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Geothermal Country Update for Ecuador, 2005 -2010

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ABSTRACT

Ecuador is located on the active convergent plate margin of Southamerica, which is characterized by a broad continental volcanic arc with abundant active volcanoes and intense seismicity. Earlier geothermal exploration, carried out from the mid 1970's to the earlier 1990's by government institutions with the aid of foreign technical assistance programs, defined a combined theoretical potential of about 500 MWe for the three most promising geothermal prospects, namely: Tufiño-Chiles, Chalupas and Chachimbiro, located in the highlands of central-north Ecuador. A dozen of other geothermal prospects, related to silicic calderas, or to evolved stratovolcanoes, or even to evolved basaltic shields, like Alcedo in Galapagos, will substantially increase the inferred potential; low to medium temperature resources are abundant along the volcanic arc.

Low to medium temperature resources are abundant along the volcanic arc and are mainly related to recent NNE strike-slip faulting and local pull-appart structures; these geothermal resources are not confined to the volcanic highlands, but are also present in the fore-arc plains as well as in back-arc areas, mostly related to deep cutting basement faults.

Utilization of geothermal energy is now restricted to direct use in swimming pools (5.157 MWt and 102.401TJ/yr for annual utilization) and to a very small extend, in space heating. Nevertheless, government policies are strongly aimed to develop renewable energy resources including hydro, wind, solar and geothermal, to lessen or even eliminate the use of fossil fuels for power generation. The leading agencies are the Ministry of Electricity and Renewable Energy (MEER) and CONELEC (National Council for Electricity); substantial public funding has been allocated through MEER for geothermal exploration and eventual development.

Energy market is domminated by Hydro (51.7 %) and Fossil Fuel (44.0 %) generation, with a total installed capacity of 4557 Mwe, putting up a gross electricity production of 18609 GWh/yr (as for Dec 2008). The remainder percentage corresponds mainly to imported energy (650 MWe from Colombia and Peru). The increase in power demand is about 150 MWe per year.

Production from renewable energy sources in Ecuador, mainly solar and wind, is still negligible (2.42 MWe), but is planned to increase in the future, including geothermal. The Tufiño-Chiles geothermal prospect owns the especial status of Bi-National Project, due to its location on the Ecuador-Colombia border. The political decission to go geothermal has been taken by the Ecuadorean government and initial public funds have been allocated since late 2008. MEER already completed the first geothermal gradient exploration hole, ever, in Ecuador, on the Tufiño prospect, to a depth of 554 m and final diameter NQ (76 mm). Chachimbiro has been allocated 1 MUSD for geophysical exploration starting 2009 and reconnaissance geological and geochemical surveys are underway in Chacana-Papallacta prospect. This and several other high and low-medium temperature geothermal prospects in Ecuador await state and private investment to be developed in order to lessen the dependance on fossil fuel use. Finally, in Ecuador, geothermal energy is challenged to be cost-efficient in front of an abundant hydro resource, as well as to be environmentally safe.

1. INTRODUCTION

This paper is a follow up of the previous country update for the interval 2000-2005, published in the Proceedings of WGC2005 in Antalya, Turkey (Beate & Salgado, 2005). We preferred to keep most of the content as in the previous update, mainly regarding Geology Background and description of Geothermal Resources and Potential, but introducing necessary changes where applicable and relevant along the text, and updating the respective figures and tables.

Ecuador is a democratic republic, located on the ecuatorial edge of western Southamerica; it has 13 986 906 inhabitants living in a territory of 256 370 km2 (INEC 2001); the official language is Spanish and the GNP was 23264 M USD for the year 2008 (www.ecuadorencifras.com).

Since the approval of the new Constitution in 2008, the government has steared towards a stronger participation of the state in exploration and development of the country's energy and mineral resources. It is the aim of the government to substitute as much, and as soon as possible, the fossil fuels for power generation with indigenous, clean, renewable energy resources, mainly hydro, but also including wind, solar, geothermal and biodigestors.

The lead government agency in charge of exploration and development of geothermal energy resources is the Ministry of Electricity and Renewable Energy (MEER– Ministerio de Electricidad y Energia Renovable), which is aided by CONELEC (Consejo Nacional de Electricidad – National Council for Electricity) on electrical issues, by CNRH (Consejo Nacional de Recursos Hídricos – National Council for Water Resources) on water issues and Ministerio del Ambiente (MDA – Ministry for the Environment) on environmental issues.

In the following pages we present an overview of Ecuador´s geological setting, a description of the geothermal resources and potential, together with the history of exploration, the state of geothermal utilization and a discussion of the actual and future development.

2. OVERVIEW OF ECUADOR´S GEOLOGICAL SETTING

Geographically and geomorphologically, mainland Ecuador consists of three regions: the coastal plains or COSTA, the Andes mountain chain or SIERRA and the Amazon basin or ORIENTE. A fourth region comprises the Galapagos Islands, located about 1000 km to the W of mainland Ecuador, in the Pacific Ocean (see fig.1).

The Andes are the backbone of the country. They were formed by multiple accretion since Jurassic times (Aspden &Litherland, 1992; Eguez and Aspden, 1993), and consists of two paralell NNE striking mountain chains: a) the Cordillera Real (CR or Eastern Cordillera), which are sublinear belts of metamorphic rocks intruded by both, S and I – type granitoids of early Mesozoic age. b) the Cordillera Occidental (CO or Western Cordillera) consists of late Mesozoic to Early-Cenozoic basalts and volcaniclastics, which represent accreted oceanic terrains (Hughes and Pilatasig, 2002); these rocks are intruded by Tertiary granitoids. Both cordilleras have been uplifted and are capped by late Tertiary volcanics. Between the two Cordilleras is the Interandean Valley (IAV), which is laterally bonded by active faults, mostly thrust faults, and comprises thick Late-Tertiary to Recent volcaniclastic and epiclastic sedimentary sequences. Covering both Cordilleras in its northern half, a well developed, broad, calk-alkaline volcanic arc extends northwards into Colombia (Barberi et al., 1988; Hall & Beate, 1991). The arc is of Quaternary age and consists of more than 50 volcanoes, of which at least 30 are active. The southern part of the Andes shows only extinct volcanic activity due to the flattening of the slab since late Miocene (Gutscher et al., 2000).

The Oriente is an extensive sedimentary basin, which overlies cratonic basement (Baldock, 1982) Older rocks include Jurassic batholiths and a Cretaceous carbonate platform, covered by Tertiary epiclastic sediments. Large thrust folds cut the sequence with a NS strike.

Quaternary alcaline volcanoes are present along the central W margin of the basin in a back-arc setting.

The Costa is the flat region W of the Andes; it comprises a late-Cretaceous to Cenozoic fore-arc basin underlain by early Mesozoic oceanic crust. No active volcanism is present in this region. The Galápagos Islands represent, together with the submarine Carnegie Ridge, the Galapagos hot spot trace above the Nazca Plate. The islands consist of about fifteen basaltic shield volcanoes, increasing in age towards the East, hence most of the actual volcanic activity occurs on the westernmost islands of Fernandina, Isabela and Roca Redonda.

