Presented at "Short Course VI on Utilization of Low- and Medium-Enthalpy Geothermal Resources and Financial Aspects of Utilization", organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, March 23-29, 2014.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

LaGeo S.A. de C.V.

GEOTHERMAL DEVELOPMENT IN CHILE

Daniel Almarza Farías
Centro de Energías Renovables (CER)
Agustinas 640, Piso 16, Santiago
CHILE
dalmarza@cer.gob.cl

ABSTRACT

Chile has over 15% of the world's active and dormant volcanoes which form a continuous line about 4,000 km long. As a result, over 300 geothermal areas have been identified throughout the country. Geothermal resource potential is in the range of 16,000 MW, according to a preliminary estimate, while market based studies place the potential in a range of 1,750-5,200 MW for the year 2030. Chile has regulated geothermal development for private sector involvement since the year 2000 and although there have been more than US$ 380 million of investment commitment for exploration and over 85 exploration and exploitation concessions granted, currently, there are no projects in operation. The two most advanced projects are Cerro Pabellón and Curacautín, both with tested production wells and environmental approval for a 50 and 70 MW geothermal power plants respectively. The nature of the Chilean electricity market and the remote location of geothermal resources create high up-front cost for the development of any projects. Although these barriers may seem hard to overcome, unprecedented government and international support for geothermal have the potentials to accelerate projects to start the operation of the most mature projects by 2018. As for low-enthalpy geothermal, the lack of a proper regulation has clearly slowed the deployment of this technology, limiting its use to recreational purposes.

1. INTRODUCTION

Geothermal exploration in Chile was first conducted in 1907 in a geyser field in the northern region of Chile; soon after, Italian pioneers started the first geothermal exploration program in Antofagasta in the 1920s. However, systematic exploration started between 1968-1976 with a series of geological, geophysics and geochemistry studies in determined locations in the northern part of the country supported by a cooperation agreement between the Chilean Economic Development Agency (CORFO) and the United Nations. The exploration ended with the drilling of a well in the zone el Tatio, afterward economic crisis triggered the end of State driven exploration. From then on, only two institutions carried out occasional research and further studies, the University of Chile and the National Service of Geology and Mining (SERNAGEOMIN).

In the year 2000, the first law that regulated geothermal energy was enacted, but it was not until 2004 that rules of procedure for the implementation of the law were published. The law promotes the exploration and exploitation of geothermal resources by the private sector and establishes the existence of exploration and exploitation concessions. Further improvements in the rules of procedure

were made in the year 2013, to streamline the concession process and provide developers with long-term certainty over development rights.

Because of the need of diversifying sources of energy, the government of Chile has a continued interest to promote geothermal development. Currently, the government is actively mobilizing different states agencies and engaging international cooperation to form an unprecedented support for geothermal in Chile, which may finally move projects into operation.

2. GEOTHERMAL RESOURCE AND MARKET POTENTIAL IN CHILE

Geothermal resources of the Andean region of Chile occur in close spatial relationship with active volcanism, which arises by the convergence of the Nazca and South America Plates. Chile is located in the pacific Fire Belt, a belt of volcanoes and earthquake epicentres where abundant resources of thermal energy can be found. The country has over 15% of the world's active and dormant volcanoes, forming a continuous line over 4,000 km long. As a result, Chile is one of the largest under-developed geothermal countries in the world.

Geological and geochemical reconnaissance surveys in the north a south regions have allowed to make a preliminary estimate of geothermal potential in Chile, approximately of 16,000 MW at least for 50 years of geothermal fluids with temperature exceeding 150°C, located at a depth less than 3,000 meters (Lahsen, 1986). On the other hand, market based studies estimate that the potential for geothermal is between 810 and 3,105 MW by the year 2021 (Comisión Asesora para el Desarollo Eléctrico (CADE), 2011) and most recently, in a joint platform that integrated different stakeholders of the electricity market, estimated between 1,750 and 5,200 MW of geothermal installed capacity by the year 2030 (Comité Técnico de la Plataforma Escenarios Energéticos Chile 2013, 2013).

3. REGULATORY FRAMEWORK AND GEOTHERMAL DEVELOPMENT IN CHILE

In January of 2000, the Law 19.657 that regulates geothermal energy was enacted, establishing a framework for the exploration and exploitation of geothermal energy in Chile. The law states that geothermal energy is a good susceptible of exploration and exploitation after the proper concession is granted.

