Geothermal Development in Chile

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ABSTRACT

Geothermal exploration in Chile is currently very active and is driven by the need for energy security. Considering the fact that Chile has to depend on imports to meet more than 75% of its energy requirements, the interest of the government to encourage the development of the geothermal resources has been renewed. In this country, there are more than 300 geothermal areas located along the Chilean Andes, associated with Quaternary volcanism, occurs in the extreme north (17°-28°S) and central-southern part (33°-46°S). Preliminary assessment of the geothermal potential of these two volcanic-geothermal zones gives a value in the order of 16,000 MW for at least 50 years from the geothermal fluids with temperatures exceeding 150°C, and located at a depth less than 3,000 m. Due to increasing need of new source of energy in Chile, during the last several years there has been a renewed interest in the development of the geothermal resources following the initiatives of the government. At present, detailed exploration is being carried out by the state-owned oil company (ENAP), as well as private companies. They are conducting geological, geochemical and geophysical surveys and have also drilled 7 exploration holes, in northern and the central-southern part of the country. At least 2 of these holes are likely to be used for development, at the El Tatio geothermal field. In total, about 20 geothermal areas are currently under exploration by several private companies. It is expected that the first 40 MWe geothermal power plants will be installed before 2015 at the El Tatio. Direct use of the geothermal resources are only for recreational and tourist purposes, in spas and swimming pools.

1. INTRODUCTION

Systematic geothermal exploration in Chile started in the northernmost part of the country (17° to 24° S) towards the end of 1968, through a collaborative project between the Chilean Development Corporation (CORFO) and the United Nations Development Program (UNDP). In this project, reconnaissance survey was done in many geothermal areas, while detailed geological, geochemical and geophysical surveys in selected areas, viz., Suriri, Puchuldiza and El Tatio geothermal fields, were carried out during 1968-1976. They were followed by drilling of large number of exploratory wells and feasibility studies for power generation at El Tatio and Puchuldiza (Lahsen and Trujillo, 1975; Lahsen, 1976).

Since then, basic volcanological and geochemical studies in the geothermal areas have been occasionally conducted by the University of Chile, foreign institutions and the National Geological Survey of Chile (SERNAGEOMIN), in many geothermal areas (e.g. Lahsen, 1986, 1988; Hildreth, et al., 1984; Grunder et al., 1987, Hauser, 1997). ENAP, in collaboration with other companies, resumed geothermal exploration in the country between 1995 and 1999. In 1995, a 274 m deep slim exploratory well drilled in the Nevados de Chillán geothermal area, encountered wet steam with a temperature of 198°C (Salgado and Raasch, 2002).

In January 2000, the Chilean government enacted a Geothermal Law providing the framework for the exploration and development of geothermal energy in Chile. The law provides the regulations for exploration and exploitation concessions, which are granted by the Ministry of Mines. Exploration concessions are valid for two years and can be extended for two more years after completing 25% of committed budget. Exploitation concessions give the exclusive right to own the geothermal power and by products, to use the land and to transfer or sell it without any restriction.

Because of the need for diversified sources of energy, Chile is undertaking unique investment programme on geothermal exploration. During the last 5 years, there has been a renewed interest for the government of Chile to encourage the development of this indigenous energy resources. SERNAGEOMIN is doing detailed geological studies in the geothermal areas, for which geological maps are not available. CORFO is contributing with funds for pre-investement geothermal studies. This cofinancing tools allows to subsidize up to 50% (not exceeding US$60,000) of the cost of the studies and up to 2% of the total estimated investment. The Ministry of Mines and the National Energy Commission (CNE) are formulating professional teams for the management of the geothermal concessions. As a result, the geothermal exploration and development is currently very active.

2. GEOLOGICAL BACKGROUND

Geothermal resources of the Andean region of Chile occur in close spatial relationship with active volcanism, which is primarily controlled by the convergence of the Nazca and South America Plates. Two main volcanic zones can be distinguished within the Chilean Andes: the Northern Volcanic Zone (17ºS-28ºS) and the Central-Southern Volcanic Zone (33ºS-46ºS) parallel to the coast (Fig.1). At present, the Andean volcanic arc represents one the largest undeveloped geothermal provinces of the world.

In northern Chile, the Quaternary volcanism is emplaced along the High Andes and part of the Altiplano. The volcanic rocks of this zone include calc-alkaline ash-flow tuffs and lavas. During the Pliocene and Quaternary times, an extensional tectonic phase caused differential uplifts along nearly N-S, NW-SE and NE-SW trending fault systems. Volcanic vents and hydrothermal manifestations occur within the small grabens associated with these fault systems (e.g. El Tatio and Puchuldiza geothermal fields).