Geodynamic processes are controlled since Late Oligocene by the nearly orthogonal convergence between Nazca and Southamerican plates, which has generated regional uplift and crustal faulting and deformation as well as extensive volcanism (Lonsdale, 1978). The northern half of the country is part of the North Andean Block, which moves at 6-10 mm/yr in a NE direction along strike-slip faults entering the gulf of Guayaquil (Ego et al.,1993). This compressive regime formed several intramontane basins of pull-appart nature between the two cordilleras since Miocene. The IAV has been formed as a spindle shaped basin by displacement along a restraining bend in a transpressive regime since about 6 Ma due to an increase in the coupling of Carnegie ridge in the subduction zone (Spinkings, 2001; Winkler, 2002; Villagomez, 2002). This setting, as well as the extensive Quaternary volcanism, favours the presence of high heat-flow anomalies along the ecuadorean Andes, hence, the availability of heat sources for geothermal systems to exist are plenty.

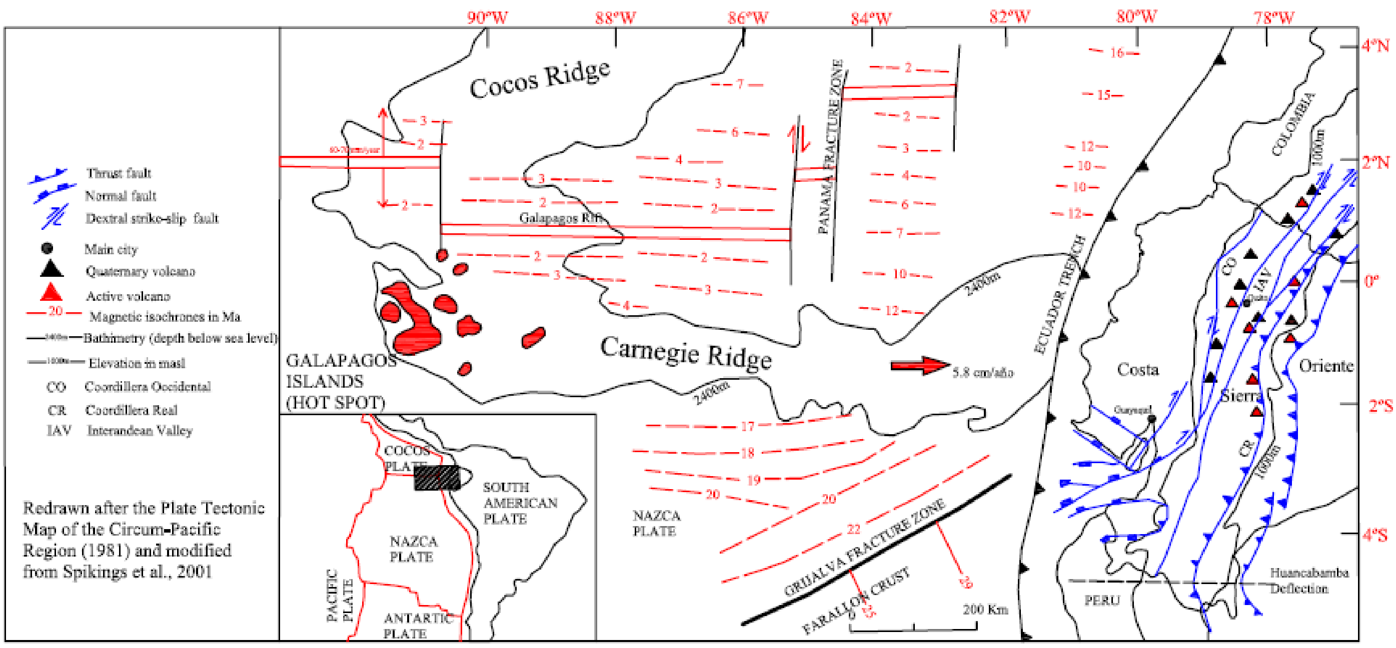

Fig. 1 Geodynamic Setting of Ecuador, showing mainland Ecuador on South American plate and the Galapagos Islands on Nazca plate

3. GEOTHERMAL RESOURCES AND POTENTIAL

The Reconnaisance Study of the Geothermal Resources of Ecuador, carried out from 1979 to 1980, started geothermal exploration in Ecuador. It was aimed to find high-temperature hydrothermal systems along the Andes in the areas of recent volcanism, following the methodology recommended by OLADE (1978). The report (INECEL/OLADE 1980) produced by INECEL (Instituto Ecuatoriano de Electrificación, now defunct) and OLADE (Organización Latinoamericana de Energía), together with AQUATER (Italy) and BRGM (France), sumarized the areas of interest in two main groups: Group A (high-temperature; Tufiño, Chachimbiro and Chalupas) and Group B (low-temperature; Ilaló, Chimborazo and Cuenca). INECEL, through its Geothermal Project, carried out follow-up prefeasibility studies between1981 and 1992, first on Tufiño with OLADE and ICEL (Instituto Colombiano de Electrificación), since the project has the status of Bi-National (Ecuador – Colombia), and later on Chachimbiro and Chalupas. In 1985, INE (Instituto Ecuatoriano de Energía, now defunct), carried out prefeasibility studies for low-mid temperature resources at Ilaló and Cuenca prospects, but funding for drilling failed because potential industrial and direct uses showed up to be non economic for the time. The Tufiño prospect gained the first priority for exploration and the results of advanced geological, geochemical and geophysical surveys indicated a high-temperature resource underneath volcan Chiles (INECEL-OLADE-AQUATER, 1987). Results of scientific surface studies on Chachimbiro and Chalupas indicated the existence at depth of high-temperature resources. Results were summarized by Beate (1991) and by Almeida (1990, 1992), who also gives an assessment of the potential for these three prospects, based on surface data, totaling 534 MWe. INECEL´S Geothermal Project was shut down in 1993 and since than and until 2008, no further goverment-run geothermal exploration has been done in Ecuador. A privately funded MT survey in Tufiño (Tecniseguros, 1994) confirmed the presence of a deep high-temperature resource, but the number of soundings was not enough to fully constrain the size of the reservoir; shortly after, a final agreement with the Ecuadorean State failed. Further desk-top studies, were written with the aim to promote development of the Tufiño prospect as a Bi-National project (Coviello, 2000; Aguilera, 2001), without success, mainly due to the absence of both, a proper legal framework for geothermal activities and the availability of initial high – risk funding.

In 2008, the Ecuadorian government through the MEER, re-starts geothermal exploration, aiming to develop one or more of the former INECEL geothermal prospects for power generation. Several state-run exploration inniciatives are currently under way:

A geothermal drilling program, comprising four to six small-diametre gradient holes in Tufino – Chiles Prospect and operated by MEER, just completed (as on May 2009) borehole PGT-1 to a total depth of 554 meters and final diameter NQ (76 mm); this is the first geothermal exploration borehole drilled in Ecuador , ever.

