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Present Status of Geothermal Exploration in Chile

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ABSTRACT

More than 300 hot spring areas are located along the Chilean Andes, associated with Quaternary volcanism. Systematic geothermal exploration in the northern part of the country started by the end of 1968, followed by basic geological, geochemical and volcanological surveys in many geothermal areas of southern Chile. These studies, together with wells drilled in El Tatio and Puchuldiza (northern Chile), allowed a preliminary assessment of the geothermal potential of the country of several thousands of MW. Renewed interest in geothermal exploration in Chile has been encouraged by the enactment of the Geothermal Law in 2000, which governs the regulatory aspects of the exploration and exploitation concessions, and also by the uncertainties regarding the imports of natural gas from Argentina, the vulnerability of hydropower to periodic droughts, and the environmental cost associated with hydropower and fossil fuels.

Recently, a 4-year-long geothermal research project (2000 – 2003) was carried out by the University of Chile, in association with the National Oil Company (ENAP) and the collaboration of institutions from Germany, Italy and New Zealand. The main purpose of this project was to determine the geothermal potential of the central-southern zone of Chile. Detailed geological, hydrogeological, geochemical and, to a lesser extent, geophysical surveys, were completed in two selected areas, where inferred fluid were estimated to be over 250°C. Geothermal exploration in southern Chile has been also conducted by ENAP in the Calabozos thermal area, located 250 km SE of Santiago. This area consists of a liquid-dominated geothermal system, with water and gas geothermometry temperatures between 235° C and 300° C.

During the same period, Geotérmica del Norte (GDN), a joint venture between ENAP and the National Copper Corporation (CODELCO), followed up on geothermal exploration in northern Chile. Geochemical and geophysical surveys conducted at El Tatio geothermal field turned out to confirm most of the previous findings about this field. Geothermal exploration surveys undertook by GDN also led to the identification of Apacheta, a new thermal prospect located 60 km NNW of El Tatio; there, reservoir temperatures of ≥ 250°C have been estimated.

The numerous geothermal prospects of the Chilean Andes account for one of the largest undeveloped provinces of the world. However, a stronger governmental policy in favor of renewable energies is required to foster the development of geothermal resources.

1. INTRODUCTION

Interest in geothermal energy in Chile dates back to the beginning of the last century. At that time (1908), members of the Italian colony at the Antofagasta city created a private society named Preliminary Community of El Tatio; this society carried out the first geothermal exploration program in the country. During the period 1921-1922, an Italian technical group from Larderello drilled two wells of about 70-80 m depth (Tochi, 1923).

Systematic exploration in the northernmost region of the country (17° to 24° S) resumed by the end of 1968 as result of a project subscribed by the Chilean Development Corporation (CORFO) and the United Nations (UNDP). Geological and geochemical reconnaissance of many hot-spring areas and detailed geological, geophysical and geochemical surveys in selected areas such as Suriri, Puchuldiza and El Tatio geothermal fields, were performed during the period 1968-1976. These endeavors were followed by drilling of a number of exploratory wells and feasibility studies for power generation at El Tatio and Puchuldiza (Lahsen, 1976).

From that time, basic volcanological and geochemical studies were occasionally conducted by the University of Chile, the National Geological Survey and others, in many geothermal areas (e.g. Lahsen, 1986, 1988; Grunder et al., 1987, Hauser, 1997). Between 1995 and 1999, a joint-venture between ENAP and UNOCAL Corp. resumed geothermal exploration in northern Chile. In Southern Chile, geological and geophysical exploration conducted by ENAP, in collaboration with the French Geothermal Company (CFG), culminated in 1995 with the performance of a 274 m deep slim exploratory well in the Nevados de Chillán geothermal area. This well encountered wet steam with a temperature of 198°C (Salgado and Raasch, 2002).

By early 2000, a Geothermal Law was enacted providing the framework for the exploration and development of geothermal energy in Chile. The law establishes the existence of exploration and exploitation concessions, which are granted by the Ministry of Mines. Exploration concessions are valid for two years and may be extended for further two years. Exploitation concessions give the exclusive right to own all the geothermal power and brines, to use the land and to transfer or sell it without any limitation.

