Presented at Short Course on Geothermal Development in Central America – Resource Assessment and Environmental Management, organized by UNU-GTP and LaGeo, in San Salvador, El Salvador, 25 November – 1 December, 2007.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

LaGeo S.A. de C.V.

REVIEW ON ESTIMATED POWER POTENTIAL AND REALISTIC DEVELOPMENT OF GEOTHERMAL RESOURCES IN LEADING GEOTHERMAL COUNTRIES

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ABSTRACT

A review of the estimated world geothermal assessment reveals that the most likely geothermal potential of the world for electricity generation is 210 GWe, with a minimum and maximum range from 50 to 2,841 GWe. If the maximum world potential of 2,841 GWe could be fully harnessed, this would translate to roughly 76 percent the total installed capacity in the world. To date, only 8.9 GWe of installed capacity is attributed to geothermal, representing an insignificant amount of 0.3 % of the total world potential. Further review of the geothermal development in leading geothermal countries of the world indicates various reasons for the slow phase and apparent lack of interest in some countries to enhance the development of this indigenous resource. The Philippines appears to have taken the higher risk of accelerating its geothermal development in response to long term uncertainty in the supply of fossil fuels, and in further securing its independence from imported energy sources. New Zealand considers that their policy on more sustainable management of the country's resources as a factor in hesitating to develop many areas in their country. Indonesia, which has the biggest potential in the world, has been lagging behind its target, brought about by an impasse between the government's desire to make the geothermal electricity price affordable to average consumers and the desire of foreign investors to ensure recovery of their investments. In some cases, financial crises and economic downturns lead to the deferment of many programs subsequently stunting the growth of the industry. Mexico and the US led in allowing market driven economy to govern the phasing of their geothermal development. Japan's geothermal development is concentrated only on existing operating fields, hindered by uncertainty on new discovery and long gestation period. Iceland was a pioneer in direct use of geothermal energy but has during the last decade rapidly developed its high temperature fields for power generation. The installed capacity by the end of 2007 is close 500 MWe or tenfold of what it was ten years ago. This pace of geothermal power development in Iceland is expected to continue for the next five years at least.

1. INTRODUCTION

The world consumption for energy is projected to increase by 71 percent from 1994 to 2030, growing by 2.6 percent annually for the same period. This projected growth is almost 60 percent higher than those experienced from 1990-2003 (Figure 1). The world electricity consumption is projected to double by the year 2030 at 30,000 Billion kilowatt-hours from 2003, at a slightly lower growth rate of 3.8 percent compared to 4.3 percent from 1980-2003 (Figure 2). According to the World Energy Agency, approximately 80 percent of the world primary consumption is being provided by fossil fuels, with 35 percent oil, 23 percent coal and 22 percent natural gas (Fridleifsson, 2006). Considering the 2003 consumption of 82,595 Thousand Barrels Per Day of oil and the estimated oil reserves as of 2006 at 1,292.935 billion barrels by Oil and Gas Journal (IEA, 2007b), the oil reserves may be depleted in 42 years if no new additional discoveries are made**.**

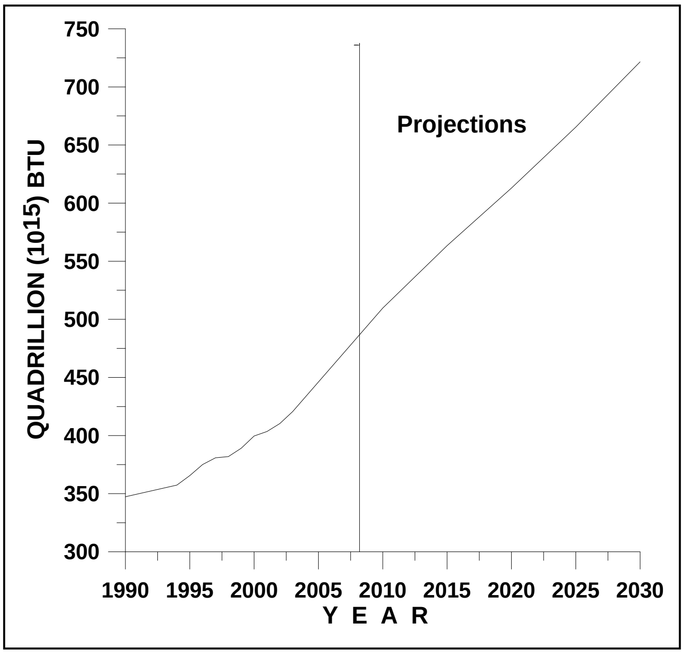

FIGURE 1: Total world annual primary energy consumption. (From International Energy Annual, 2007c)