Chachimbiro Geothermal Prospect received 1 MUSD of state funding for geophysical exploration to site deep exploration holes, which is ready to start under the operation of ESPE (Escuela Politecnica del Ejercito).

CONELEC commissioned a desk-top study on a 50 MWe plant for the Chalupas Geothermal Prospect as a project profile (Beate, 2008), as well a an assessment of Ecuador Geothermal Prospects.

Former ELECTROGUAYAS (now part of CELEC – Coorporacion Electrica del Ecuador; National Utility Corporation) funded (starting Dec. 2008) a geological and geochemical Reconnaissance Study of Chacana Caldera for geothermal resources, as well as an upgrade report on Tufiño, Chachimbiro and Chalupas geothermal prospects, which final report is due July 2009.

3.1 Description and Assessment of Geothermal Prospects

This assessment takes into account the earlier studies mentioned above, as well as new data generated in the last decade, especially on the regional geology of the two main cordilleras (Litherland & Eguez, 1993; CODIGEM-BGS, 1987 - 2000), the tectonic evolution of the intramontane sedimentary basins (Hungerbuehler et al. 2002) and on the recent volcanoes of the continental volcanic arc and its geodynamic implications (Bourdon, 2002; Chiaradia et al., 2009).

It is a description of “what”, “where” (see Fig.2) and the characteristics of the geothermal prospects regarding its resource and potential. It follows an order of priority from more to less attractive regarding electrical uses, but are for overall interest regarding direct uses, being the main difference the state of actual knowledge.

3.1.1 Tufiño – Chiles geothermal prospect

This prospect is located in the CO (Cordillera Occidental or Western Cordillera), at 35 km W of the city of Tulcán, 7 km W of the villages of Tufiño and Chiles, in the province of Carchi (Ecuador) and Nariño department (Colombia). The development area lies across the Ecuador - Colombia border and comprises about 4900 ha; likely drilling sites at SE slopes of Chiles volcano are between 3800 and 4200 masl, where climate is wet and cold most of the year and vegetation is grassy. Gravel roads give access to the area, where the principal activities are agriculture and cattle farming. The cities of Tulcán and Ipiales are the main load centre.

Volcan Chiles, a moderate size, andesitic to dacitic, stratocone active in late Pleistocene, constitutes the main heat source, which is reinforced by Cerro Negro de Mayasquer, an active dacitic volcano adyascent to the W of volcan Chiles. These two volcanoes are built up on top of a thick pile of late Terciary volcanics (Pisayambo Fm.) overlying accreted oceanic crust of Cretaceous age (Pallatanga Terrain). Reservoir rocks could be fractured Tertiary volcanics, affected by the intersection of active NNE -.trending regional strike-slip faults with local E-W faults, which are likely to produce reasonable permeability.

Acid hot springs, up to 55°C (see table 1A), occur 2 – 3 km to the East of Volcan Chiles, along E-W faulting, with a strong H2S smell. Bicarbonate springs are common several km to the East, close to the villages of Tufiño and Chiles. Fossil silica sinter terraces, about 1 km East of the acid springs, show that neutral chloride waters, indicative of a high temperature hydrothermal system, discharged at this site sometime in the past. Extensive areas of hydrothermally altered rocks are found 2.5 km N and 1.5 km S of volcán Chiles. These are at ambient temperature, but show local emission of H2S, and have been active in the Holocene; it is likely that the shallow part of the system has sealed up. Gas geothermometers indicate reservoir temperatures as high as 230 °C. Location of acid springs and altered ground suggest considerable size of reservoir, mostly overlain by rugged terrain. Resistivity data (Schlumberger and MT soundings) confirm the existence of a geothermal reservoir under volcan Chiles massif, with a fault-controlled E-wards lateral outflow on East flank (INECEL-OLADE-AQUATER, 1987). Elevation of top of reservoir is below 3100 masl with 100 °C waters, but exploitable temperatures are 200 – 300 m deeper, indicating a drilling target for production at 1000 to 1500 m depth; this is indicated by the presence of a thick conductive layer, which is shallow (about 100 m) below the acid springs, but deepens 400 to 500 m towards E (outflow).

The altered ground towards S indicates a low temperature conductive layer associated with steam-heated rocks consisting of clays. Best sites for exploration-production drilling appear to be to the W of the acid springs, at about 3800 – 4000 masl, which would need the building of 1 – 3 km long access roads from the existing gravel roads. Water for drilling might be scarce in the dry season. Inmediate future work should involve the drilling of three exploration wells to at least 2000 m depth, following a complementary MT survey to fully constrain the reservoir size. This should allow to lessen the risk in choosing drilling targets, since production zones are probably fault-controlled. Almeida (1990) gives an estimate of 138 MWe for the Tufiño prospect, based on surface data.

In 2009, 1 MUSD of state funds was allocated to the Tufino prospect to carry out 4 shalow (500 m), small diameter (NQ or 76 mm) gradient bore holes, which is operated by MEER. The first hole, PGT 1, which is the very first geothermal hole to be drilled in Ecuador, reached a total depth of 554 m in May 09. Lithology comprises till, lavas and thick sequence of rather low permeability volcaniclastics (microbreccias) and associated sediments as sandstone and siltstone. Low permeability would be expected along the upper conductive seal cap of the geothermal system. A preliminary temperature measurement at bottom hole rendered 50 deg. C. This hole is located on the E lower flank of volcan Chiles. The other holes are planned to be drilled in the following months, also in and around the eastern flank, in the vicinity of the hot springs and the lateral outflow, according to MEER officials.

