

Geothermal Power Generation in Italy 2005–2009 Update Report

Guido Cappetti, Paolo Romagnoli and Fabio Sabatelli

Enel Green Power, Via Andrea Pisano 120 - 56122 Pisa (Italy)

guido.cappetti@enel.com

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ABSTRACT

In Italy, the geothermal resources are mainly used for the purposes of generating electricity. An overview on the development of the activities carried out in the five-year period 2005- 2009 is presented in this paper.

All of the plants in operation are located in Tuscany, in the two “historical” areas of Larderello-Travale and Mount Amiata. In the year 2008, with the installed capacity of 810.5 MW (711 MW efficient capacity) the gross electricity generation reached 5.5 billion kWh and in 2009 two additional units were commissioned, increasing the capacity up to 842.5 MW

In the Larderello-Travale area the positive results of the deep drilling and of the reinjection programs have made it possible, notwithstanding the long and intensive exploitation history, to increase the steam production. Four additional units were thus installed in the period 2005-2009 with a total capacity of 100 MW, of which 52 MW represent a net capacity increase, while 48 MW replaced old units, decommissioned because obsolete. In the same area, a new deep exploration program (3D seismic surveys and 11 exploratory wells of 3000-4000 m) begun in 2004 was completed in 2008 with positive results, but the time-consuming authorization procedures have delayed the development programs.

In the Mount Amiata area, despite the huge potential of the deep reservoir, the pending acceptability problems from local communities have hindered further developments: no new wells have been drilled and no new power plant construction started.

In order to overcome these acceptability problems, an agreement was signed between Enel and Tuscany Region, which includes additional specific studies on environmental aspects related to geothermal activities.

In the period 2005–2008, twenty-three wells were drilled, totalling 54,500 meters, and 17 AMIS plants (the H₂S and Hg abatement technology developed by Enel) were installed and are currently in operation.

1. THE ELECTRICITY MARKET IN ITALY AND THE NEW COMPANY ENEL “GREEN POWER”

In accordance with the liberalization process of the electricity market in Italy, Enel was obliged to reduce its quota of electricity generation below 50% (it was 73% in 1998) and 15,057 MW of its generating capacity were sold to other operators in the period 2001-2003. As a consequence, several international competitors are now present in the Italian electricity market and Enel, which is still the main operator, has now a quota of about 30% of electricity generation.

From April 1st, 2004 the Italian Power Exchange has been operating and in the same year an independent private company, called TERNA, was established for the ownership and management of the national high voltage electric grid (transmission network).

In the year 2007 the electricity needs in Italy reached 360.2 billion kWh, with a domestic contribution of 87.2%, while a relevant 12.8% was imported.

The electricity generation capacity and production data in Italy as of 2007 are summarized in Table 1. As regards the 314 TWh of domestic electricity generation, 82.5% comes from fossil fuels, 12.2% from hydro and 5.3% from geothermal, biomass, wind and solar (*Figure 1*). Even if the contribution of geothermal electricity generation is only 1.8% of the whole Italian generation, it covers about 25% of the electricity needs in Tuscany, giving a substantial contribution to the green energy generation in this Region.

Specific policies for supporting the development of renewable resources have been adopted in Italy. As from the year 2001, all of the operators (importers and producers of electricity from non-renewable sources) have to supply a quota of their input into the grid from renewable sources within the following year. This quota was initially, i.e. from the year 2002, set at 2% of the total energy, produced or imported, exceeding 100 GWh (excluding cogeneration, auxiliary consumption and exports).

The conceived mechanism provides a great deal of flexibility: operators are allowed to meet their obligations either by generating directly or by purchasing from others some or all of the necessary “green” energy, or simply their rights (as in the spirit of the “Green Certificates”).

According to a Decree Law issued on January 2004, the initial quota of 2% was increased to 2.35% for the year 2005, to 2.7% for 2006 and to 3.05% for 2007 to keep up with international commitments for the CO₂ emission reduction. With a subsequent law of 2007, the quota were updated to 3.80% for 2007 and a yearly increase of 0.75% per year was fixed up to 2012, giving a final quota of 7.55% for this year.

The value of the “Green Certificates” was modified at the end of 2007, making it equal to the difference between 18 Eurocent/kWh and the average market price of the electricity; a multiplying coefficient (different for each renewable energy source; it is 0.9 for geothermal) has then to be applied to this difference. Small power plants (typically below 1 MW) are allowed a fixed price (again, differentiated by source; it is 20 Eurocent/kWh for geothermal). The calculation mechanism may be updated every three years.