Quaternary volcanism in Central-South Chile is restricted to the Andean Cordillera. This volcanic activity has given rise to stratovolcanoes, pyroclastic cones and calderas, with associated lavas and pyroclastic flows. Lahar type flows from these volcanoes usually cover extensive areas of the Central Depression. From 33° to 34°S, most of the thermal areas are associated with the Pocuro fault system, where upper Cretaceous and Tertiary volcaniclastic rocks are dominant (Hauser, 1997). Between 39° and 46°S, the geothermal activity is partially controlled by the 1,000 km long, NNE Liquiñe-Ofqui Fault Zone (LOFZ; Hervé 1984), an intra-arc dextral strike-slip fault system (Cembrano et al., 2000), associated with second-order intra-arc anisotropies of overall NE-SW and NW-SE orientation.

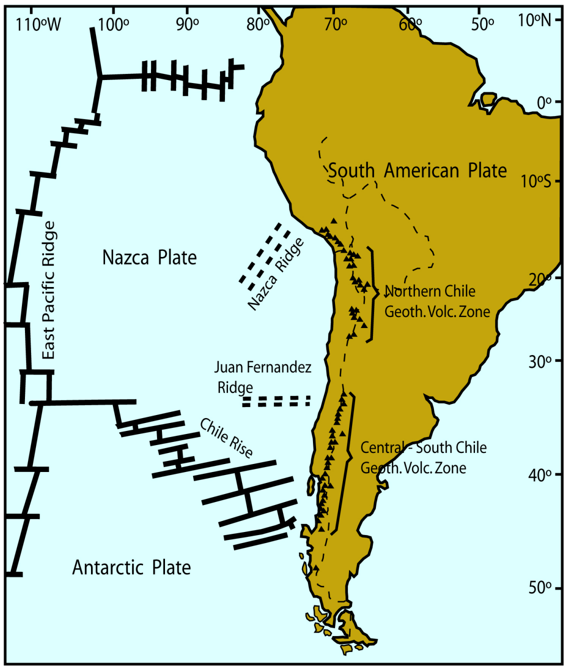

Figure 1: Active volcanic-geothermal zones of northern and central-southern Chile.

3. GEOTHERMAL RESOURCES AND POTENTIAL

All the Chilean high temperature thermal spring areas are associated with the Quaternary volcanic zones (Lahsen, 1976, 1988). In areas where the Quaternary volcanism is absent, such as along the volcanic gaps of Andean Cordillera (28°-33° and 46°-48°S), as well as in the Coastal Range, thermal springs are scarce and their temperatures are usually lower than 30°C.

Geological and geochemical reconnaissance survey in many geothermal areas of northern and southern Chile, together with more detailed geological, geochemical and geophysical surveys in selected areas such as El Tatio and Puchuldiza have allowed a preliminary assessment of the geothermal potential of the country, in the order of 16,000 MW for at least 50 years, from the geothermal fluids with temperatures exceeding 150°C, and located at a depth less than 3,000 m (Lahsen, 1986).

By the end of 2009, 38 concessions are under regional reconnaissance with the objective to narrow the focus and identify areas of potential interest. All of these areas have some superficial indicator and the current analysis involves geological surveys, volcanological studies, geophysical and geochemical surveys to identify more limited areas for detailed exploration using drilling tools (Figs.2 and 3).

In the Northern volcanic-geothermal zone there are about 90 thermal areas (Fig.2), which are largely chloride type. In this zone, 6 geothermal prospects are under exploration by ENG, the National Geothermal Company (ENAP-ENEL), Energia Andina a joint venture between ENAP and Antofagasta Minerals S.A.; and by other companies related with copper mining. The areas where exploration programmes are being carried out are Suriri, Puchuldiza, Lirima, Apacheta and El Tatio. At Apacheta and El Tatio geothermal areas, 4 holes have been drilled up to depth of 1,700 meters. Preliminary estimate of the potential of these areas is between 400 MWe to 1,000 MWe, and preliminary results of the drilled holes indicate a potential of 5-10 MW per well.