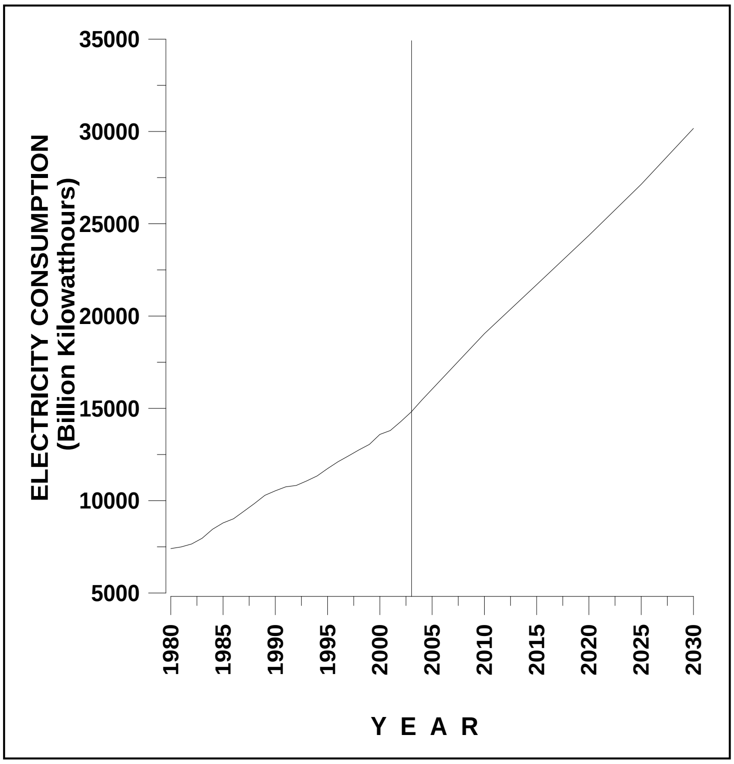

FIGURE 2: Total world annual electricity consumption. (From International Energy Annual, 2007a)

The major disruptions in the world oil supply that occurred during the Arab-Israeli war (1973-1974), Iranian Revolution (1978-1979), Iraq-Iran War (1980-1981) and the Gulf war (1990-1991) had largely affected the economic growth of many countries. The uncertainty on the stable supply of these fuels still lingers to date because of the ongoing troubles in the Middle East particularly in Iraq and Afghanistan which started in the aftermath of the attack on the World Trade Centre in New York. With the volatile prices of these traditional energy sources, majority of people living within the poverty line in developing countries cannot afford to access it in the future. In the World Summit for Sustainable Development (WSSD) held in Johannesburg, South Africa in 2002, the importance of energy in the economy and the social well being of mankind were underscored which led to the formulation of the Johannesburg Plan of Implementation emphasizing that access to reliable and affordable energy services facilitates the eradication of poverty (WEA, 2004).

The above-mentioned events, forecasts and prevailing sentiments bring to the fore the crucial role of renewable sources of energy which includes wind, solar, hydro, biomass and geothermal. Countries in Asia, like the Philippines and Indonesia, and in Central America are fortunate to have been endowed with geothermal resources, because of their strategic location within the high-heat flow region that characterizes the Pacific Ring of Fire. The responsibility to tap these indigenous resources rests solely on each respective government and other stakeholders like the environmentalists, financing institutions and the international community. The economic benefits derived from this indigenous source of energy by the Philippines, which has very limited petroleum deposits, can be easily demonstrated by the country's foreign currency savings from 1977 to 2005 in terms of its displacement on imported oil. These savings amounted to 7.075 billion dollars.

Iceland´s economy continues to be propelled by its inexpensive and efficient use of geothermal energy, using both the high and low temperature geothermal resources, which supply about 54 percent of its primary energy requirement (Ragnarsson, 2005). Other leading geothermal countries like the USA, New Zealand, Italy and Japan develop their geothermal resources even though they comprise a measly fraction of their energy mix to reduce their dependence on fossil fuels and as part of their commitment to the Kyoto protocol in offsetting and reducing their contribution on greenhouse gas emission. This paper presents an overview of the geothermal potential and how development took place around the world especially in leading geothermal countries to promote further geothermal development in Central America and in other countries.

2. WORLD GEOTHERMAL ENERGY POTENTIAL

The general estimate on the potential of geothermal energy in the world has been published by various workers showing wide disparities in their results (Table 1). Two of the main techniques involve the following considerations:

- Estimation of the total heat stored in the rock down to 3 km (EPRI,1978)
- Empirical correlation of number of volcanoes with direct link to geothermal fields for power generation (Stefansson, 2005)

The first method deals with the volumetric estimation of the total stored heat in a given volume of rock and is applied generally in assessing the reserves of most geothermal resources. Electric Power Research Institute (EPRI, 1978) has estimated that the heat stored in the rocks down to 3 km depth below the continents is 12 x 10^{12} GWh_{th} or 43 x 10^{6} EJ. This amount of heat represents the total energy consumption by mankind for 100,000 years based on the world consumption of 420 EJ per year or 55,800 years based on the projected annual world consumption in 2030 (Figure 1).