“Green Certificates” are awarded to new power plants in operation after April 1999 and for a period that was initially

8 years and subsequently extended to 12 years; for plants in operation after January 2008 they are awarded for 15 years.

As in 2008 the average market price of the electricity was approximately 7 Eurocent/kWh, the value of the net kWh generated from new or recent geothermal power plants awarded with "Green Certificates" is around 17 Eurocent/kWh; this incentive makes it possible to proceed in Italy with the exploration, development and utilization of deep geothermal resources, up to 3500 – 4000 m depth, which require the drilling of very expensive wells.

State incentives for the direct use of heat from geothermal sources are also provided as tax exemption.

1.1 Enel Green Power

In response to the growing demand for renewable energy, recorded in recent years as a result of commitments signed by many governments aimed at reducing CO₂ emissions, a new company, Enel Green Power, fully owned by Enel Group, was established in December 2008.

This company draws its strength from Enel expertise and experience in geothermal, small-hydro, wind, biomass and solar power generation and is dedicated to developing and managing energy generation from renewable resources both in Italy and abroad (Europe and American continent).

At present, Enel Green Power operates in sixteen Countries and is the world leader in this sector, with 17.2 TWh produced (covering the energy consumption of 6.5 million families and avoiding 13 million tons of CO₂ emissions every year). The installed capacity is around 4500 MW and there are over 500 plants currently in operation or under construction around the world.

2. GEOTHERMAL POWER GENERATION: CURRENT STATUS AND DEVELOPMENTS

The historical trend of electricity generation from geothermal resources in Italy is given in *Figure 2*, where two different increase phases are shown: the first one in the period from the 1930s to the mid 1970s, related to the development of the shallow carbonate reservoirs, with well depths up to about 1000 m; the second one from the beginning of the 1980s up to now, when the fluid production has been increased thanks to the positive results of the deep drilling activity and to the artificial recharge of the depleted shallow reservoirs by means of the reinjection of the water and the condensed steam.

During the year 2008, with an installed capacity of 810.5 MW, the electricity gross generation has picked up to 5520 GWh. The complete list of the power plants in operation is given in Table 2; taking into account the real operating conditions of the plants in the different areas (pressure, temperature, non-condensable gas content in the steam), the total running capacity is 711 MW.

Two new 20 MW units (Sasso 2 and Nuova Lagoni Rossi that will replace the old 8 MW Lagoni Rossi plant) are currently under construction and will be commissioned in the year 2009, increasing the total installed capacity from 790.5 MW as of December 2004 to 842.5 MW as of December 2009 (Cappetti et al., 2005).

It is worth noticing that 4 new units were installed in the Larderello field in the period 2005-2009, with a total capacity of 100 MW, of which 52 MW represent a net capacity increase, while 48 MW replaced old units decommissioned because obsolete.

On the basis of the positive results of the deep exploration program, two additional 20 MW units (Nuova Radicondoli Unit 2 and Chiusdino 1) have been planned in Travale-Radicondoli area and their commissioning is foreseen in 2010-2011.

A picture of the 40 MW Nuova San Martino power plant, commissioned in 2005, is given in *Figure 3*.



Figure 3: Nuova San Martino (40 MW) power plant

All of the power plants are remotely controlled and operated from a *Remote Control Station* located in Larderello, where 12 people work in round the clock shifts (24/7), thus ensuring a continuous overseeing. In this way, every plant operating parameter can be monitored and analyzed and it is also possible to shut down and restart any unit from the Remote Station. This solution has allowed a better plant operation, at the same time dramatically reducing operating costs.

2.1 The innovative plant for Hg and H₂S abatement (AMIS)

Enel developed and patented a proprietary technology, named "AMIS", for the abatement of hydrogen sulfide and mercury emissions, particularly suited to the characteristics of Italian geothermal power plants (featuring a high NCG content, equipped with direct-contact condensers and with unattended operation). Mercury removal is obtained by absorption on specific sorbents, while H₂S is catalitically oxidized to SO₂ and then scrubbed using geothermal water from the cooling towers. This solution allows an unattended operation, while all the operating parameters are monitored from the Remote Station (Sabatelli et al., 2009).