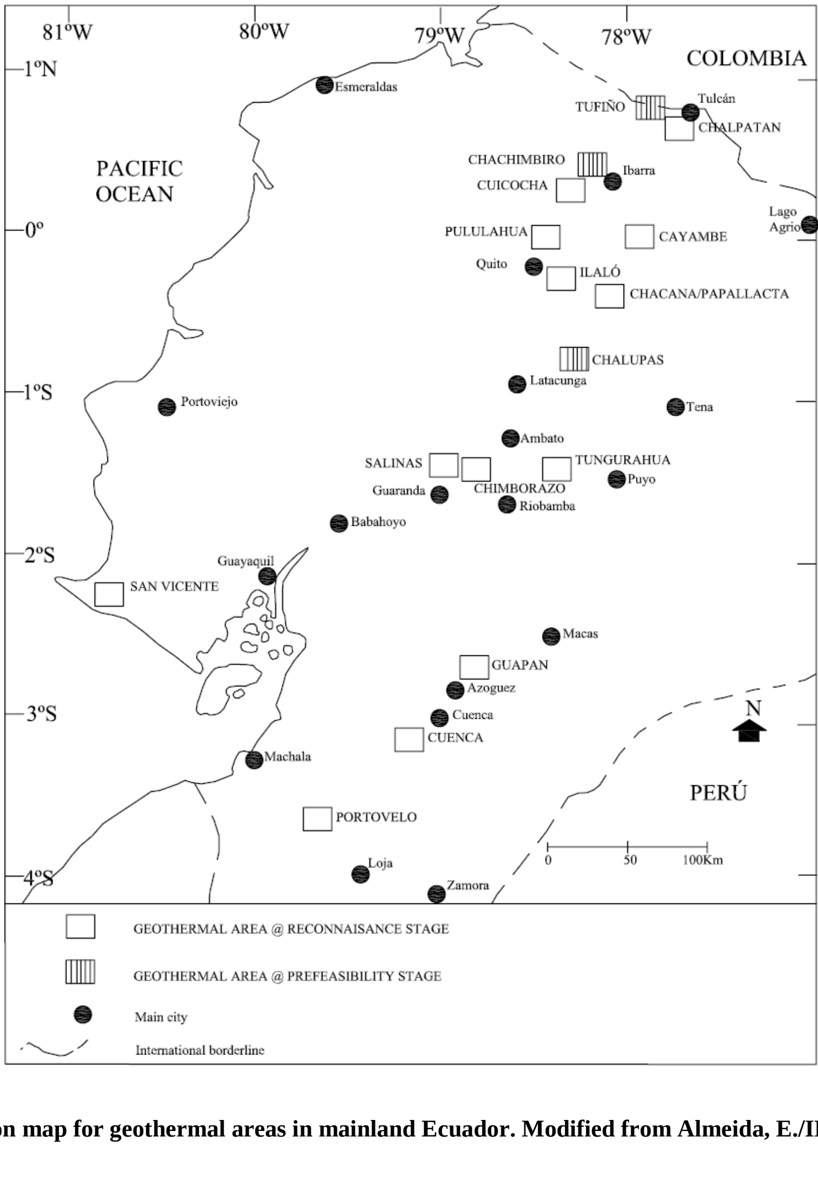

Fig. 2 Location map for geothermal areas in mainland Ecuador. Modified from Almeida, E./INECEL, 1990

Table 1A. Chemical Composition of hot spring waters from several geothermal areas of mainland Ecuador (all values in ppm).

Hot Spring	T°C	ph	Na	K	Ca	Mg	HCO3	Cl	SO4	SiO2	B	Altitud (masl)
Tufiño 1 (Aguas Hediondas)	41	3.1	78	18	328	64	----	320	1300	226	----	3850
Tufiño 2	53	5.9	149	34	100	70.6	350	110	550	159	----	3530
Tufiño 3	40	6.2	134	3.1	104	70.7	670	74	2100	157	----	3260
Chachimbiro 1	58	6.3	1250	155	77	47	661	2040	30	200	----	2618
Chachimbiro 2 (Pitzantzi)	41	6.7	665	63	248	145	1276	879	10	168	----	2740
Chachimbiro 3 ***	47.2	6.23	1329	117	102	54.9	861	2060	29.4	183	52.6	2580
Chacana 1 (Papallacta-Termas)	66	6.8	1350	80	337	54	1425	619	440	80	----	3510
Chacana 2 (Papallacta-Tambo bajo) ****	57.8	6.15	1306	59.82	278	11.2	576.45	2114	236.6	----	19.8	3550
Chacana 3 (Papallacta-Tambo alto) ****	64.6	6.39	916	79.76	106.4	33	672.22	1352	115.6	----	18.99	3910
Ilaló 1 (La Merced*)	34	6.8	134	9	43	54	616	71	14	131	----	2610
Ilaló 2 (El Tingo*)	41	7.2	441	33	34	155	1824	275	17	74	9	2460
Ilaló 3 (Tolontag-Chacana*)	50	6.7	1150	78	313	57	1780	508	1480	93	28	3420
Chalupas 1	35	6.8	312	38	9.6	16	858	39	5	153	1.5	3740
Chalupas 2	25	6.1	245	14	29	74	937	87	0.4	----	2	3520
Tungurahua 1	52	7.0	525	74	212	450	1445	450	450	190	----	1910
Tungurahua 2	36	6.8	217	28	171	240	1525	49	328	154	----	2840
Chimborazo	47	7.5	682	7.5	320	0.5	37.9	1340	252	48	----	3660
Salinas****	17	6.84	16646	2418	1320	307	2003.9	29787	1989	----	----	3519
San Vicente****	37.9	6.41	2382	15.4	2764	0.2	579.5	8368	----	----	----	70
Guapán 1**	45	6.7	5600	160	363	65	3090	5160	35	42	105	2660
Guapán 2****	46.9	6.79	3641.4	124.9	90.3	69.3	2525.4	4826	63.2	----	----	2670
Baños Cuenca 1	73	7.4	750	59	184	23	782	874	233	66	14.2	2715
Baños Cuenca 2	56	6.6	743	59	152	24	890	861	227	59	13	2720
Portovelo**	57	7.1	84	22	145	0.2	19	200	288	27	7.8	630

Sources: INECEL 1992
* INE 1986
** De Grys et al., 1970
---- not determined
*** Aguilera et al., 2005
**** IG/EPN – INGV, 2009

3.1.2 Chachimbiro geothermal prospect

This prospect is located on the E slopes of the CO, at about 20 km W of the city of Ibarra in the province of Imbabura. It is accessed by gravel and dirt roads. Climate is temperate and vegetation changes from forested to grassy on a rather rugged topography. Possible drilling site location are at elevations of 3500 masl. A 4900 ha development area has been proposed, with elevations varying from 2800 to 4000 masl. The area is partly inside the Cotacachi – Cayapas Ecological Reserve and land is used for agriculture.

The heat source is the Quaternary Chachimbiro volcanic complex, which includes the collapsed mid Pleistocene andesitic volcano Huanguillaro, the caldera filling rhyodacitic Hugá dome and the Late Pleistocene Chachimbiro – Pucará NNE line of dacitic domes, the youngest of which (Pitzantzi dome) is only 5000 years old (Beate 2001); older Yanaurcu volcano (andesitic to rhyodacitic) as well as late Pleistocene Pilavo volcano (basic andesite), are located to the W of Huanguillaro. The whole complex is underlain by mid-Terciary vulcaniclastic sediments (Silante Fm.) and by intenselly tectonized Cretaceous oceanic basalts and asociated sediments (Pallatanga Terrain). Active NNE trending faults cut the volcanic complex, assuring reasonable permeability.

Reservoir rocks could be fractured volcanics related to dome activity and concealed proximal lava flow facies related to early volcanic activity covering the basement rocks; and locally fractured upper marine sediments and oceanic lavas of the basement itself.

Near – neutral chloride – bicarbonate hot springs are present to the East of the system, with temperatures ranging 40 to 55 °C (see table 1A) . Possible deep-temperatures are 225 - 235°C, although temperatures at the root of the system can be somewhat higher than 260`C (Aguilera, 2005) Fault controlled areas of hydrothermally altered rocks with no anomalous temperature, crop out in the central part of the area, showing light H2S smell, indicating selfsealing of the upper part of the system. Resistivity soundings on the E part of the area, reveal a lateral outflow to the E. There are no deep-reaching resistivity surveys in the centre of the system.