The second method which was adopted by Stefansson (2005) deals with the empirical correlation of the existence of active volcanoes along the plate boundary regions of the earth which have direct link to most

geothermal fields for electrical generation., i.e., in the USA, Iceland, Philippines, Indonesia, New Zealand, Japan, Mexico and Italy. From this approach, the most likely geothermal potential of the world for electricity generation is 210 GWe, with a minimum and maximum range from 50 to 2000 GWe. If the maximum world potential of 2,841 GWe could be fully harnessed based on Stefansson (2000), this would translate to roughly 76 percent the total installed capacity in the world at 3,736.32 GWe (IEA, 2007). The lower limit was calculated based on the results of the studies conducted by Steingrimsson et al. (1991) showing that the volumetric estimates are usually 4-5 times higher than the numerical simulation modelling results. The maximum range represents the hidden resources which are found to be 5-10 times those of the identified resources based on studies in the USA and Iceland (Stefansson, 2005).

TABLE 1: Estimates of the world's geothermal potential for electricity generation based on various workers (After Bertani, 2003)

Authors	Useful Accessible Resource Base	GWe	[1]Installed Capacity (%)	[2]Years To Develop	Comments
Fridleifsson, 1999	12,000 TWh/y	1,522	0.58	7,424	
Gawell, 1999	35-72 GWe	same	12.4-25.43	171-351	Present Technology
Gawell, 1999	66-138 GWe	same	6.4-13.48	322-673	EGS/Drilling improvements
Stefansson, 2000	22,400 TWh/y	2,841	0.31	13,859	
Stefansson, 2002	167 EJ/yr	588	1.51	2,868	Energy Conversion to power @10%
Cataldi, 1999	123 EJ/yr	433	2.06	2,112	Reserve on land, Energy conversion to power @10%
Stefansson, 2005	50-2000 GWe	same	0.45-17.80	244-9756	

[1] *Percentage of the installed capacity with respect to the estimated world potential*
[2] *Number of years required to develop the estimated world potential based on annual growth rate*

3. GEOTHERMAL DEVELOPMENT IN LEADING GEOTHERMAL COUNTRIES

The eight leading geothermal countries contribute 93 percent of the total geothermal installed capacity in the world (Table 2). The development rates in these countries vary significantly with the Philippines leading the annual absolute capacity increase in the last 15 years, increasing by 69 MWe per year. Iceland leads the group in terms of percentage increase at 41.5 percent but is only adding capacity at an annual rate of 18.5 MW. Each country therefore deals differently with their respective energy needs and set out policies based on many considerations. Indonesia is the only country so far that has shown remarkable increase both in the absolute and percentage annual capacity growth at 43 MWe and 30 percent respectively. However, its total installed capacity is only 41 percent of that of the Philippines. Like Iceland and Indonesia, the development in the Central American region is also in double digit figure at 15 percent, and could rapidly increase with the concerted efforts by the member countries. While each country and its geothermal resources are unique due to their political structure; economic status, environmental setting, geographical location and accomplishments from these leading geothermal countries should provide the direction on how other countries could pursue their geothermal objectives.

Comparing the total installed capacity at 8.9 GWe shown in Table 2 and the maximum geothermal potential of the world at 2,841 GWe shown in Table 1; we can conclude that only 0.31 percent of the total geothermal potential estimates are currently used. With the current development rate of 0.205 GWe per annum, it will take 245 years to fully harness the minimum geothermal potential of the world and about 13,859 years for the maximum potential of the identified resources. This shows that there is a lot of space for the geothermal community to maximize fully the benefits of this indigenous energy.

TABLE 2: World geothermal installed capacity, MWe (IGA, 2005)

Country	1990	1995	2000	2005	AAI* (MWe)	AAI (%)
USA	2774.60	2816.70	2228.00	2544	63.2	2.8**
Philippines	891.00	1227.00	1909.00	1931	69.3	7.8
Mexico	700.00	753.00	755.00	953	58.9	2.4
Indonesia	144.75	309.75	589.50	797	43.5	30.0
Italy	545.00	631.70	785.00	790	16.3	3.00
Japan	214.60	413.71	546.90	535	21.4	10.0
New Zealand	283.20	286.00	437.00	435	10.1	3.6
Iceland	44.60	50.00	170.00	202	18.5	41.5
Central America	130.00	263.40	406.90	424	19.6	15.1
Total	**5831.72**	**6833.38**	**7974.06**	**8912**	**205.4**	**3.5**

* AAI= Average Annual Installation (1990-2005)
**Ave: Year 2000- 2005

3.1 The USA

The United States is the world leader in geothermal development, with an installed capacity of 2,544 MWe in 2005. The total identified potential for electrical production, estimated by the United States Geological Survey, stands at 22,990 MWe (Muffler, 1979). A recent evaluation of potential in just California and Nevada by GeothermEx, Inc. (Lovekin, 2004) places the most likely combined total for those two states at 6,200 MWe, equivalent to three times the existing capacity. The total installed capacity is barely 11 percent of the country's total potential, and only 0.27 percent of the total existing generating capacity at 1,000,000 MWe or 1 TW, and 0.48 percent of the total generation mix (Lund et al., 2005 and Tester, 2007). Most of the geothermal installations in the US are located in the states of California and Nevada, where geothermal electric generation accounts for 6 percent in California. In the Big Island of Hawaii, geothermal electricity contributes significantly at 25 percent of the total requirements.