The exploration concession gives the developer the right to carry out exploration work to determine geothermal potential. It has a validity of 2 years extendable for 2 more, with a maximum area of concession of 100,000 ha. The exploitation concessions awards the developer the right to carry out all the activities required for geothermal energy generation, including drilling, construction, commissioning and operation of an extraction system; the production and processing of geothermal fluids in electrical or thermal energy. It has an indefinite duration, with a maximum area of concession of 20,000 ha.

So far exploration is most intensive in the northern volcanic zone, were there about 90 thermal areas, and over 47 exploration concessions (Figure 1). However, the exploration in central-southern volcanic zone is also quite active, there are over 200 geothermal areas (Lahsen et al., 2010) and over 32 exploration concessions.

Table 1 shows the developments made so far in terms of hectares and investment commitment.

Almost 14 years have passed after the approval of the law, and there are so far no high enthalpy geothermal projects in operation. The main reason is high up-front cost and access to the electricity market; there are several reasons to explain this situation.

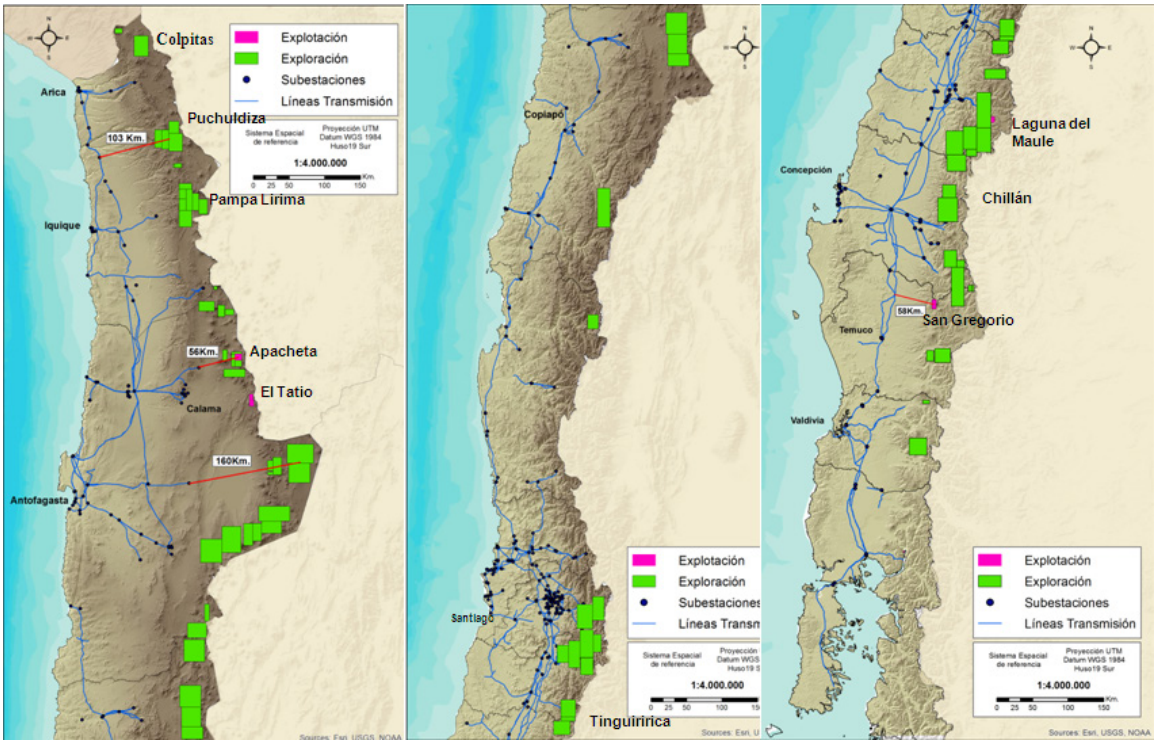

FIGURE 1: Geothermal concessions by area, data as of November 2013
Source: Ministry of Energy.

TABLE 1: Geothermal energy concessions, data as of November 2013. Source: Ministry of Energy.

Status	**Quantity**	**Hectares**	**Commitment US$**
Exploration Concessions	79	3 million	380 million
Exploitation Concessions	7	38.000	1160 million

The high altitudes and arid environment of the north create logistic difficulties for the location of camps and the extraction of industrial sites. On the other extreme, the glacial morphology of the south complicates access and there is also a limited window of time when work can be carried out. This cost can be more expensive given the absence, at this moment, of a consolidated geothermal industry. Additionally, as geothermal resources are remotely located, companies need to find big resources that can justify long transmission lines (Barria, 2013). Finally, geothermal developers that are in a very advanced stage are experiencing problems to participating in the electricity market, as for financing they require long term PPAs, and therefore are unable to participate in the spot market (Hiriart and Santa Rita, 2013).