Recently, a 4 years-long geothermal research project (2000 – 2003) was conducted by the Geology Department of the University of Chile, in association with ENAP, in the central-southern part of the country. The aim of this project was the characterization and assessment of the geothermal resources and their possibilities for power generation and direct applications. Based on geological and geochemical reconnaissance of many hot spring areas, several areas were selected as promising for electrical applications, including the areas of Nevados de Chillán and Puyehue – Cordón Caulle. During the same period, a joint venture between ENAP and (CODELCO), undertook a geothermal exploration program in northern Chile and also in some places of the southern part of the country. Follow up to these geothermal investigations has not been possible due to the lack of support and commitment from any lead institution, research center or permanent program other the projects mentioned above.

2. GEOLOGICAL AND TECTONIC SETTING

The subduction of the oceanic Nazca and Antarctic plates under South America account for the seismicity, tectonism and magmatism of the Andean margin. From west to east, this margin includes the Coastal Range, the Central Depression and the Volcanic Arc of the Andean Cordillera. To the west, it is flanked by the Perú-Chile Trench and to the east by a foreland thrust belt and basin. North of 46°S, the Andean volcanic arc adjoins the Nazca plate; south of 48°S it faces the Antarctic plate (Fig. l).

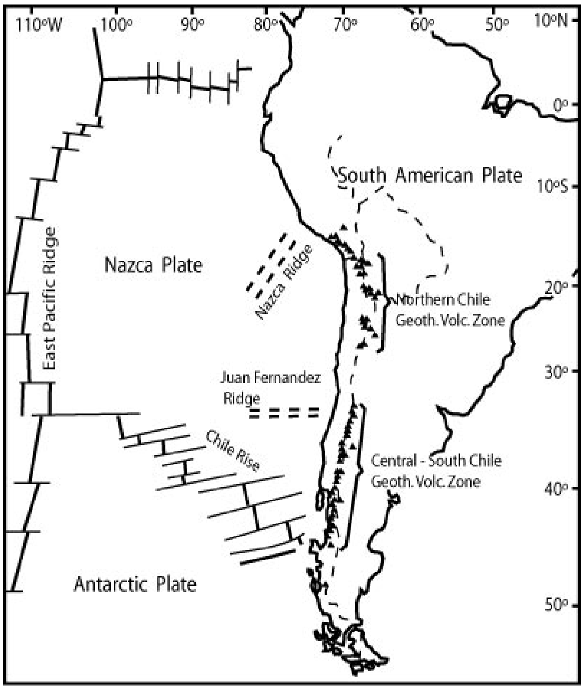

Figure 1: Active volcanic-geothermal zones of northern and central-southern Chile.

The distribution of the Quaternary volcanism is controlled by the dip and morphology of the Benioff zone. North of 28°S and south of 33°S, the downgoing slab easterly dips about 30°. In between (28°-33°S), the Benioff zone dips at only 5°-10° and the Quaternary volcanism is absent. Between 46° and 48°S, the Chile Rise descends beneath the South American plate giving rise to the triple junction of the South American-Antarctic plates. This segment also exhibits a volcanic gap; south of 48°S, the subduction of the Antarctic plate under the South American plate has generated about six major Quaternary volcanoes.

2.1 Volcanic-geothermal activity of Northern Chile

In northern Chile (l7°-28°S), the Quaternary volcanism emplaces along the High Andes and part of the Altiplano block. The volcanic rocks of this zone include calc-alkaline ash-flow tuffs and lavas erupted from calderas and stratovolcanoes that crown the highest summits of the Andes. They range in composition from basalt to rhyolite with a clear predominance of hornblende and biotite andesites and dacites. Although volcanic activity has been intense during the Quaternary, only a few volcanoes such as Isluga, Olca, San Pedro, Lascar and Llullaillaco, have remained active until present; many others show occasional to permanent hydrothermal activity (Fig. 2). During the Pliocene and Quaternary times, an extensional tectonic phase produced differential block uplifts along nearly N-S, NW-SE and NE-SW trending fault systems. Volcanic vents and hydrothermal manifestations occur associated with small grabens connected with these fault systems (eg. El Tatio and Puchuldiza geothermal fields).