The most impressive geothermal growth in the US occurred in the 80's where a total of 1900 MW were added to the grid (Figure 3). The levelling of the growth from 2000 onwards was brought about by the reduction in field capacity at the Geysers (454 MW) due to reservoir depletion and the retirement of some plants. Additional capacities are being restored through the injection of effluents,

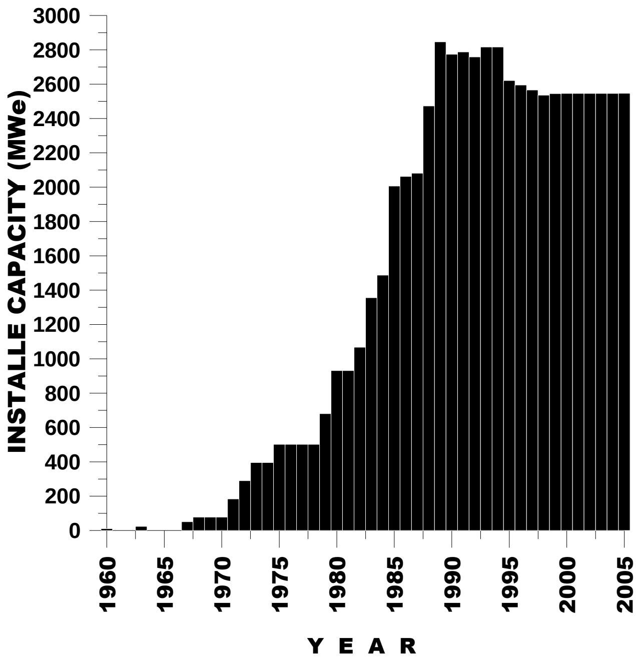

FIGURE 3: Total annual installed capacity in the US.

resulting in the restoration of 77 MW and possible addition of new power plants in the abandoned areas at 100 MW (Dellinger, 2004; GRC, 2003).

To promote the use of renewable energy, Renewable Portfolio Standards in a number of western states had been passed with the aim of significantly creating an impact on renewable development in general and increased interest in geothermal exploration and development in particular. This market-driven policy ensures that a minimum amount of renewable energy is included in the portfolio of electricity resources serving a state (Lippman, 2006). A production tax credit was also passed by Congress and signed into law in 2004 providing for a 1.8 cent per kilowatt hour credit, greatly improving the competitiveness of geothermal against fossil fuel generation (Gawell, 2004). The government also provides support for research and development of geothermal resources through cost sharing with industry and through research being conducted at a number of the national laboratories. Ongoing efforts are directed at Enhanced Geothermal System, downhole diagnostics, enhanced evaporative cooling, mixed binary working fluids, corrosion resistant coatings and co-production of minerals. An EGS is defined broadly as engineered reservoirs that have been stimulated to emulate the production properties of a high grade commercial hydrothermal resource. This could be considered the technology of the future that would allow many geothermal resources around the world, which could not be presently developed because of lack of permeability, to be engineered to attain commercial level for production. The USDOE is also funding a number of state programs aimed at removing barriers to geothermal development.

The projection up to 2010 is that there would be an additional 632 MWe capacity if all the planned new capacity comes on-line; representing an average annual increase of 18 per cent, well above the growth rate in the last 5 years. More likely growth will still occur in the Western states of California, Nevada, Idaho, Utah and Oregon. When the recent report on EGS by Tester (2006) is considered, the potential for tapping geothermal heat in the US could reach 100,000 MW or more by 2050.

3.2 The Philippines

The Philippines remains the second largest producer of geothermal energy in the world with an installed capacity of 2,027 MW (Figure 4). Table 2 shows that since 1990, the Philippines ranks first in building power plants on average annual basis. Disregarding the years where no power plants were being built, the Philippines was building power plants from 1977-1984 at 127 MW per year and from 1993-1999 at 170 MW per year. A total of 658 wells were drilled in the country in its quest for maximum development of geothermal resources (Figure 5). This unparalleled growth in development has been attributed to many factors. Firstly, to the impetus placed by the government in searching and developing indigenous sources of energy to reduce the country's dependence on imported oil. Secondly, was the strategic location of the Philippine archipelago; along the 40,000 km stretch of the Pacific Ring of Fire, a zone of frequent earthquakes and volcanic eruptions along the basin of the Pacific Ocean. Third, but not the least, was

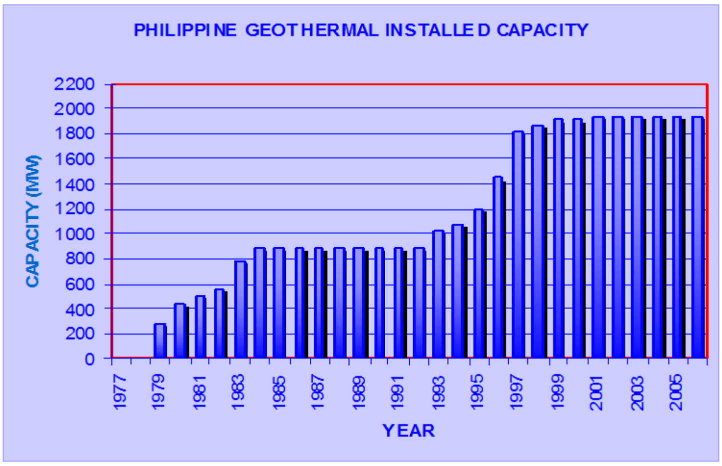

Figure 4: Total annual installed capacity in the Philippines. (After Sarmiento, 2007b)

the bold and aggressive strategies adopted by the government in putting more risk capital by fast-tracking the completion of geothermal projects (Alcaraz and Datuin, 1981; Sarmiento and Bjornsson, 2007).