The first commercial AMIS installation was started up at the beginning of 2002 in the Mt. Amiata area, where environmental concerns are of foremost importance. As of May 2009, 19 AMIS plants are in operation and 3 are under construction; once completed, the gaseous effluents of 23 out of the 33 geothermal units in operation at the end of 2009 will be abated, corresponding to over 80% of the total emissions. Untreated power plants are more remotely located or have lower H₂S emissions, so that AMIS installation is not foreseen for them in the next future. The installation of the AMIS plants was carried out by Enel on a voluntary basis with a total investment of about US\$ 50 million, as no air quality standards were violated by geothermal emissions, thus demonstrating Enel commitment to environmental issues. A picture of an AMIS plant is shown in *Figure 4*.



Figure 4: AMIS plant

The operational experience so far obtained allowed a better understanding of the performances of AMIS plants, as well as of the sulfur chemistry within the process; at the same time, it suggested various technical improvements, some of which have already been applied, while others are still in progress.

In 2008, the averaged availability of AMIS plants (hours of operation/hours of operation of the associated power plant) exceeded 90%, with only 1-2 outages per thousand of operating hours.

3. GEOTHERMAL FIELDS UPDATE

All of the Italian geothermal fields in operation for electricity generation are located in Tuscany (*Figure 5*): Larderello, Travale/Radicondoli, Bagnore and Piancastagnaio (the two latter being located in the Mt. Amiata area).

The activities carried out over the last five years have been concentrated mainly in the Larderello and Travale/Radicondoli areas, because serious acceptability problems from local communities have hindered further developments in the Mt. Amiata area, where the high potential deep reservoir could be further exploited.

3.1 Larderello

The explored area is about 250 km², where 200 wells produce superheated steam at pressure between 2 and 18 bars and temperature ranging from 150°C to 270°C. The non-condensable gas content ranges from 1 to 15% by weight. The installed capacity is 594.5 MW as of December 2009, with 22 units in operation.

Since the late 1970s, reinjection and deep exploration programs were started in this area with the aim of sustaining/increasing steam production. The reinjection of the steam condensate back into the shallow carbonate reservoir formation has been highly beneficial, especially in the most depleted area (Valle Secolo) and made it possible to increase the reservoir pressure and, accordingly, the steam production (Cappetti et al., 1995).

The deep exploration program showed the presence of permeable layers within the *Metamorphic Basement*, up to 3000 - 4000 m depth, with reservoir pressure and temperature increasing with depth up to 7 MPa and 350°C (Barelli et al., 1995, 2000; Bertani et al., 1995; Cameli et al., 2000).

The two strategies made it possible not only to sustain, but also to increase the steam production in the areas under

exploitation for several years and to install new power plants.

3.2 Travale/Radicondoli

The explored area covers approximately 50 km²; 27 wells produce superheated steam at pressure ranging from 8 to 20 bars and temperature of 190-250°C. The non-condensable gas content is in the range of 4 - 8% by weight. The installed capacity is 160 MW with 6 units in operation. Two additional 20 MW units are planned and the commissioning is foreseen in 2010-2011.

The deep exploration showed also in this area the presence of permeable layers within the *Metamorphic Basement*, which resulted at the same depths and with the same reservoir temperature and pressure as in the Larderello area. Moreover, some of the deep wells (at depths of about 4000 m) showed the presence of productive layers also in the *Granite* underlying the *Metamorphic Basement*.

The production from the *Granite* formation has opened new perspectives for the deep exploration and development programs in this area.

3.3 The deep exploration program in the Larderello - Travale/Radicondoli area

It must be pointed out that the deep drilling activity proved that the two old and shallow fields of Larderello and Travale/Radicondoli represent the “outcropping” of a unique, wide and deep (3000-4000 m) geothermal system, with an extension of about 400 km². At a depth of about 3000 m, the same temperature and reservoir pressure was found (300-350°C and 6-7 MPa) both inside the field and in the marginal areas.

On the basis of the positive deep drilling results, a new deep exploration program was implemented in the period 2004-2008 in order to verify the possibility of increasing further the steam production from the deep layers of the Larderello-Travale/Radicondoli geothermal system (Cappetti et al., 2005).

This program included 3D seismic surveys in some selected areas and the drilling of exploratory wells.

An accurate joint interpretation of the well data and of the seismic surveys evidenced that a marker, known in literature as “H” horizon, is the main potential drilling target. It generally corresponds to the metamorphic aureole produced by the Pliocene granitic intrusions and is very often associated with the presence of fractured and productive levels. Its permeability seems to be related with the granite emplacement and the intrusions themselves can be productive, since they are locally affected by fractures.

