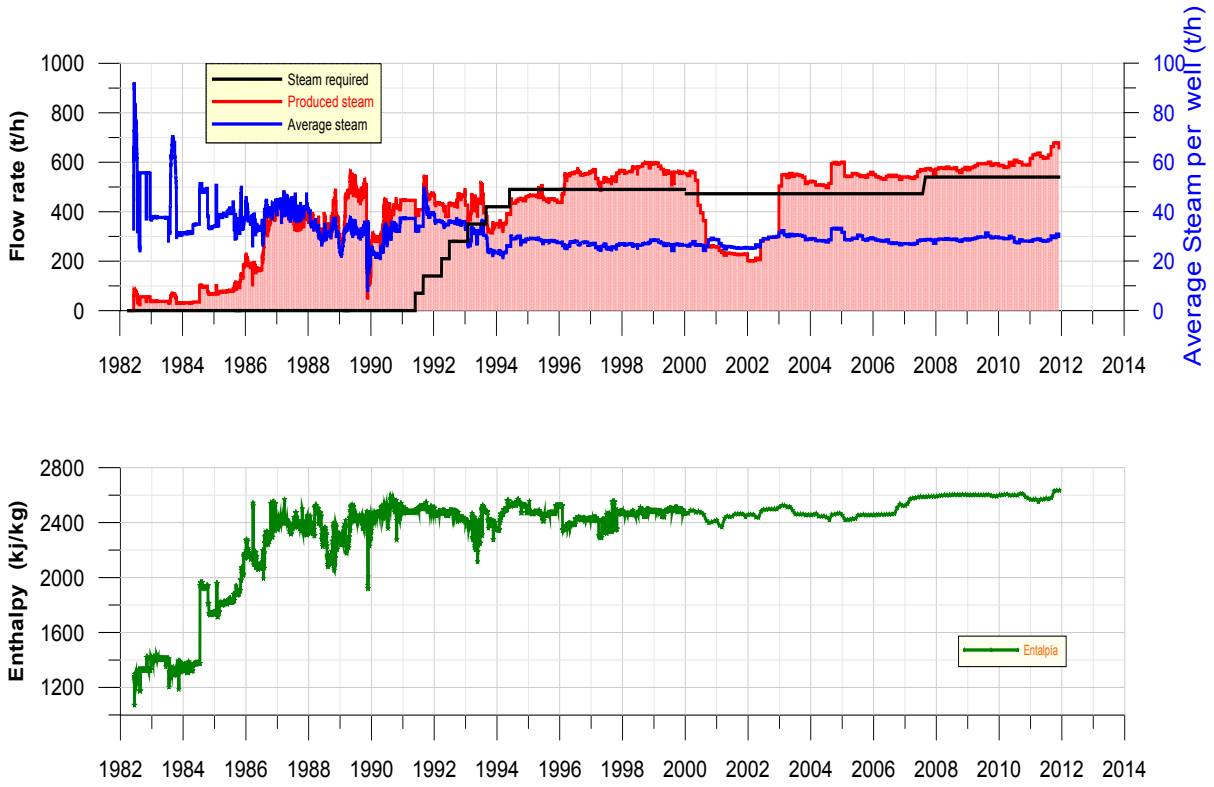

FIGURE 6: Historic production of Los Humeros Geothermal Field

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 0.788 million tons of steam at an annual mean rate of 90 t/h (Figure 7). The annual average production per well was 22t/h. Unlike Los Humeros, wells of Las Tres Virgenes produce much brine: in 2013 the associated brine was 2.42 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 2013, 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 2013 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 2013, the mean capacity factor has been increased compared with 2012, thus contributing with almost 65% of the total isolated generation system in that part of the country. In 2014 it is expected to increase the capacity factor in this field to be comparable to Los Azufres and Los Humeros.

5. NEW GEOTHERMAL DEVELOPMENTS

The National Development Plan 2015-2018 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

FIGURE 7: Historic production of Las Tres Virgenes Geothermal Field

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 6.