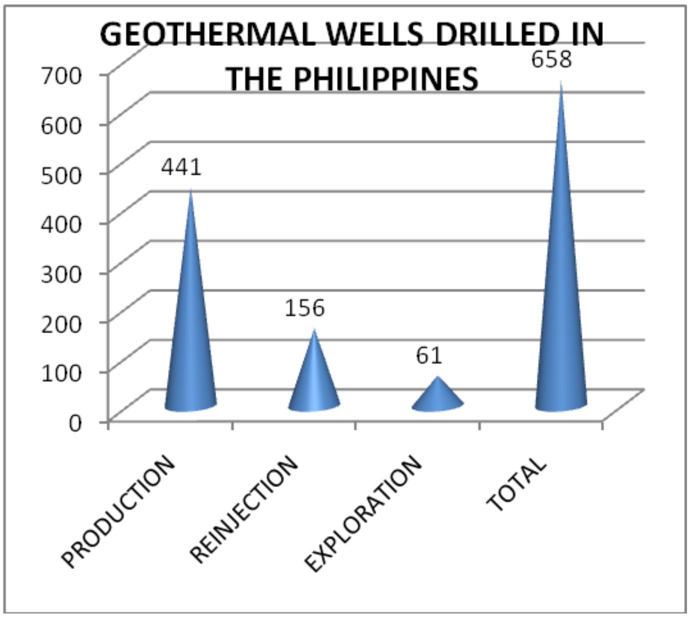

FIGURE 5: Total number of geothermal wells drilled in the Philippines as of 2005 (After Sarmiento, 2007b).

Geothermal development in the Philippines is a lasting legacy of the geothermal pioneers in the energy industry of the country. Alcaraz (1976) estimated that the Philippines geothermal potential of $2x10^6$ MW-century is of magnitude that could be harnessed reliably to contribute significantly in the country's energy requirement. The estimate was based on the stored heat in 25 identified volcanic centres that are distributed throughout the country with associated thermal surface manifestations. If all this potential could be harnessed by current technology, this power is good for 200,000 MW for 1000 years. To date, the installed capacity is only 42.3 per cent of the identified resources of 4,790 MWe. But geothermal already forms part of the mainstream sources of energy contributing 12 percent in the total installed power capacity and 19 percent in the total electricity generation mix (Figure 6).

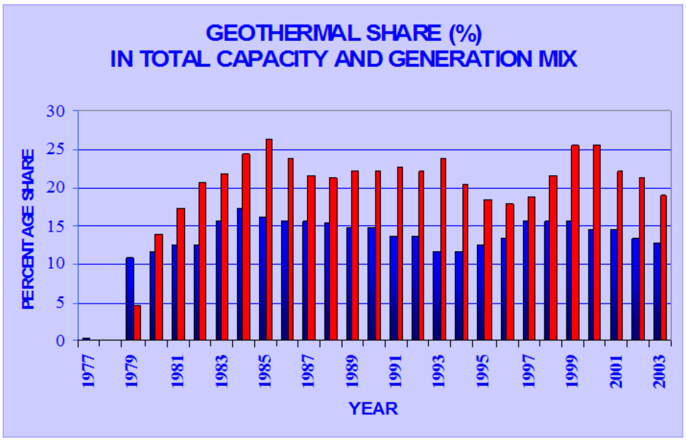

Figure 6: Annual mix in the installed capacity and generation mix from the Philippines (After Sarmiento, 2007b).

The initial works leading to the successful development of geothermal energy in the Philippines were carried out by the Commission on Volcanology dating back in the early 60's, with the utilization of 250 kW turbo-generator to light up an electric bulb in Tiwi, Albay. The development jumpstarted with the government signing an agreement with Unocal to develop and operate the Tiwi and MakBan geothermal fields in Luzon, thus availing of their expertise obtained from developing the Geysers fields in California.

To provide the impetus in the country's geothermal development, PNOC Energy Development Corporation was created in 1976 to lead the government and the private sector in searching and harnessing this indigenous resource. To avoid costly mistakes and reinventing the wheel so to speak, the government further tapped the expertise from New Zealand in developing and commissioning the first 112.5 MW of the Tongonan and the Palinpinon geothermal fields in the Visayas region. This was accomplished with only 7 years after its creation. It pursued exploration works in Bacon-Manito, Mt. Apo in Mindanao, Northern Negros, Mt. Labo and several other areas whose potentials remain untapped due to lack of permeability. To date PNOC EDC accounts for about 1,200 MW of installed capacity, about 58 percent of the total installed capacity in the country.