The amplitude analysis carried out on the “H” marker signals allowed the identification of potential drilling targets; 11 directional exploratory wells were drilled in order to reach these 3D seismic targets and they showed different productivity values. In fact, the relationship between the amplitudes of the seismic signal and the degree of permeability/productivity is difficult to ascertain and it seems to vary according to the areas. The best results were obtained in the Radicondoli/Travale area, where the deep wells have clearly shown the presence of high productivity, fractured layers in the bottom section of the H horizon (Fiordelisi et al., 2005; Casini et al., 2010).

3.4 Mount Amiata

Two geothermal fields are located in this area: *Bagnore* and *Piancastagnaio*. They were discovered between the late 1950s and the early 1960s, with wells producing steam from the shallow *carbonate reservoir*. In the late 1970s, a deep exploration program was begun and the results were very successful in both of these fields, revealing the presence of fractured layers at depths ranging from 2500 to 4000 m inside the *Metamorphic Basement* underlying the shallow carbonate reservoir (Bertini et al., 1995). This deep reservoir is *water-dominated*, with a pressure of around 200 bars and a temperature of 300-350°C at 3000 m depth (Bertini et al., 1995).

The produced fluid is a two-phase mixture that is separated at wellhead at 20 bars; the non-condensable gas content in the steam ranges from 6 to 8% by weight. Higher values occur in the steam produced from the shallow carbonate reservoir that feeds a back-pressure unit and is condensed downstream to supply heat for a large greenhouse complex in Piancastagnaio.

As of December 2009, the total installed capacity is 88 MW, with 5 units on line. The picture of the two 20 MW Piancastagnaio 4 and 5 plants is given in *Figure 6*.



Figure 6: Piancastagnaio 4 and 5 power plants in Mt. Amiata area

The presence in this area of a high potential deep reservoir has been proved, but serious acceptability problems with the local communities have hindered further developments over the last ten years.

4. DRILLING

In the period 2005 - 2008 a total of 23 wells were drilled in the Larderello - Travale/Radicoindoli area, for a total drilled depth of 54.5 km. Ten of these wells are relevant to the deep exploration program (three of these wells are deeper than 4,000 m), other ten wells are relevant to the maintenance and development programs and three wells are relevant to the reinjection/injection program.

No drilling activity was performed in the Mount Amiata area due to the above mentioned acceptability problems with the local communities.

The summary of the drilling activity is given in Table 6.

5. PERSONNEL AND INVESTMENTS

The number of professional personnel allocated to geothermal activities is given in Table 7.

The overall investments are shown in Table 8; the values are lower than in the previous five-year period due to the

delay of development projects caused by the already mentioned environmental and acceptability problems.

6. CONCLUSIONS AND FUTURE PROSPECTS

In Italy, the liberalization of the electricity market has been already completed and several international competitors are now present. Enel is still the main operator with a quota of about 30% of electricity generation.

In response to the growing demand for renewable energy a new company, Enel Green Power, fully owned by Enel Group, was established in December 2008 with the aim of developing and managing the energy generation from renewable resources both in Italy and abroad. At present, this company is the world leader in this sector, with 17.2 TWh/yr produced in sixteen countries of Europe and American continent.

As far as geothermal development is concerned, the incentives introduced in Italy over the last few years (Green Certificates) allowed a further extension of the activities aimed at exploring and developing the deep-seated geothermal resources, with well depths up to 4000 m.

In the shallow and most depleted areas of the Larderello field, the reinjection strategy led to an increase in steam production.

Two units were installed in 2005 and two more units will be commissioned in the year 2009, with a total capacity of 100 MW, of which 52 MW are a net increase of capacity, while 48 MW replaced old units decommissioned because obsolete.

The total installed capacity as of December 2008 was 810.5 MW and the gross electricity generation picked up to the value of 5,520 GWh/y, which represents 25% of the electricity needs of Tuscany, the region where all geothermal fields in operation are located. Two additional units are under construction and the total installed capacity will reach 842.5 MW by the end of 2009.

A deep exploration program including 3D seismic surveys and eleven exploratory wells 3000-4000 m deep was completed in the Larderello-Travale/Radicoindoli area to verify the possibility of a further increase of steam production from the deeper part of the reservoir. The results have been very positive, but the strong interaction occurring between geothermal activities and territory, taking into account that we operate in Tuscany, has placed serious hindrance to the development of new projects.