As for low-enthalpy geothermal, the lack of a special regulation can explain in many ways the absence of projects. The law that regulates geothermal does not address in any specific way to low-enthalpy geothermal, although it does exclude thermal waters for touristic and medical purposes. As a result, low enthalpy geothermal has to struggle with the high demanding prerequisites and regulations established for large geothermal projects. Thus, so far low-enthalpy geothermal has been limited to recreational purposes and occasionally in demonstrative projects. However, since 2009 there is a proposed bill in congress willing to address this problem by creating special regulation for the development of low-enthalpy geothermal.

Even though there are considerable challenges for the development of geothermal, there are two project that are well advanced in terms of exploration, Cerro Pabellón and Curacautín, located in the northern and central-south volcanic zone respectively.

Cerro Pabellón (Apacheta concession)
Enel Green Power

Located in the northern volcanic-geothermal zone, the initial geothermal exploration at Cerro Pabellón (Figure 1) was conducted by ENG, the National Geothermal Company (ENAP-ENEL).

FIGURE 2: Geothermal project Cerro Pabellon. Source: Enel Green Power.

The company has conducted exploration in the area with favourable results. Two production wells (1,800 m, 245°C), 2 injector wells and 1 slim hole (700 m, 210°C). Results from the wells show a potential for 5-10 MW per well.

This was the first project to obtain environmental approval for a 50 MW geothermal plant and a 70 km high voltage line, which will connect to the Northern Interconnected Power Grid (SING). The projects consist of a 40 MW condensation plant and binary plant with a 10 MW additional capacity; it has an estimated cost of US$ 180 million and is planned to be operational by 2018.

Curacautín (San Gregorio concession)
Mighty River Power

The Curacautín project (Figure 3) is located in the central-southern volcanic zone, in the limits between Biobío and La Araucania Region, near the Tolhuaca volcano.

FIGURE 3: Geothermal project Curacautín. Source: Mighty River Power.

The company has conducted exploration in the area with promising results. Two production wells have been drilled (2,500 m, 290°C), 4 slim holes (1,100 m, 300°C), with a potential between 3-12 MW per well. In well Tolhuaca N4, a high-temperature, high-pressure, low-gas steam reservoir was discovered. The well was extensively flow tested over a period of 38 days and it is capable of producing at least 13 MW.

Since May 2013, the project has an environmental approval to build a 70 MW geothermal plant which will be connected to the Central Interconnected Power Grid (SIC). The project has an estimated cost of US$ 330 million and is planned to start operation in 2018.

4. INSTITUTIONAL SUPPORT, INTERNATIONAL FINANCING AND COOPERATION

The Ministry of Energy through its renewable energy division is continuingly creating the optimal market condition to boost renewable energy projects, which can guarantee their involvement in the energy mix. The Ministry of Energy is responsible for the administration of geothermal concessions as well producing new regulation to foster geothermal projects. In late 2013, a new study started,

conducted by the Ministry, called "Strategic development plan for geothermal energy in Chile for 2050" to provide a long term framework for the development of geothermal projects, which will cover regulatory aspects, incentive mechanism, new procedure and short, medium and long-term plan to boost the development of the geothermal industry. Additionally, the Ministry has been able to leverage international cooperation, specifically, the Clean Technology Fund, in which in its last revision plan the government proposed to reallocate US$ 33 million to a Geothermal Risk Mitigation Program (MiRiG) (Clean Technology Fund, 2013). The proposed MiRiG Program would encourage private investors in geothermal energy through risk transfer mechanism reducing exploration cost and risks, and mobilizing private capital to ensure a sustainable growth in the long term.

The Renewable Energy Center (CER), the implementing arm of the Ministry of Energy, continues to promote renewable energy through market orientation for private investors, knowledge management for decision makers, capacity building and co-financing renewable energy initiative. Is important to note that CER is currently financing pre-investment studies for grid-connected large scale renewable energy projects, in which geothermal energy is applicable and financing self-supply renewable energy projects where low-enthalpy geothermal energy can also participate. Specifically for geothermal, CER has conducted efforts in capacity building for the public sector involved in the environmental assessments of geothermal projects, studies for the application of low enthalpy geothermal, as well as continuous work with the industry to provide inputs for policy design for the Ministry of Energy.