2.2 Volcanic-geothermal activity of Central-Southern Chile

Like in northern Chile, Quaternary volcanism in central-south Chile (33°-46°S) is restricted to the Andean Cordillera. This volcanic activity has given rise to stratovolcanoes, pyroclastic cones and calderas, lavas and pyroclastic flows. Laharic flows from these volcanoes usually cover extensive areas of the Central Depression. From 33° to 34°S, most of the thermal areas occur associated with the Pocuro fault system, where upper Cretaceous and Tertiary volcanoclastic rocks are dominant (Hauser, 1997). Between 39° and 46°S, the volcanic-geothermal activity is 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. Volcanic rocks of this segment vary from basalts to rhyolites, showing a predominance of hornblende and biotite andesites and dacites north of 35°S, whereas further south, olivine and pyroxene basalts and basaltic andesites are the most usual rock types. At least 25 volcanic centers, among which are Tupungato, Nevados de Chillan, Llaima, Antuco, Villarrica, Cordón Caulle, Calbuco, and Hudson, are still active, with frequent eruptions in historical times. Many of them show permanent solfataric and/or fumarolic activity (Fig. 3).

3. GEOTHERMAL RESOURCES AND POTENTIAL

Geological and geochemical reconnaissance in many hot spring areas of northern and southern Chile, together with more detailed geological, geochemical and geophysical surveys in selected areas such as El Tatio and Puchuldiza allow a preliminary assessment of the geothermal potential of the country, on the order of 16,000 MW for 50 years, contained in fluids with a temperature over 150°C, and at a depth less than 3,000m (Lahsen, 1986).

Chilean high-temperature spring areas are located along the Andean Cordillera, 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. Northern and central-southern geothermal areas are distinct in the chemistry of the hot springs. While in northern Chile hot springs and well waters from high-enthalpy liquid-dominated geothermal reservoirs are of chloride type, in central-southern Chile chloride waters are rather scarce. Chloride springs have been mainly reported between 33° to 36°C (e.g. Hauser, 1997), in association with thermal areas occurring in the vicinity of Mesozoic epiclastic and evaporatic rocks, which could account for the chemistry of the thermal discharges. Examples include Termas del Flaco (35°S), San Pedro (35°S), Llolli (35.4°S), and Campanario (36°S). South of 36°S, thermal springs are dominated by acid-sulfate and bicarbonate types, such as in the thermal areas of Copahue (37.51°S), Nevados de Chillán (36.7°S) and Cordón Caulle (40.5°S). A summary of the main geothermal prospects identified so far is presented below.

3.1 Northern Chile

3.1.1 Puchuldiza

The Puchuldiza geothermal system is located in the Tarapacá Región of northern Chile, 160 km northeast of the city of Iquique. The geothermal system is located in a volcano-tectonic depression bordered by dip-slipped NS, NW-SE and NE-SW trending faults. The oldest geological unit recognized in the area corresponds to a continental sequence of shales, tuffaceous sandstones and conglomerates of Cretaceous age, which is overlain by a thick sequence of Miocene to Pliocene silicic volcanic rocks (lavas and ash-flow tuffs) and fluvial deposits, that might constitute good aquifers at depth (Lahsen 1976, 1988). The thermal activity is grouped into two main thermal areas, from east to west: Puchuldiza (s.s) and Tuja. The latter is the smallest thermal focus lying about 5 km from Puchuldiza. Most of the springs are of neutral chloride-type, emerging at boiling temperature (86°C). Chemical geothermometry suggested reservoir temperatures in the range of 180° to 210°C (Mahon and Cusicanqui, 1980).

Geophysical surveys, including electric, magnetic and gravity methods, were deployed in order to determine the subsurface conditions. A low resistivity pattern (< 10 Ohm-m) agreed quite well with the low gravity and the low magnetic anomalies, suggesting an area of about 28km^2 for the geothermal reservoir. Five slim exploration wells were drilled between 1975 and 1977 to depths from 428 to 1013m. These wells encountered feed zones shallower than 600 m deep at temperatures < 175°C.