Recommendations for future work include a) detailed geological mapping with emphasis on volcanic features and structure; b) carry out a MT survey to get a comprehensive picture of the resistivity structure of the system and thus site the exploration wells; and, c) drill three wells to a depth of about 2000 m, spaced 1000m appart, in relative flat area between the dacitic domes, depending on the results of MT survey. This will need to upgrade 5 km of existing dirt road, plus some site access.

Nearest major load centre is Ibarra. A high voltage transmission line, 20 km from the area, connects Colombia to the ecuadorean grid. A potential of 113 Mwe has been estimated by Almeida (1990) from interpretation of surface data.

Geohemical data (Aguilera et al., 2005) support the existence at depth of a high enthalpy geothermal system, which is promising and deserves a high exploration priority; in this regard, the Chachimbiro prospect has been allocated

1 MUSD of state funds in 2009 for exploration activities, mainly geophysics (MT – survey) to be operated by ESPE (Escuela Politecnica del Ejercito – Politecnical University of the Army) as a research project.

3.1.3 Chalupas geothermal prospect.

This prospect is located 70 km SSE from Quito, at the crest of the CR (Eastern Cordillera), in the province of Napo. It can be accessed from Latacunga along gravel and dirt roads. Average elevation of prospect is 3600 masl, climate is cold and wet for most of the year and vegetation is grassy. Topography is mostly flat. The area of interest, the Chalupas caldera floor, is greater than 200 km2. Latacunga is the nearest load centre at a distance of 30 km.

The Chalupas caldera is12 km in diametre and formed after the explosive eruption of about 100 km3 of rhyolitic pumitic ash (INECEL, 1983; Beate, 1985;). Hammersley (2004) obtained an age of 211 ka for the ash in biotite. Volcanic activity resumed after caldera collapse, building Quilindaña volcano inside it, which is andesitic to dacitic in composition; youngest intracaldera lava flows have a basaltic andesite composition and are affected by glacial erosion of the Younger Dryas Glacial advance, about 11 ka. The huge volume of erupted silicic magma as well as the persisting volcanic activity through time, garantees the presence of a heat source in the area as pointed out by Bloomquist, 1995. Due to the formation of the caldera by collapse, high permeability is expected at depth; regional NNE trending faults cross the caldera structure. The caldera collapse affected a thick pile of late Terciary intermediate volcanics (Pisayambo Fm.), which overly the Triassic-Jurassic metamorphic basement (blue qtz gneises of Tres Lagunas Granite).

The caldera has been eroded by glaciers and partly filled by cold water-saturated morraines; hence, only few low temperature springs, between 30 to 40 °C (see table 1A), are found at the edges of the caldera structure, and are too diluted to give an estimate of the deep temperature. This may be also indicative of the abscence of a shallow high-temperature system. Fault controlled hydrothermally altered rocks appear in the N and S caldera rims; christobalite is found at the W rim affecting pre-caldera lavas. Other alteration zones may be concealed underneath the morraine cover. A gravity survey shows the caldera structure, the geometry of the basement as well as the regionally N-trending Peltetec fault (Beate, 2001).

Future work should carry out a Schlumberger resistivity survey with traversing (mapping) measurements at 500 m spacing, and a dozen of deep vertical electrical soundings (VES), as to define the upper surface of any geothermal system, since the topography is mostly flat and reasonable accessible. Depending on the results of the Schlumberger survey, a deeper-penetrating, comprehensive MT survey at 1km grid spacing is strongly recommended. If the system is shallow, this prospect may be suitable for a program of shallow temperature-gradient wells (400 to 500 m deep) to confirm high temperatures and sample deep fluids. If results are encouraging, an exploration drilling program is recommended at a spacing commensurate with the size of the system as defined. Almeida (1990) estimates a potential of 283 Mwe for the Chalupas prospect, from interpretation of surface data.

3.1.4 Chacana-Papallacta geothermal prospect

This prospect is located at 60 km to the E of Quito on the CR (Eastern Cordillera), in the province of Napo. Elevations range between 3200 and 4000 masl on ragged topography covered with grassland and few forested patches. Climate is wet and cold for most of the year.

The main load centre is Quito and a high voltage transmission line runs already through, as well as paved and gravel roads. Developement area has not been defined yet due to lack of data. The prospect is mostly located in environmentlly sensitive territory, namely the Antisana and Cayambe-Coca ecological reserves.

The heat source are the younger volcanics of the Chacana caldera complex, which has been persistently active through all the Quaternary (the last 2-3 million years). Important rhyolitic eruptions occurred 240, 180 and 160 ky ago producing ash-flow deposits, thick plinian pumice falls and a large obsidian flow; voluminous andesitic and dacitic lava flows were erupted 40 and20 ky ago, outside and inside the 35 km N-S diameter silicic Chacana caldera (Hall & Beate, 1991; Hall & Mothes, 2001; Hall & Mothes, 2008).

An almost 2 km thick pile of volcanic rock from the Chacana complex, including thick intra-caldera ignimbrites, and the underlying late Terciary Pisayambo Fm., constitute the cover to the early Mesozoic metamorfic basement. The collapse structures of the coalesced caldera complex , as well as major active NNE – trending faults cut the entire sequence, assuring reasonable permeability. The central – W part of the caldera has been uplifted by resurgence and several postcaldera dacitic to rhyolitic domes have been emplaced along the rim and inside the caldera structure.

Hot springs, mainly located inside the caldera in the Papallacta area, show temperatures between 40 and 67 °C (see table 1A). The springs are near- neutral alkaline chloride waters with anomalous high concentrations of boron and arsenic, typical of a high temperature water-dominated geothermal system. Travertine is deposited in aprons on river banks and terraces; more distal waters tend to be of bicarbonate type. Deep temperatures are estimated to be in eccess of 180 °C. Fossil hydrothermal alteration zones are abundant along the N, S and central parts of the caldera structure, as well as along main NNE – trending faults. No active ground alteration is visible nowadays, sugesting a sealing up of the shallow parts of the system. No geophysical surveys have been done in the area to date.

Actual work by CELEC, former ELECTRGUAYAS (a state-owned Utility Company) comprises geological mapping of the caldera complex as well as a comprehensive geochemical survey of hot spring waters and gases; analytical results and reporting is under way. Overall estimates for geothermal potential look promising and final reconnaissance report is due in July 2009. Future work, depending on positive results, should include geophysical surveys in the most promising parts of Chacana caldera, mainly MT traversing and griddind, with the aim to better understand the system(s) and site exploration holes.

3.1.5 Chimborazo geothermal prospect

This prospect is located 35 km NW of Riobamba, at the crest of CO (Western Cordillera), in the province of Chimborazo. Elevations are in the range of 3500 to 4500 masl, vegetation is scarce and grassy at best, topography is hummocky and climate is cold through the whole year. Access is good along paved and gravel/dirt roads. The load centres are the cities of Ambato, Guaranda and Riobamba, situated inside a radius of 40 km.

The development area is of 4200 ha, situated on the NNW slope of Chimborazo volcano.