SERNAGEOMIN is a decentralized service that advices the Ministry of Mining; it contributes to governmental programs by developing mining and geological policies and offering geological information to governmental agencies, private investors and general public. SERNAGEOMIN is one of the public institutions that have done geothermal exploration, mainly geochemical, vulcanological studies, as well as detail geology of geothermal areas. In 2008, SERNAGEOMIN signed a contract with the German Bank KFW for the development of a geothermal program, with the objective of generating geological information orientated to the development of geothermal projects, specifically directed to: diminish the high exploration risk, spread the application and uses of geothermal and create technical and professional capacity in geothermal.

In 2011, the Andean Geothermal Centre of Excellence (CEGA) began its operations, funded by the National Commission of Research and Technology (CONICYT) comprised of a team of researchers from the Faculty of Physical and Mathematical Sciences at the University of Chile, along with scientists from other national institutions such as Pontificia Universidad Católica de Chile, Universidad Católica del Norte, Universidad de Concepción and UDA, and also international institutions. Its seven main research fields are: Magmatic Systems, Heat-Water-Rock Interaction, Fluids Geochemistry, Reservoir Architecture and Geofluid Dynamics, Structural Geology and Tectonics, Geophysics, and Surficial Processes and Environmental Impact. CEGA seeks to generate the necessary scientific knowledge to turn geothermal energy into a sustainable, environmentally friendly and economically competitive resource, in order to help increase the energy matrix of Chile and the Andean countries.

5. CONCLUSIONS

Chile has exceptional geothermal resources and over 13 year of regulatory framework for geothermal energy and has currently no projects in operation. Currently, geothermal exploration is very active, with over 86 exploration and exploitation concessions and with two projects in an advanced stage, Cerro Pabellón and Curacautín, with 50 and 70MW planed capacity, respectively.

The lack of projects in operation can be explained due to the high up-front cost created by the remote location of resources, lack of consolidated industry and the difficulty to participate in the electricity market.

Although these challenges are not be easily overcome, the need to diversify sources of energy and the high potential of geothermal is driving the government and international cooperation to actively invest in geothermal development. Optimistically, the committed support will be enough to mobilize the most advanced projects and to accelerate the projects that are in an exploration stage.

If low-enthalpy geothermal is to be develop soon, a special regulation needs to be in place to avoid the high prerequisite that small projects have to suffer; a proposed bill by the government already in congress seems to be the answer.

AKNOWLEDGEMENT

Special thanks are due to Luciano Gonzalez of Ministry of Energy, who has provided the information about geothermal concessions and the investments in geothermal exploration and also to Andres Bauza and Pablo Tello from the Renewable Energy Center (CER) for their help and thoughtful comments.

REFERENCES

Barria, C., 2013: *Geothermal energy in Chile.* Ministry of Energy, presentation at the Global Geothermal Development Plan Roundtable, 21 pp. Web: https://www.esmap.org/sites/esmap.org/files/5-1%20GGDP%20Day2_Chile.pdf

Clean Technology Fund, 2013: *Investment plan for Chile – Revision*. Report, 29 pp. Web: https://www.climateinvestmentfunds.org/cif/sites/climateinvestmentfunds.org/files/CTF_IP_Revision_Chile_Sept2013.pdf

Comisión Asesora para el Desarrollo Eléctrico (CADE), 2011: *Informe final.* Ministry of Energy, report, 180 pp. Web: http://www.minenergia.cl/documento/descargar/id/5472

Comité Técnico de la Plataforma Escenarios Energéticos Chile 2030, 2013: *Visiones y temas clave para la matriz eléctrica.* Escenarios Energéticos Chile 2030, 112 pp. Website: http://escenariosenergeticos.cl/wp-content/uploads/Escenarios_Energeticos_2013.pdf

Hiriart, G., and Santa Rita, A., 2013: *Reporte del estado de la geotermia: Chile.* Agencia Internacional de Energías Renovables(IRENA), 52 pp.

Lahsen, A., 1986: Origen y potencial de energía geotérmica en los Andes de Chile. In: Frutos, J., Oyarzún, R., and Pincheira, M. (editors), *Geología y recursos minerales de Chile.* Universidad de Concepción, Chile, 423-438.

Lahsen, A., Muñoz, N., and Parada, M. A., 2010: Geothermal deveopment in Chile. *Proceedings World Geothermal Congress 2010, Bali, Indonesia*, 7 pp. Web: http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/0118.pdf