3.1.2 Apacheta

The Apacheta geothermal system is located in the Antofagasta Región in northern Chile, 120 km east of Calama city. This prospect was accidentally discovered by CODELCO, while drilling a shallow water well (Salgado and Raasch 2002). Surface thermal activity consists of two superheated fumaroles on top of Cerro Apacheta. The geothermal system is hosted by a 3 to 5 km wide, NW-trending graben, nesting a Pliocene to Pleistocene sequence of andesitic and dacitic lavas, breccias and tuffs blanketed by a 100 m thick package of ash-flow tuffs. The most recent volcanic activity consists of Late-Pleistocene dacite lava domes extruded along the northeastern border of the graben. The basement of the area comprises Tertiary continental epiclastic rocks. Recent geochemical and geophysical surveys carried out in this area are auspicious, with gas geothermometry indicating reservoir temperatures over 250°C. MT and TDEM survey detected a low resistivity boundary (< 10 ohm-m) extending over an area of 25 km^2 (Urzúa et al., 2002).

3.1.3 El Tatio

El Tatio geothermal field is located near the Bolivian border, 95 km east of Calama city and the copper mine of Chuquicamata. It lies in a north-south down-faulted block (El Tatio graben). The thermal manifestations scatter over an area of more than 35 km^2, including geysers, boiling and hot springs, mud ponds, steaming ground and some fumaroles in the uppermost levels of the eastern part of the graben. The geothermal system is associated with an thick 2000 m), Upper Miocene to Pleistocene volcanic sequence of silicic lavas, breccias and ignimbrites, which is underlain by Upper Cretaceous and Tertiary continental sedimentary formations (Lahsen, 1976).

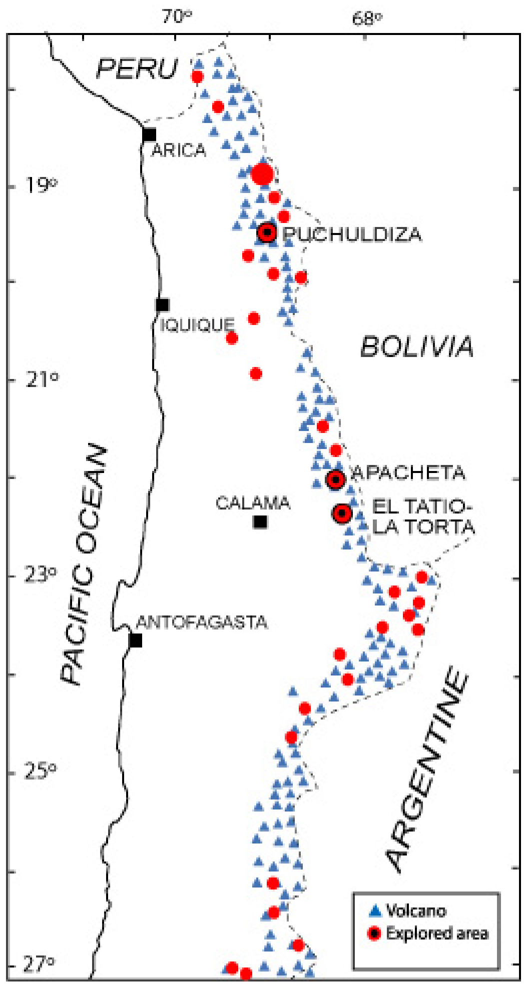

Figure 2: Geothermal areas of the Northern Chile.

Schlumberger surveys yielded a low resistivity anomaly (< 10 ohm-m) reaching over 30 km^2, and extending further southeast beyond the limits of the graben. Between 1969 and 1974, thirteen wells were drilled. The first six slim holes were drilled down to 571 to 735 m depth, recording temperatures in excess of 252°C. Wells seven to thirteen were drilled to depths between 873 to 1,820 m, reaching up to 256°C (Lahsen and Trujillo, 1975). A concealed subhorizontal lateral outflow to the northwest was also depicted from the temperature inversion of some wells. A technical and economic feasibility study for a power plant of 15 or 17 MWe, was made in 1975 (ELC –Electroconsult, 1975).