Chimborazo is a big composite stratovolcano, reaching 6310 masl on its summit and starting at 4000 m at its base. Composition of its products vary from basaltic andesites and andesites through dacites and rhyolites, beeing the later between 1 and 2 My old and the former between 5 and 10 ky old. Last eruption produced small phreato-magmatic (?) surges, only 1.7 ka old. The whole edifice rests on Terciary vulcaniclastic sediments (Saquisilí Fm.) which overly accreted Early Cretaceous ocean crust (Pallatanga Fm.). Reservoir host rocks are likely to be composed of fractured volcanic rocks. Active faults cut the prospect area, but are concealed due to thick Pleistocene tephra cover.

Only one hot spring exists in the area to the NNW foot of the volcano, with a temperature of 47°C and a dilute neutral chloride chemistry (see table 1A). The fluids show water –rock equilibrium and indicate deep reservoir temperatures between 120 and 150°C.

No geophysical survey has been done yet. A Schlumberger resistivity survey is recommended to determine the location of the outflow structure.

3.1.6 Cuenca geothermal prospect

The hottest springs of this prospect are located 7 km SW of the city of Cuenca (2700 masl) in the province of Azuay. The geothermal system lies some 20 km further SW at an elevation of about 4000 masl, at the crest of the CO (Western Cordillera), where the climate is cold and wet. Topography varies from flat on top, to gentle downhill slopes to locally rugged. Vegetation is grassy at high elevations to patchy forested at lower altitudes. Land is used mainly for agriculture and cattle raising. Access to upper part is scarce along few dirt roads, but gravel roads are more common in lower parts. Cuenca is the main load centre.

A development area of 6000 ha is proposed, which lies partly inside an environmentally protected area and covers the mid-upper part of the Quimsacocha outflow.

The heat source is the Late Miocene-Pliocene Quimsacocha volcanic complex, located about 25 km SW of Cuenca. It produced a cal-alcaline andesitic shield with lava flows and breccia, an extensive high sulfidation epithermal Au-Ag deposit, a caldera forming rhyolitic ignimbrite (Tarqui Fm.) at about 5 My and late intrusive and extrusive caldera - filling domes of dacite and rhyolite porphyries of adakitic signature at about 3.6 My (Beate, 2002); volcanic activity did not resumed after extrusion of the domes.

The Quimsacocha volcanic complex overlies a thick pile of volcaniclastic sediments of late Miocene age (Turi Fm.), which in turn cover Mesozoic basement rocks. Major NE-trending faults cut the whole sequence and serve as primary channelways for the deep fluids, indicating reasonable permeability. Likely reservoir host rocks are the Late Miocene volcanics as well as previously silicified volcaniclastics of Turi Fm.

With a temperature of 75°C, the Baños hot springs are the hottest in mainland Ecuador (see table 1A). The waters are of the alkali chloride – bicarbonate type and deposit travertine along 8 m high and 200 m long ridges. Deep temperatures of at least 200°C are indicated. These springs represent the likely lateral outflow of the Quimsacocha geothermal system, at about 20 km to the SW of Cuenca. Extensive high grade fossil hydrothermal alteration has been mapped along SW – NE strike and include silicification and clay alteration, which indicate probable former deep boiling zones. Today, the system is self-sealed.

Future work includes: a) sample, analyse and interpret thermal waters and gases as well as hydrothermally altered rocks to characterise the geothermal system and define deep conditions. b) carry out a Schlumberger resistivity survey, consisting on traversing (mapping) measurements at 500 m spacing, and a number of VES to define the top of the outflow. c) a deeper reaching MT survey may be recommended , especially in the upper part of the area, to locate the drilling targets in order to reach the deep hot fluids.

3.1.7 Other geothermal areas

CHALPATÁN is a Late Pliocene – Early Pleistocene andesitic to silicic collapse caldera, 5 km in diameter, located in the IAV about 20 km SW of Tulcán. Few warm springs crop out along NNE trending regional faults, which cut the main structure. Spring waters are likely to be related to a deeper reservoir of moderate temperature (INECEL-OLADE-AQUATER, 1987), which deserves a closer look.

CUICOCHA is a 3 ky old explosion caldera, 3 km in diametre, asociated to dacitic domes. It is located 45 km SW of Ibarra on the crest of the CO, at the S flank of andesitic Cotacachi volcano. The caldera hosts a cold water crater lake with few subaqeous gas outcrop. Distal bicarbonate spring water show a positive 18Oxigen shift (Almeida, 1992) and may be related to a hydrotermal sistem below the caldera.

CAYAMBE is a big composite central stratocone, located on top of the CR, about 60 km NE of Quito. Its composition varies from andesitic to dacitic in a time range of 100 ky and its last eruption is historic (around year1770, dacitic tephra), which indicates a long lasting heat source. Hot springs are known to exist but at remote sites of difficult access.

PULULAHUA is a young dacitic dome complex, showing a 3 km diametre explosion caldera, which formed 2400 years ago. It is located 20 km N of Quito, on the Cordillera Occidental. Low-temperature bicarbonate springs and the young age of the complex, may indicate a deeper , hotter system with reasonable good permeability, due to the caldera structure as well as to the fact that important regional N to NNE striking faults cut the rim on its W side. Quito is the nearest load center.

GUAGUA PICHINCHA is situated 10 km W of Quito on the Cretaceous oceanic basement rocks of CO. This volcano has been active for the last 50 ky. Several events of debris avalanche and later dacitic dome growth, did affect the earlier basal andesitic edifice. The actual caldera is 3 km in diametre and 600 m deep, and opened to W. The flat caldera floor hosts on its W ramp a dacitic dome, extruded 330 years ago and a colapsed dome complex extruded 4 years ago (Monzier at al., 2002). Active faults cross the structure and hydrothermal alteration is widespread. Pre-eruption situation showed a vigorously high temperature hydrothermal system underneath Pichincha caldera as indicated by geothermal fumaroles, steaming ground, hydrothermal explosion craters and neutral chloride outflow. A dacitic feeder-dike intrusion, which occured in 1999, disrupted the western part of the geothermal system, causing phreatic explosions, which eventually reached Quito. Studies are needed to assess the actual recovery of the hydrothermal system and its geothermal significance.

ILALO, located about 25 km SE of Quito, is a warm springs area at the IAV on the southern foothills of old, inactive andesitic Ilalo Volcano. This area was studied in the early 1980's by INE (Instituto Nacional de Energia, now defunct) for low-medium enthalpy geothermal resources. Spring water analysis are shown in table 1A and isotope data indicated a source from E. Results from surface studies were not encouraging due to low oil prices. It is likely that the Ilalo springs are distal diluted outflows of the high temperature geothermal system of Chacana caldera, located about 35 km to the E. The out flow is partly controlled by the regional WNW striking Antisana lineament. This fact should focus geothermal exploration on Chacana caldera as the heat source for Ilalo springs.

TUNGURAHUA, located 30 km SE of Ambato, is a young andesitic stratovolcano constructed above an older avalanched volcanic edifice of Late Pleistocene age, which in turn rests above the metamorphic basement of CR (Hall et al., 1999). NS-trending regional faults cut the area. Several hot springs, between 40 and 55°C (see table 1A), are situated on the N slope and on the foothills of the volcano, but it is not clear if they derive from a high temperature geothermal system or from heating of deep circulating groundwaters by hot magmatic fluids; hence, no reliable deep temperature can be obtained. At present, the volcano almost completed its tenth year of moderate to intense strombolian eruptive activity associated to the ascent of basaltic andesite magma. Nevertheles, despite the continous volcanic activity, the nature of the hot springs hasn´t changed yet.