Aiming at the retrieval of a constructive and mutually beneficial relation with the territory, Enel has set going a number of initiatives with the intent of achieving a reduction of environmental drawbacks and an increase of acceptability. New design solutions have been envisaged to reduce the noise and visual impact of drilling pads, gathering systems and power plants.

An innovative plant for the abatement of mercury and hydrogen sulfide (called AMIS) was designed by Enel and 20 abatement plants were installed and are now in operation.

On the basis of the programs already in progress, an increase of 80 MW of the installed capacity for the period 2010-2015 can be regarded as a reasonable target.

TABLE 1: PRESENT AND PLANNED PRODUCTION OF ELECTRICITY (Installed capacity)

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (Wind, Solar, Biomass and Waste)		Total	
	Capacity MWe	Gross Prod. GWh/y	Capacity MWe	Gross Prod. GWh/y	Capacity MWe	Gross Prod. GWh/y						
In operation												
In December 2007	810.5	5569	68005	258811	23409	38481	—	—	4138*	11026	96362	313887
In December 2009	842.5											
Total projected use by 2015	922.5											

* This value is the Efficient Capacity

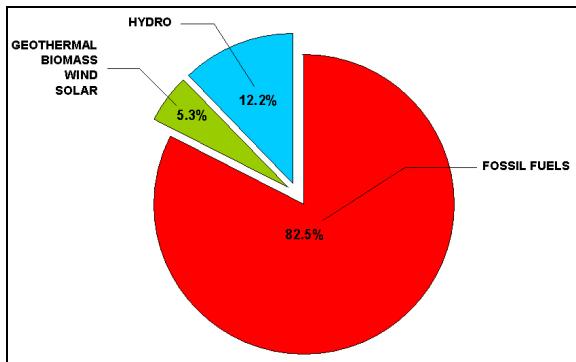


Figure 1: Electricity Generation in Italy (2007)

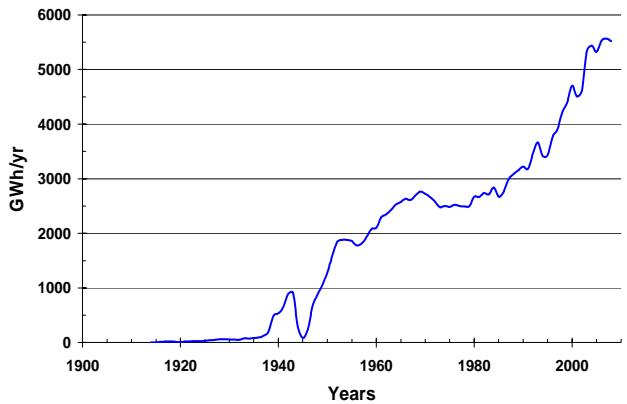


Figure 2: Yearly geothermal power generation

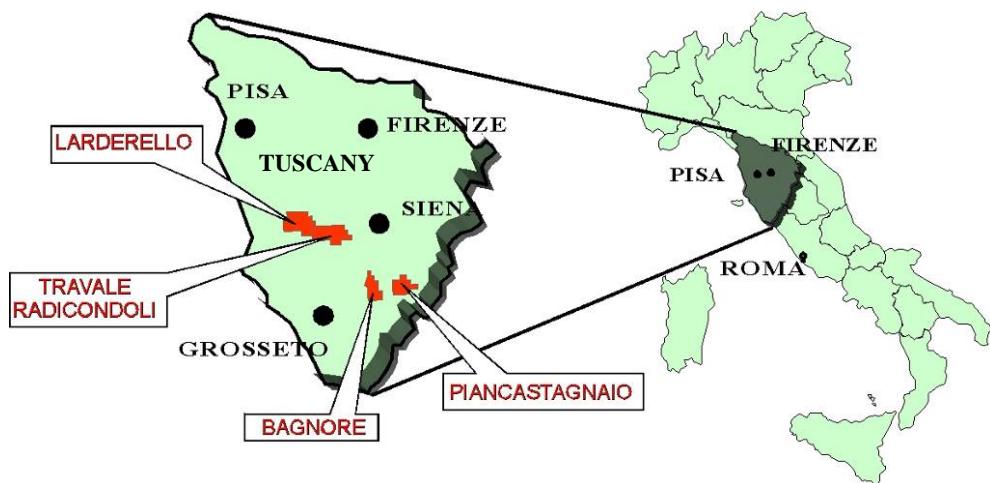


Figure 5: Location of the geothermal fields in Italy

TABLE 2: UTILISATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2008

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.
 2) 1F = Single Flash D* = Steam with entrained water separated at wellhead
 2F = Double Flash B = Binary (Rankine Cycle)
 D = Dry Steam