The achievement in the decades of the 70's and the 80's was not sustained because of political instabilities that severely affected the country's economy from the mid 80's to the early 90's which all but stifled the programs of government. This hiatus in the energy program, where no additional geothermal plants were built, was bridged beginning in the early 90's when a number of events occurred and rekindled the stagnant power program. The tumultuous events in fact led to the 1990 development objectives of the country largely met in spite of the compressed time scale (Javellana, 1995).

These events include the following:

- An energy crisis on Luzon in the early nineties which led to severe power shortages resulting in rotating brownouts in Metro Manila and eventually led to the state owned power corporation (NPC) relinquishing its state monopoly in power generation.
- Resurrection in late 1992 of a Government Energy Department which had been disbanded six years previously following a change in government.
- Development of strong initiatives in the energy sector and implementation of a country wide Master Energy Plan by the Department of Energy in 1993.
- Enactment in 1990 of Build-Operate Transfer legislation (Republic Act 6957) allowing for private sector development of geothermal and other types of power plant and facilities.
- Revision to the Geothermal Development Act which are intended to make geothermal exploration and development more attractive to private investors (in progress).

As a result of these power reforms, PNOC Energy Development Corporation set its foot into the power generation business and engaged several foreign companies in constructing the power plants in Leyte and Mindanao under the Build Operate Transfer (BOT) scheme. The duration of the BOT cooperation is for 10 years, and the contractors are paid per MW of energy generation through the Energy Conversion Agreement (ECA). PNOC EDC acts as the steam field operator which supply steam to the BOT power plant. PNOC EDC is paid by NPC through a Power Purchase Agreement (PPA) for every MW dispatched to the electricity grid. A rapid upswing in the total installed capacity was accomplished using this approach resulting in the commissioning of more than 708 MW from 1993-1997. To date all these BOT power plants have been turned over to PNOC EDC except the 108 MW from Mindanao that is due in 2009.

Further reforms in the power sector industry were initiated starting in 2001 to address the state power company's inefficiency and huge debts. The Electricity and Power Industry Reform Act (EPIRA) of 2001 was approved by Congress allowing the privatization of the generation and transmission assets of the NPC. This law intends to encourage private capital infusion to the power market to free up the large amount of funds that government regularly infused to the state power firm. The geothermal power plants owned by NPC are included in these assets sale. In the development of greenfield areas, the DOE introduced the Philippine Energy Contracting Round (PECR) patterned after the oil and gas industry practices of bidding out areas available for concessions. This is also intended to attract foreign investments in what appears to be a monopoly of the state owned PNOC EDC in steam field development. In the 2007 PECR, three private companies submitted applications in three areas against none in the last two contracting rounds held in 2005 and 2006. Awards are expected to be granted before the year ends.

In the aftermath of the 1997 financial crisis that stretched up to 2006, no geothermal power plants were added except the 49 MW unit that was commissioned in February, 2007, in Northern Negros. The economics of many fields of small capacities have also been affected by the recent reforms in the electricity sector (EPIRA) in view of the requirement for new plants to make connections to existing transmission lines. This has added significant costs to their development.

3.3 Mexico

Mexico is the third largest producer of geothermal energy in the world with an installed capacity of 987 MWe (Figure 7). Since 1986 and 1987, significant installations were only added in 2002 and 2003 for about 210 MW. Mexico's geothermal program appears to have diminished because there has been a long period where hardly anything has been done for 15 years, despite its probable reserves of 4,600 MWe and about 10,500 MW of total potential for medium and high temperature resources. To promote the development of renewable energies to reduce the country's dependence on hydrocarbons, an advisory body was created by the Secretary of Energy in 1999 which is a collegial body composed of representatives from the industry, commerce, academy, government and development banks. The aim of the body is to promote renewable energy within the framework of the market, which would now be dependent on the availability of resource, oil prices, and the decision of stakeholders to support or oppose a proposed geothermal development. The only reason why geothermal is getting attractive is because of the international interest on the reduction of greenhouse gases (GHG), but with the market conditions getting a more important role than environment, the prospect for geothermal development is not very good, with geothermal being treated only as an additional source of energy rather than as an alternative source. The country is also relying on the development of the hot dry rock technology or the enhanced geothermal system (EGS). Several forecasts were made by various workers in Mexico and the most realistic was that made by Huttrer (2001) which predicted the annual capacity in Mexico to be 1080 MW, a value very close to the 2005 installed capacity. The forecasts made by Alonzo (1985) and Mercado (1982) that installed capacity in Mexico would be 2,440 MW and 4,000 MW in 2007 and 2010 respectively, now appear unrealistic.