SALINAS is located 15 km NNE of Guaranda, on Late Terciary volcanics (Zumbahua Fm.), which overly the Cretaceous basement of CO. Highly saline (due to evaporation) warm springs at 19 deg. C (see table 1A), asociated to recent faults, indicate the presence of a heat source at depth, which could consist of shallow dacitic stocks, likely related to the formation of a local high sulfidation epithermal Ag-Au system. Hydrotermal alteration is widespread, but not active. It is likely that the system has sealed up. Local agribusiness is very active in the area, which is located at an elevation of 2700 to 3200 masl. Production of geothermal heat for direct uses may have high demand.

GUAPÁN is located 20 km NNE of Cuenca, very close to Azogues. Several hot springs, with temperatures up to 49.6 °C and high solute concentrations (TDS = 10000 to 13000, De Grys, 1970, and IG/EPN – INGV, 2009, Table 1A), occur in Late Cretaceous and Miocene sediments on the E margin of the Cuenca Basin. No active or recent volcanism has been reported in the area, although shallow, late Tertiary intrusions are likely to exist at depth along regional faults. Thick, extensive travertine deposits are asociated with the springs, which are fault controlled along a WNW-strike; these have been lately lowering its discharge due to carbonate self- sealing. Geothermometry indicates deep temperatures up to 210 to 235 Deg. C. Guapan is a promising high temperature geothermal prospect, sited at a load centre, which should have high priority for exploration and development, although one foreseable problem to overcome is carbonate scaling.

SAN VICENTE is located in the Santa Elena peninsula, about 100 km W of Guayaquil. The springs are saline waters with temperatures up to 38 °C (Table 1A). They are related to recent faults, which cut the Mid -Late Terciary marine sedimentary sequence of the Progreso basin as well as the Cretaceous basement, made of ocean floor basalts. No recent volcanism is reported in the area and the water is likely to be heated up by normal geothermal gradient due to deep circulation. The waters are likely contaminated by sea water and by petroleum brines from nearby oilfields as indicated by a high methane content (IG/EPN-INGV, 2009), or could represent seepages along the accretionary prism. The spring waters are used for spas and mud baths. There are not enough data to assess a resource, but demand for direct use may be high due to fast development of the area.

PORTOVELO is located about 150 km S of Guayaquil at the Portovelo-Zaruma gold mine district on the western foothills of CO. Country rocks are Mid-Tertiary volcanics which were intruded by dioritic plutons about 15 my ago. The area is cut by active faults. Hot springs show temperatures between 30 and 57 °C (see Table 1A) and seem to pick up remnant heat through deep circulation. Waters are used for bathing purposes; direct use may be increased with the help of drilling.

ALCEDO is located on Isabela Island, in the Galápagos Archipelago. It shows extensive hydrothermal alteration, numerous explosion craters (at least seven), strong superheated fumaroles discharging vapor at 97 °C and a heat source related to a primary basaltic origin but also to shallow rhyolitic intrusions associated with explosive silicic volcanism of recent age (~ 120 ka Geist, 1994) like obsidian flows and rhyolitic plinian tephra. The area is situated on the SSW caldera structure, which might indicate good permeability at depth, were a shallow high-temperature water-dominated geothermal system is present. Empirical gas geothermometry indicates temperatures of 260 to 320 deg.C for this intracaldera reservoir, which is probably capable of producing up to 150 MWe (Goff et al, 2000). This spectacular geothermal prospect is located inside the Galápagos National Park , and any innitative to explore and exploit it must obey strict environmental regulations, if a geothermal permit is granted at all. Other limitations are the lack of any infrastructure, few distant power users without transmission line and scarce or no water for drilling.

4. GEOTHERMAL UTILIZATION

Today, utilization of geothermal resources in Ecuador is restricted to direct uses only, that is for bathing resorts, balneology and swimming pools. Lately, the first use of space heating at private Termas Papallacta Spa Resort Hotel has been commissioned, but data are not available yet. Also several projects for direct use in fish hatchery await funding for development. A summary of many, but not all, hot and warm springs used for swimming pools is shown in table 3/8, giving a total installed capacity of 5.157 MWt and an annual energy output of 102.401 TJ/yr, which is the same as for 2005 update.

5. DISCUSSION

Tables 1/8 to 8/8 show clearly that conventional energy generation by fossil fuels (44%) and hydro (51.7%), dominates by far the ecuadorean energy market, with a total installed capacity of 4557 MWe and a gross production of 18609 GWh/yr (CONELEC, 2009). They also show that, at present, other forms of energy production, i.e. nuclear and geothermal are non-existent and other renewables like wind energy are very small (2.42 MWe). In the future, the general trend is to favor hydro, with an increase in renewables and a substantial decrease in fossil fuel, which in turn favors geothermal energy development.

Table 3/8 shows the utilization of geothermal energy for direct use, without changes since the 2005 update. This information has to be taken as a minimum estimate for hot spring waters used for swimming pools. Inlet-temperature is a safe parameter, but outlet-temperature has been arbitrarily assumed to be 35°C if temperature is above 40°C, 20°C if it is between 30 and 40°C and 15°C if it less than 20°C. The average flow rate has been assumed to be 63% of the maximum flow rate, which is also arbitrary. The max. flow rate has been measured at the spring in most cases, but in others it has been estimated. This activity has been improving towards efficiency in last years, but is difficult to assess due to lack of data and specific studies.

Tables 2/8 and 4/8 are left blank because in Ecuador, there is no electricity production from geothermal and there are no heat pumps installed. Table 6/8 includes the first geothermal exploration drilling program ever undertaken in Ecuador. It is operated by MEER with a 1 MUSD budget for 2009 for four small diameter gradient holes to a total drilling of 2000m into the eastern lateral outflow of Chiles volcano at Tufiño – Chiles geothermal prospect. The first hole was successfully completed in May 2009 to a depth of 554 m into the upper conductive layer and the other holes shall be drilled until the end of this year. Some very shallow wells have been drilled in the last decades to obtain water for swimming pools, but data are scarce and wells are not included here as geothermal wells; most wells have been drilled to obtain water only for agricultural or industrial uses, without using any heat.

Allocated professional personnel to geothermal activities (Table 7/8) has increased substantially in the last year, mainly from the side of the government (MEER and CONELEC), Public Utilities (former ELECTROGUAYAS, now CELEC and universities in Quito (ESPE, EPN), although it is non existent in the private industry and Foreighn Aid Programs are in the making. One foreign consultant from INGV-Palermo/Italy has participated in the ELECTROGUAYAS Chacana Geothermal Project for the geochemical reconnaissance survey and report is due June 2009.