Locality	Power Plant Name	Year Commissioned	No. of Units	Status ¹⁾	Type of Unit ²⁾	Unit Rating	Total Installed Cap.	Annual Energy Produced 2008 GWh/yr	Total under Constr. or Planned
						MW _e	MW _e		MW _e
<u>Larderello</u>	Valle Secolo	1991	2		D	60	120	893	
	Farinello	1995	1		D	60	60	368.5	
	Nuova Larderello	2005	1		D	20	20	126.9	
	Nuova Gabbro	2002	1		D	20	20	160.6	
	Nuova Castelnuovo	2000	1		D	14.5	14.5	122.3	
	Nuova Serrazzano	2002	1		D	60	60	272.3	
	Nuova Sasso	1996	1		D	20	20	126.5	
	Sasso 2 (*)								20
	Le Prata	1996	1		D	20	20	126.7	
	Nuova Monterotondo	2002	1		D	10	10	63.5	
	Nuova San Martino	2005	1		D	40	40	332.5	
	Nuova Lago	2002	1		D	10	10	86.1	
	Lagoni Rossi 3	1981	1		D	8	8	40.7	
	Nuova Lagoni Rossi (*)								20
	Cornia 2	1994	1		D	20	20	121.1	
	Nuova Molinetto	2002	1		D	20	20	132.3	
	Carboli 1	1998	1		D	20	20	96.7	
	Carboli 2	1997	1		D	20	20	125.6	
	Selva	1997	1		D	20	20	145.6	
	Monteverdi 1	1997	1		D	20	20	108.3	
	Monteverdi 2	1997	1		D	20	20	132.7	
	Sesta	2002	1		D	20	20	84.4	
SUBTOTAL			21				562.5	3666.3	40
Travale-Radicondoli									
	Nuova Radicondoli	2002	1		D	40	40	300	
	Nuova Radicondoli GR 2								20
	Pianacce	1987	1		D	20	20	116.9	
	Rancia	1986	1		D	20	20	157.7	
	Rancia 2	1988	1		D	20	20	156.5	
	Travale 3	2000	1		D	20	20	131.8	
	Travale 4	2002	1		D	40	40	346.1	
	Chiusdino 1								20
SUBTOTAL			6				160	1208.9	40
Mt. Amiata									
	Bagnore 3	1998	1		1F	20	20	169.7	
	Bagnore 4								40
	Piancastagnaio 2	1969	1		D	8	8	30.2	
	Piancastagnaio 3	1990	1		D*	20	20	160.4	
	Piancastagnaio 4	1991	1		D*	20	20	139.1	
	Piancastagnaio 5	1994	1		D*	20	20	145.3	
SUBTOTAL			5				88	644.7	40
TOTAL			32				810.5	5520	120

(*) The two plants Sasso 2 and Nuova Lagoni Rossi are under construction and will be commissioned in 2009. Nuova Lagoni Rossi will replace the old unit Lagoni Rossi 3 and consequently the units in operation will be 33 and the installed capacity will increase to 842.5 MW as of December 2009.

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF

GEOTHERMAL RESOURCES FROM JANUARY 1, 2005 TO DECEMBER 31, 2008

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration	(all)	10				33.8
Production	>150° C	10				19.5
	150-100° C					
	<100° C					
Injection	(all)	3				1.2
Total		23				54.5

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

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

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	15	—	10	—	—	58
2006	15	—	10	—	—	56
2007	15	—	10	—	—	58
2008	15	—	10	—	—	68
2009	15	—	10	—	—	70
Total	75	—	50	—	—	310

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

Period	Research & Development Incl. Surface Explor. & Exploration Drilling Million US\$	Field Development Including Production Drilling & Surface Equipment Million US\$	Utilisation		Funding Type	
			Direct Million US\$	Electrical Million US\$	Private %	Public %
2001-2004	24	116		236	100	
2005-2009	88	94		181	100	

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