Recently, ENAP associated with CODELCO resumed the former exploration works in El Tatio, with emphasis in constraining the southeastern border of the low resistivity anomaly previously delineated, in the direction of La Torta silicic dome. Geochemical and geophysical studies including MT-TDEM surveys were completed, after which the low resistivity anomaly was found to extend several kilometers further southeast (Cumming et al., 2002).

3.2 Central-Southern Chile

3.2.1 Calabozos

The Calabozos geothermal area (35.23°S) is located 240 km southeast of Santiago, in the central-southern zone of Chile, near the border with Argentine. The promising geothermal possibilities of this area were formerly pointed out by Hildreth et al. (1984) and Grunder et al. (1987), based on the large volumes of erupted silicic magma, the high flow rates of the thermal springs (>240 l/sec) and the estimated subsurface temperatures of more than 250°C. According to these authors, this geothermal system is related to a 26x8 km Late Pleistocene composite ring-structure caldera and a faulted resurgent dome, with many rhyodacitic to dacitic ash-flow sheets associated with the caldera collapse. Hot springs and fumaroles are found along the caldera margin and the resurgent fault systems. The basement of the Calabozos volcanic complex include Mesozoic marine clastic, gypsiferous and carbonate rocks, late Cretaceous and Tertiary volcanic and plutonic rocks, and Miocene pyroclastic sequences (Gonzalez and Vergara, 1962).

Hot springs range from chloride and chloride-sulfate to bicarbonate types, suggesting a liquid-dominated geothermal system. MT-TDEM geophysical surveys in conjunction with water and gas geothermometry, have been recently conducted by ENAP, obtaining subsurface temperatures between 235°C and 300°C (Salgado and Raasch, 2002).

3.2.2 Nevados de Chillán

The Nevados de Chillán geothermal area is located 76 km southeast of the city of Chillán, in central-south Chile. It is associated with a 13 km long, NW-trending volcanic chain comprising polygenetic and flank volcanoes and calderas (Dixon et al., 1999). The volcanic complex has been built over a basement of Cretaceous to Miocene plutonic rocks, Miocene sedimentary and volcanoclastic rocks and Plio-Pleistocene basaltic lavas, and ash-flow tuffs accounting for explosive activity prior to the edification of the current volcanic centers (Niemeyer and Muñoz , 1984).

The thermal manifestations of Nevados de Chillan are grouped into two main areas, namely, Las Termas and Aguas Calientes. Las Termas lies over the southwestern part of the volcanic chain and consists of acid-sulfate waters, saturated and super-heated fumaroles, with temperatures as high as 125°C, and extensive acid-sulfate hydrothermal alteration. The Aguas Calientes area is located 5 km to the east of Las Termas, in the inner part of a recent caldera (younger than 40 ka; Dixon et al., 1999), concentrating the largest outflow of the geothermal system. More than 500 l/s of hot springs of neutral sulfate-bicarbonate type emerge from tephra layers with temperatures over 70°C. Infiltration of melting water, which potentially leaches sulfur from ore bodies found nearby, followed by mixing with deeper steam-heated bicarbonate waters, has been suggested to explain the chemistry of these hot springs (Sepúlveda and Lahsen 2003). The existence of such a shallow bicarbonate aquifer is supported by the exploratory well drilled by CFG and ENAP in Las Termas area (274 m deep), which tapped a wet steam feed zone at 198°C. The inferred chemistry of the parent fluid was a <1000 ppm mixed chloride-bicarbonate aquifer. Solute geothermometry suggests a subsurface temperature greater than 200°C for the shallow aquifer (Salgado and Raasch 2002).