Table 8/8 shows that public investment has been allocated to geothermal activities in this last five year term (2005 to 2009) in the amount of 2.2 MUSD for research of the Tufiño, Chachimbiro and Chacana geothermal prospects. This has been possible due to the firm political decision of the present administration to explore and develop the geothermal resources in Ecuador.

General policies and planning regarding electrical energy are issued by the government through the Ministry of Electricity and Renewable Energy (MEER). The MEER coordinates the electric energy issues with CONELEC, which is in charge of the regulation of the sector, its electrification master plan, of supervising power generation projects, concessions/contracts for power generation, prices and environmental issues. One of the problems in the electricity market is the availability of energy, rather than the installed capacity, since the reservoirs for hydro generation are in some cases small and fossil fuels are expensive and not always at hand. This situation favours the demand of geothermal power as base load. The problem is temporarily solved by importing energy fron Colombia and Peru (about 500 GWh/yr or 650 MWe), but this tendency should reverse in the next years, with the commissioning of the new hydro projects under construction.

Any project to generate electricity, including geothermal, needs a contract/permit issued by CONELEC, which in turn demands a water-use permit from CNRH and an environmental permit from the Ministry of the Environment. According to the new Constitution 2008, energy in any form belongs to the state and its exploration and development is strictly regulated by the government., since energy is a strategic issue.

6. FUTURE DEVELOPMENT AND INSTALLATIONS

Since the government has taken the political decision to fund, explore and develop clean, indigenous, renewable energy resources, including geothermal energy, it is foreseeable that in the near future, say the next 5 to 10 years, Ecuador will have its first geothermal power plant. Direct uses will also be explored and developed, most probably by the tourist, agribusiness and fish- hatching sectors.

Due to higher oil prices and to locally and regionally increasing energy demand, geothermal energy uses can become cost-efficient in relation to conventional hydro, oil and gas, and to other renewable energy forms. Public investment plays now a key role in funding future geothermal enterprices for both, electric and direct uses.

Several regions in the country remain un-explored for geothermal resources, namely the sedimentary basins in the Costa, the back-arc volcanic chain with recently active alkalic volcanoes and the sedimentary basins in the Oriente, as well as the Galapagos Archipelago. This increases the exploration potential for geothermal resources in the country, in addition to the follow up exploration of the prospects cited above. Application of actual and future technology will allow to find hidden resources, those where geothermal evidence at surface is nil (Duffield and Sass, 2003) and approach EGS technologies as well. A good start will be to re-assess and update geothermal data nationwide and to produce both, the heat flow map and the geothermal map of Ecuador, as well as to get the necessary funding (public and private) to drill the most promising prospects and tap geothermal power in Ecuador.

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ANEXES (tables 1/8 – 8/8)

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 (as on Dec. 2008)	-----	----	2498	7104	2057	11293	----	----	2.42	211	4557	18609
Under construction in December 2009	----	----	150.6	793	1962	12042	----	----	----	----	2113	12835
Funds committed, but not yet under construction in December 2009	30	237	300	1580	1203	6121	----	----	7	18	1510	7719
Total projected use by 2015	30	237	2949	9477	5222	29456	----	----	9.4	229	8180	39163

Note: import of 650 MW from Colombia and Peru is not included in this table

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2009

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid (explain)
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Data for 2009 if available, otherwise for 2008. Please specify which.

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status 1)	Type of Unit 2)	Total Installed Capacity MWe*	Total Running Capacity MWe*	Annual Energy Produced 2009 3) GWh/yr	Total under Constr. or Planned MWe
Total									

* Installed capacity is maximum gross output of the plant; running capacity is the actual gross being produced.

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)
Baños Cuenca		B	8.000	73.000	35.000	-----	-----	1.272	5.040	25.261	0.629
Baños Tungurahua-	Virgen	B	5.120	53.000	35.000	-----	-----	0.386	3.226	7.659	0.629
	El Salado	B	5.000	44.300	35.000	-----	-----	0.195	3.150	3.864	0.628
	Palictahua	B	2.800	40.700	35.000	-----	-----	0.067	1.764	1.326	0.627
Chachimbiro-	Toma	B	1.500	58.000	35.000	-----	-----	0.144	0.945	2.867	0.631
	Pitzantzi	B	0.950	40.800	35.000	-----	-----	0.023	0.599	0.458	0.631
	Naugulví	B	2.000	52.000	35.000	-----	-----	0.142	1.260	2.825	0.631
Cununyacu-	Chimborazo	B	1.400	47.500	35.000	-----	-----	0.073	0.882	1.454	0.632
Guayllabamba-	Chimborazo	B	5.000	40.000	35.000	-----	-----	0.105	3.150	2.077	0.627
Ilaló-	Cununyacu	B	8.000	27.000	15.000	-----	-----	0.402	5.040	7.977	0.629
	Tingo	B	1.200	32.000	20.000	-----	-----	0.060	0.756	1.197	0.633
	San Antonio	B	12.000	35.500	20.000	-----	-----	0.778	7.560	15.456	0.630
	Ushimana	B	1.000	19.000	15.000	-----	-----	0.017	0.630	0.332	0.619
	Chunchi	B	2.000	29.500	15.000	-----	-----	0.121	1.260	2.410	0.632
	Ilaló	B	5.000	35.000	20.000	-----	-----	0.314	3.150	6.232	0.629
Papallacta-	Termas	B	1.100	53.000	35.000	-----	-----	0.083	0.693	1.645	0.628
	El Tambo	B	1.000	50.000	35.000	-----	-----	0.063	0.630	1.246	0.627
	Jamanco	B	2.000	66.000	35.000	-----	-----	0.259	1.260	5.152	0.631
	Cachiyacu	B	1.200	68.000	35.000	-----	-----	0.166	2.756	3.291	0.629
Portovelo	Río Amarillo	B	1.200	57.000	35.000	-----	-----	0.110	0.756	2.194	0.632
Tufiño	Aguas Hed.	B	3.000	53.000	35.000	-----	-----	0.226	1.890	4.487	0.630
San Vicente		B	2.000	38.000	20.000	-----	-----	0.151	1.260	2.991	0.628
TOTAL			72.470					5.157	47.657	102.401	

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. (^{o}C) - outlet temp. (^{o}C)] 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. (^{o}C) - outlet temp. (^{o}C)] 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]	5.157	102.401	0.629
Other Uses (specify)	-----	-----	----
Subtotal	5.157	102.401	0.629
Geothermal Heat Pumps	-----	-----	-----
TOTAL	5.157	102.401	0.629

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] (May 2009)	(all)				1 of 4*	0.55 of 2.0
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total					1	0.55

*geothermal gradient hole PGT-1 in Tufiño - Chiles geothermal prospect; funds commited for 4 gradient holes at Tufiño for total depth 2000 m

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 Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	---	---	2	---	---	---
2006	---	---	2	---	---	---
2007	2	---	2	---	---	---
2008	6	3	2	---	---	---
2009	10	6	3	0.3	---	---
Total	18	9	11	0.3	---	---

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	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	----	----	----	----	----	----
2000-2004	----	----	----	----	----	----
2005-2009	2.2	----	----	2.2	----	2.2