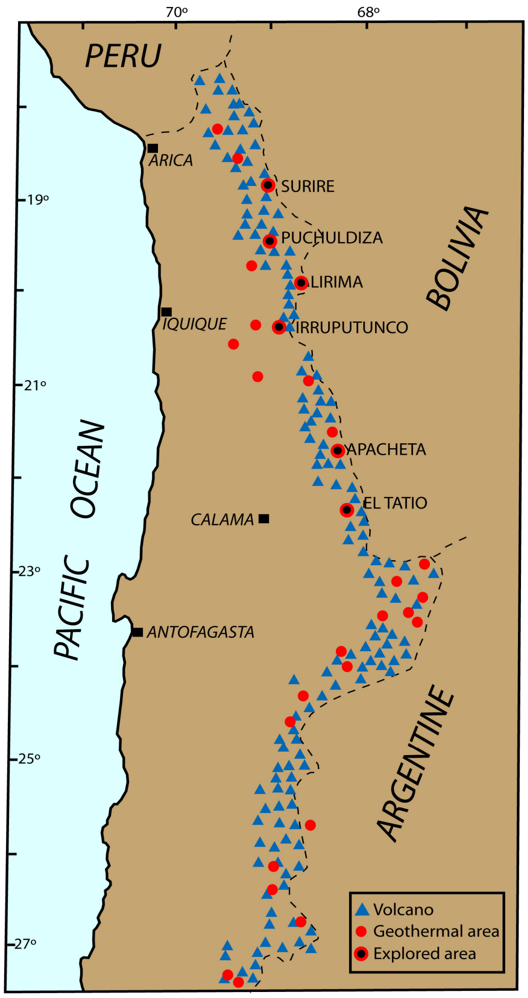

Figure 2: Geothermal areas of the Northern Chile.

In the Central-Southern volcanic geothermal zone there are more than 200 geothermal areas (Fig.3), thermal waters of the geothermal areas are of acidic-sulphate, bicarbonate and chloride type. In this zone, 7 geothermal prospect are under exploration by ENG, the University of Chile and some private companies. The exploration programmes are undertaken in Tinguiririca, Calabozos, Laguna del Maule, Chillán, Tolhuaca, Sierra Nevada and Puyehue-Cordón Caulle; while exploration slim holes have been drilled at Calabozos, Laguna del Maule, Chillán and Tolhuaca, with a potential estimated of 3-10 MW per well. Preliminary estimates of the potential for power generation from these areas vary between 600 MWe and 950 MWe.

4. GEOTHERMAL UTILIZATION

In Chile, geothermal energy has been only utilized only for recreational purposes. Current use in spa and swimming pools, account for an installed capacity of 8.27 MWt, which equals an annual energy use of 131.08 TJ/yr with a capacity factor of 0.48 (Tables 3). However, there are many private thermal spas and resorts in geothermal areas, for which quantitative information regarding the use of geothermal resources is not available. In some spas, shallow wells have been drilled to obtain hot water, while in others hot water is collected rudimentarily and piped to the buildings and pools, through shallow drains and plastic hoses. Information on private investment for direct utilization is not available.

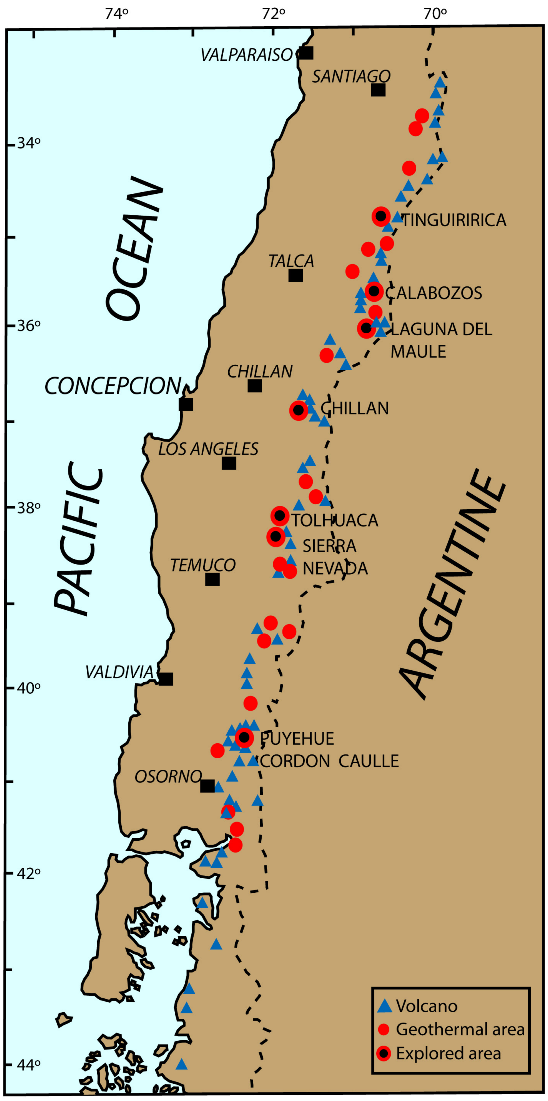

Figure 3: Geothermal areas of the central-southern Chile.

5. DISCUSSION

The present installed capacity in Chile for electric generation is 13,086 MWe, producing approximately 56,700 GWh/Year (Table 1). Of the installed capacity, 61% corresponds to fossil fueled (liquid oil, gas and coal) power plants, while 37% to hydropower plants and only 2% to the electricity generated by renewable resources (wind, biomass and hydro < 20 MWe).