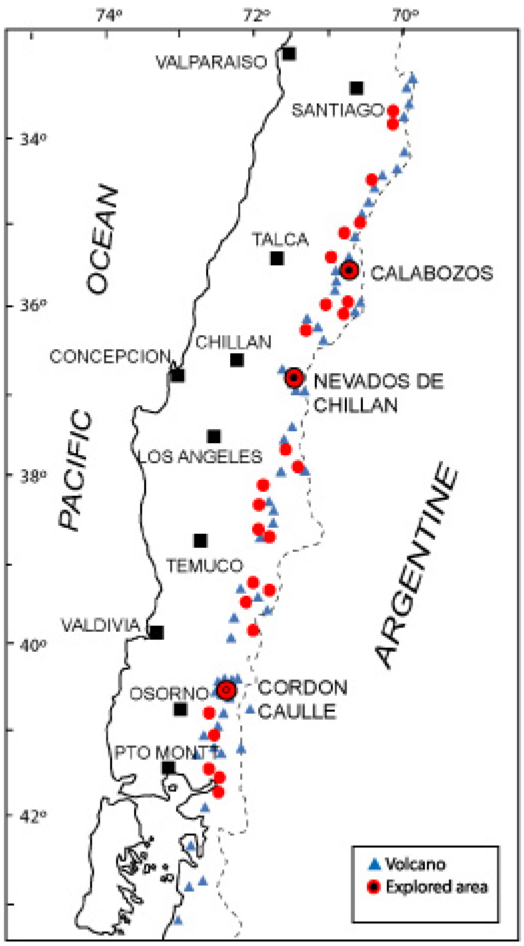

Figure 3: Geothermal areas of the Central-Southern Chile.

3.2.3 Cordón Caulle

The Cordón Caulle geothermal area is located 65 km east of the city of Osorno, in southern Chile. It is associated with the 15 km long, 5 km wide, volcanic graben bordered by NW-trending faults. Cordón Caulle is bounded to the southeast by the Puyehue stratovolcano (2235 m), which is constructed over a preexisting caldera, and by a 10 km caldera ring to the northwest. Esentially basaltic and minor dacitic lavas, tephra and ash-flow tuffs have been erupted since the Late Pleistocene (Moreno 1977). Historic dacite to rhyolite lava flows have been erupted from the southeastern border of the graben, triggering the formation of volcanic fumaroles and sulfur deposits. The basement of the volcano complex include Tertiary sedimentary rocks and ignimbrites, Miocene intrusions and minor Paleozoic plutons.

The thermal manifestations areas occur throughout the graben, specially along the northeastern margin. Fumaroles and acid-sulfate springs dominate at the top of the system (1500-2000 m) whereas boiling hot springs of alkaline bicarbonate type occur in the northern part of the graben, totalizing nearly 100 l/s. Na-K and pH-corrected silica temperatures ranging from 170° to 180°C are interpreted as subsurface temperatures of a secondary steam-heated aquifer overlying a main vapor-dominate system. Gas geothermometry suggests temperatures between 225° to 300°C for the deep reservoir (Sepúlveda et al., 2004; Sepúlveda et al., 2005, this Congress).

4. GEOTHERMAL UTILIZATION

In Chile geothermal energy has been only utilized for recreational and touristic 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 2 and 3). However, there are many private thermal baths and hotels from which quantitative information regarding the use of geothermal resources is not available. In only a few spas shallow wells have been drilled to obtain hot water, while in others hot water is more rudimentarily collected and piped to building and pools, by means of shallow drains or small caves, and plastic hoses. In general, information on private investment for direct utilization was not available either.

The personnel allocated for geothermal exploration (Table 4) only included geoscientists directly involved in the research work; administrative professionals are not included.

Geothermal exploration projects have focused on assessment of resources for electric generation, but direct uses are considered as a byproduct of the power plants. Between 1995 and 1999, investment is estimated to have reached about US2.0 millions. Between 2000 and 2004, US 5,32 millions were invested in the country, partly through public funding from state-own companies and the University of Chile, and partly through academic support and collaboration from foreign institutions, such as in the central-south geothermal research (Table 5).

5. FUTURE OPPORTUNITIES FOR GEOTHERMAL ENERGY

The electricity market in Chile is made up 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), the SING has an installed capacity of 3,645 MW, with a gross power generation of 10,399.6 GWh/yr in 2002. Due to the extreme aridity of the northern part of the country, hydro-electrical resources are virtually absent and 99.5% of the power is generated by fossil fuel-based thermal plants. The main costumers of the SING are the large copper mines (e.g. Chuquicamata, Escondida).