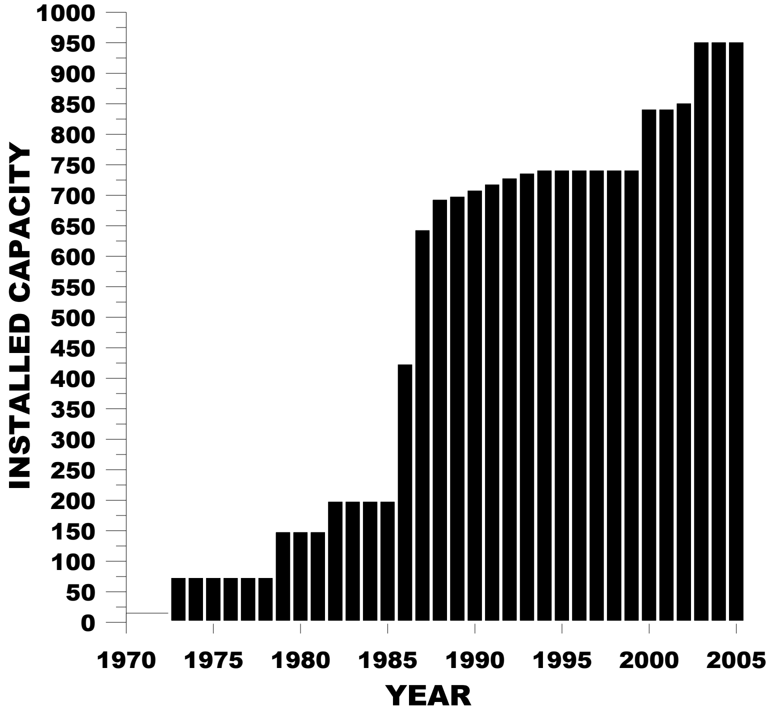

Figure 7: Total annual installed capacity (MWe) in Mexico.

3.4 Indonesia

Indonesia is considered to have the biggest geothermal potential in the world. If the potential for high and low temperature resources are combined together, the estimated reserves are between 20,000-27,000 MWe (Ibrahim et al., 2005a; Fauzi et al., 2005; Suryantoro et al., 2005; Ibrahim et al., 2005). As of 2005, the estimated proven reserves were about 3,520MWe (Pertamina) while the installed capacity was only 787 MWe, 22% of proven reserves and 3.93 % of the country's minimum potential.

The slow pace in the geothermal development was a result of the severe economic crisis that started in late 1997 which adversely affected power sector demand and growth in Indonesia. This has resulted in the failure of achieving targeted installed capacity of about 3000 MW by the year 2006 (Ibrahim et al., 2005). Electricity prices (6-8 US cents/kWh) had to be renegotiated by the government because of the very sharp drop (5 times) in the value of the local currency, forcing the government to suspend eleven geothermal projects and some of the Joint Operating Partners of Pertamina to pull out of the country.

Other factors that slow down geothermal development are attributed to the following:

- High costs of geothermal power that could not compete with other sources of energy.
- Lack of legal framework to protect private and foreign investors in terms of business certainty, existing gaps between the requirement of the Regional autonomy law and fiscal decentralization, sanctity of the contracts and economic stipulations or payment obligations, no certainty on which party or parties of government will regulate.
- Very high initial capital costs on exploration drilling.

To attract investors in geothermal development, Indonesia has prepared itself towards availing of the Kyoto Protocol's Clean Development Mechanism where developed countries could invest or purchase GHG reduction from renewable energy sources as a way of offsetting their GHG emissions. The first of such GHG credit was on the Units 4, 5, and 6 of Gunung Salak in Java to the World Economic Forum, which will make its annual meeting GHG emission neutral.

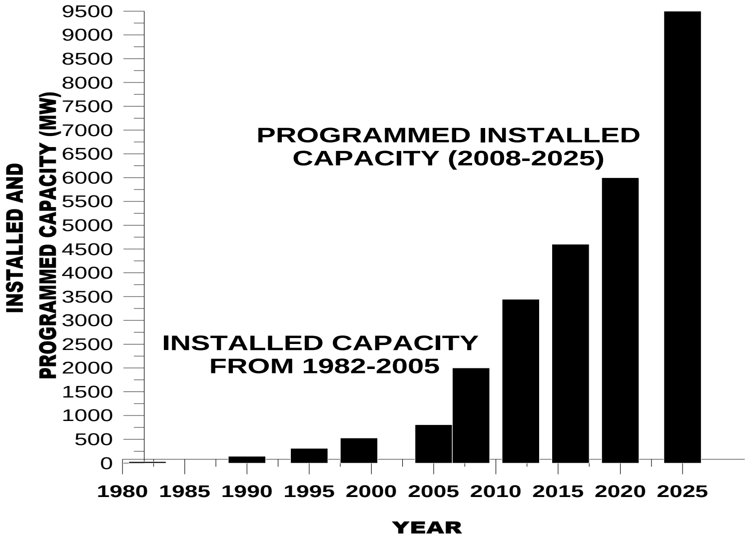

FIGURE 8: Installed capacity (MWe) and the geothermal road map in Indonesia.

Realizing that the oil field reserves are depleting fast and the tremendous potential in the geothermal resources of the country, the government is moving for a geothermal Road Map that paves the way for installing up to 9000 MW of geothermal power by 2025 (Figure 8). This towering goal means that Indonesia will be putting up 300-400 MW per year in the next 10 years and up to 700 MW per year after 2020.