The electricity market in Chile comprises of two main independent systems - the Northern Interconnected Power Grid (SING) and the Central Interconnected Power Grid (SIC). According to the National Commission of Energy (CNE, www.cne.cl), SING has an installed capacity of 3,600 MW, with a gross power generation of 14,500 GWh/yr. Due to the extreme aridity of the northern part of the country, hydro-electric resources are virtually absent and 99.6% of the power is generated by fossil fuel based power plants. The main costumers of SING are the large copper mines (e.g., Chuquicamata, Escondida). SIC has an installed capacity of 9,348 MW, supplying electricity to 90% of the population. 52% of its installed capacity relies on hydroelectricity and the remaining 48% on fossil fuels. In 2008, 56% of the commercial power generation (41,700 GWh/yr) was supplied by hydroelectricity. Due to almost null production of oil and gas in Chile, over 90% of the fossil fuels need to be imported. Under such circumstances, renewable energy resources, especially geothermal power, in Chile have become more relevant and preferred for both economic and strategic reasons.

The personnel allocated for geothermal exploration (Table 7) include only geoscientists and engineers directly involved in the research work in which administrative professionals are not included. During the last five years, there has been a great increase in the number of professional personnel working in geothermal exploration. In the past, there were about 10 professionals working per year (Lahsen et al., 2005), while in 2009 the number has reached 45.

Geothermal exploration projects are focused on assessment of resources for electric generation, while direct uses are considered as a byproduct of the power plants. Between 1995 and 1999, the investment is estimated to have reached about US$ 2 million, while between 2000 and 2004, US$ 5.32 million was invested (Lahsen et. al., 2005). However during 2005-2009 investment is near 5 times than the last 5 years period, reaching a total of US$ 25.67 million (Table 8).

6. ACNOWLEDGMENTS

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APPENDIX – STANDARD COUNTRY UPDATE TABLES

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		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 2009			8,007	32,256	4,802	23,050			277	970	13,086	56,676
Under construction in December 2009			1,300	5,330	144	692			63	252	1,507	6,274
Funds committed, but not yet under construction in December 2009	75	413	2,550	10,455	1,490	5,734			760	2,660	4,975	19,262
Total projected use by 2015	75	413	11,857	48,041	6,436	29,476			1,100	3,882	19,568	82,212

Other renewables= Wind, Biomass and Hidropower < 20 MWe

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2009 (other than heat pumps)

1) I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

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

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (^oC) - outlet temp. (^oC)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (^oC)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Mamiña	B	2.70	51	28			0.26	1.90	5.76	0.70
Pica	B	2.30	34	26			0.08	1.60	1.69	0.66
Socos	B	3.20	30	22			0.17	2.56	2.70	0.50
Colina	B	7.30	50	24			0.79	5.62	19.27	0.77
Cauquenes	B	2.80	45	30			0.18	1.80	3.56	0.63
El Flaco	B	7.00	76	45			0.91	3.60	14.72	0.51
Panimavida	B	1.80	32	25			0.05	1.40	1.29	0.82
Chillán	B	15.20	65	45			1.27	7.80	20.57	0.51
Tolhuaca	B	4.60	61	45			0.31	2.70	5.70	0.58
Manzanar	B	6.90	48	35			0.38	1.90	3.26	0.27
Huife	B	8.20	52	40			0.41	2.10	3.32	0.26
Minetué	B	2.60	41	30			0.52	1.30	3.25	0.20
San Luis	B	0.80	40	28			0.04	0.60	0.95	0.75
Palguín	B	2.90	39	28			0.12	1.80	2.61	0.69
Coñaripe	B	6.50	64	45			0.52	1.30	3.25	0.20
Liquiñe	B	13.60	46	35			0.63	3.20	4.64	0.23
Puyehue	B	5.00	70	45			0.52	3.40	11.21	0.68
Aguas Calientes	B	4.50	65	45			0.38	2.80	7.38	0.62
El Amarillo	B	4.20	55	40			0.26	2.00	3.95	0.48
Puyuhuapi	B	13.60	68	45			1.31	4.20	12.74	0.31
TOTAL							9.11		131.82	

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2009

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319 (TJ = 1
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 1
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]			
District Heating [4]			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	9.11	131.82	0.459
Other Uses (specify)			
Subtotal			
Geothermal Heat Pumps			
TOTAL			

4) Other than heat pumps
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2005 TO DECEMBER 31, 2009 (excluding heat pump wells)

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

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1)]	(all)	5				4,884
Production	>150° C	2				3,400
	150-100° C					
	<100° C					
Injection	(all)					
Total		7				8,284

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Progran
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	2	6	3	3	2	6
2006	3	6	3	5	5	8
2007	3	8	4	5	7	9
2008	6	8	4	8	8	12
2009	7	10	5	8	5	14
Total	21	38	19	29	27	49

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
	Million US$	Million US$	Direct Million US$	Electrical Million US$	Private %	Public %
1995-1999	2.00					100
2000-2004	5.32				10	90
2005-2009	13.42	12.25			56	44