The project Los Humeros III phases A and B is composed of two condensing units of 25 MW each to be commissioned in 2015 (phase A) and 2018 (phase B). Phase A includes the replacement of 3 x 5 MW backpressure units, using the same amount of steam to generate 10 MW of additional power and in the phase B, 2 backpressure units 5MW each one will be replace for one of 25MW of to generate another 15 MW of additional power.

TABLE 6: Mexican geothermal projects in the near term

Projects	2015	2018
Los Humeros III Phase A	25	
Los Humeros III Phase B		25
Los Azufres III Phase B		25
La Tres Virgenes	2	
	Total = 77	

Los Azufres III (phase B) project is scheduled for late 2015. This project consists of one 25 MW unit, which considers dismantling four 3 MW backpressure units currently in operation. Therefore, the net additional capacity in this field will be 10 MWe.

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 8 and Table 7.

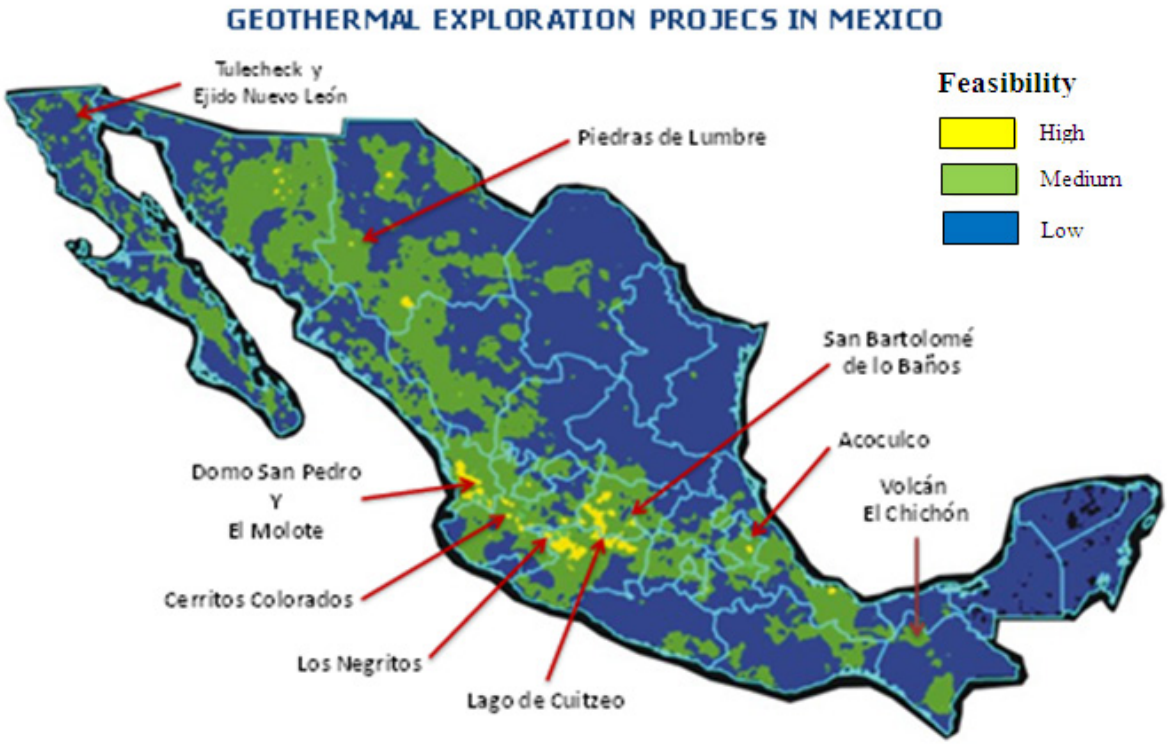

FIGURE 8: Main geothermal areas in the exploration stage

TABLE 7: 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
Tacaná, 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

6.1 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.

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.

6.5 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.

6.6 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 40 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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