The SIC has an installed capacity of 6,733 MW, supplying electricity to 90% of the population. 40% of its installed capacity relies on hydroelectricity and the remaining 60% on fossil fuels. In 2002, 60% of commercial power generation (31,971.3 GWh/yr) was supplied by hydroelectricity. During 1998, however, the SIC implemented a series of power shortages and voltage reductions in response to a severe drought period, warning authorities about the vulnerability of hydroelectricity to climate changes. From that time, the Chilean government fostered an increasing participation of natural gas in power generation. Due to almost null production of petrol and gas in Chile, over 90% of fossil fuels need to be imported.

In addition to the SING and SIC, there are two other small electricity systems in the southernmost part of the country, namely, the Aysén and Magallanes systems, accounting for an installed capacity and generation of 88 MWe and 262 GWh/year, respectively. In this way, the total installed capacity of the country reaches 10,466 MWe with a gross power production of 45,263 GWh/year (Table 1).

The electricity law has established an open market for input and operation of electricity generation companies (GC), setting up three different sale mechanisms: contract, node price and spot market. By contract, the price is fixed between the GC and a costumer of more than 2 MW. The node price is established by the government every six months, as the average marginal cost projected for the next 24 to 48 months. At this price a GG may sell to a distribution company (DC). The node price has a band determined by the average price of contracts negotiated between GC and large customers. The width of this band cannot be more than 10% of the total price. Currently (April 2004), the National Energy Commission has proposed an average node price in the SING is US$ 0.030/kwh, and US$0.031/kwh in the SIC. In the spot market, a GC can sell power without contracts in the spot market if its generation costs are lower than the marginal cost. The spot price is determined on an hour basis, depending on the variable cost of the most expensive generator running at that hour.

Imminent collapse of the current energetic system of Chile is foreseen for the next years, unless diversification of the traditional sources in undertaken. Nowadays, most natural gas imports come from the Neuquén Basin in Argentina, which imposes serious uncertainties derived from the growing demand for electricity both in Argentine and Chile, and the limited reserves of natural gas estimated for the Neuquén Basin. Exhaustion of natural gas reserves (and concomitant increase in prices) could take place as soon as in the next ten or twelve years. It is worth mentioning that Argentine has already reduced the gas supplies to Chile in 30% (May 2004). Furthermore, only one hydroelectrical project is under construction (Ralco, 570 MWe) and only 400 MWe have been scheduled by the CNE for the future. With the advent of the geothermal law, the uncertainties regarding the gas imports from Argentine, and the vulnerability of hydroelectricity to periodic droughts, new opportunities for geothermal energy are envisaged. This should be accompanied by a stronger commitment from the Chilean government to support geothermal development. Aware of the urgent need to utilize energy sources other than hydro or fossil fuels, the CNE is considering the realization of 3 geothermal projects of 100 MWe each within the next 10 years.

6. ACKNOWLEDGMENTS

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY (Installed capacity)
Information based on the National Energy Commission, www.cne.cl.

	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 2004 (December 2003)			6.396	23.368	4.068	21.888			eolic 2	7	10.466	45.263
Under construction in December 2004					570	3.38						
Funds committed, but not yet under construction in December 2004					400							
Total projected use by 2010	300	1800	8950	34100	5.038	27443			eolic 50		14.338	63.368

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2004 (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: Flow Rate (kg/s)	Temperature (^oC) Inlet	Temperature (^oC) Outlet	Enthalpy[2] (kJ/kg) Inlet	Enthalpy[2] (kJ/kg) Outlet	Capacity[3] (MWt)	Annual Utilization: Ave. Flow (kg/s)	Energy[4] (TJ/yr)	Capacity 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							8.72		131.08	

TABLE 3. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2004

[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 0.001

[2] Annual 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

[3] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
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]	8.72	131.08	0.48
Other Uses (specify)			
Subtotal			
Geothermal Heat Pumps			
TOTAL	8.72	131.08	0.48

[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 4. 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 Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2000		1	6	3		
2001		2	6	3		
2002		3	5	4		
2003		3	6	2		
2004			3			
Total		9	26	12		

TABLE 5. TOTAL INVESTMENTS IN GEOTHERMAL IN (2004) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1990-1994	?					
1995-1999	2.00					100
2000-2004	5.32					100