3.5 Italy

Italy is known to be the first country to demonstrate the use of geothermal energy on a large scale for electricity generation. Utilization of geothermal energy in Italy had been recorded since the third century BC for bathing purposes, in the extraction of boric acid in 1817 and for using geothermal steam to run an electric generator that lit the electric bulbs in 1904 in Larderello. The first commercial geothermal unit in the world was in operation there in 1913 with a rating of 250 kW. Italy took advantage of their success in this new industry and installed a total of 127 MW by 1944. It is the only country in the world that produced electricity up to 1958 when New Zealand built their first geothermal power plant in Wairakei.

The geothermal potential of Italy had been studied by various authors but the most recent and available data were published by Cataldi et al. (1983) for central and southern Tuscany and by Cataldi et al. (1978) for the whole country. The total potential refers to those depths of 3 km and summarized as follows:

Accessible resource base: 3 x10 GW-yrs $_{thermal}$
Resources: $1.5x10^4$ GW-yrs $_{thermal}$
Reserves: 1.2 $x10^3$ GW-yrs $_{thermal}$

Cataldi (1978) indicated that about 110 GW-yrs could be produced from the estimated reserves. Taking into consideration the same accounting by Cataldi (1983), part of these reserves is apportioned for the Larderello, Travale and Monte Amiata fields, which are currently producing 792 MWe or 40 GW-years. The remaining reserves of 70 GW-yrs will be equivalent to 1,400 MW for 50 years. If the same conservative development strategy by Parochiarotti and Paris (1979) will be adopted, future development may probably be up to 700 MW only.

Up to the 1960's development of geothermal resources in Italy were concentrated in the shallow reservoirs of Larderello, Travale/Rodicondoli and Amiata which had suffered production declines during the 1970's (Capetti, 2006). The energy crisis from the same period induced the renewed interest in geothermal development and more research works were conducted. Drilling up to 4000-5000 meters has indicated that permeability still exists at this depth range, allowing depleted reservoirs in Larderello to sustain production. Reinjection of fluids increased the production by as much as 50 MWe in Larderello without substantially changing the temperature of the produced fluids. By conducting acid treatment and injection of cold fluids, significant improvements in the productivity of wells were achieved. Capetti (2006) attributed the installation of 12 units with a capacity of 314.5 MW to the positive results of these techniques, with 100 MW installed in both the central and marginal areas in Larderello.

Power generation in Italy used to be monopolized by ENEL since it was established in 1962 to operate as a State Electricity Company. The move was in line with its nationalization of several thousands of electrical companies and small firms to complete the country's electric grid and adjust the price and supply of power. Production of electricity by non-utility companies was liberalized and encouraged in 1991 preceding the creation of a single European electricity market in 1992. Privatization of large public utilities led to the transformation of ENEL as a joint stock company fully owned by the Ministry of Treasury. In 1999, the government approved a law defining the basic rules for the restructuring of the Italian electricity market. One of the provisions of the law stipulated that no individual operator is allowed to generate or import more than 50 percent of the domestic and overall consumption of the country's electrical energy starting in 2003. This requires the sale of approximately 15,000 MW of power by ENEL to other operators. However, the same law provides for specific policies aimed at supporting development of renewable energy resources including geothermal. This law provides specifically that all operators have to supply a quota of their production from renewable sources into the grid by 2002 which was set at 2 percent of the total energy exceeding 1000 GWh. This quota is equivalent to 5,000,000 kWh and is large enough to spur the market effectively and is only

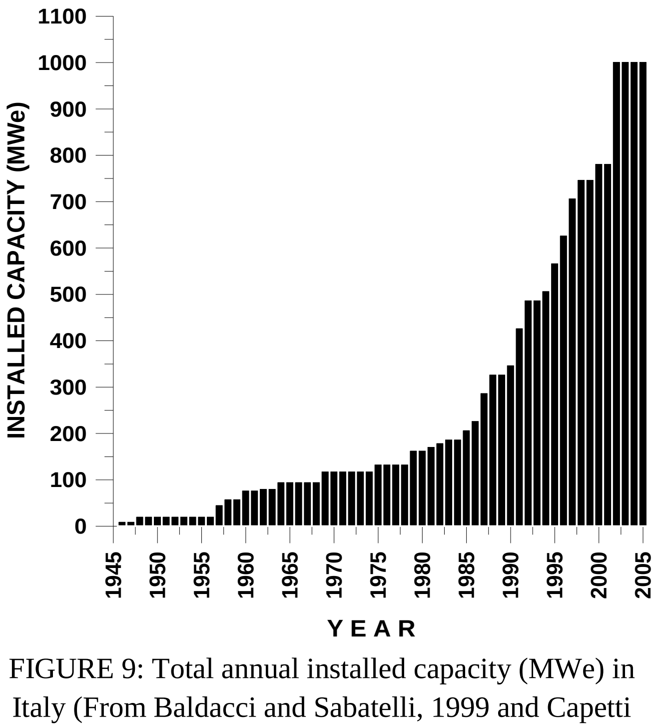

FIGURE 9: Total annual installed capacity (MWe) in Italy (From Baldacci and Sabatelli, 1999 and Capetti and Cepatelli, 2005).

applicable to new plants built or repowered after the law is to take effect. In 2003, another decree was passed fixing a yearly increase of 0.35 percent in the quota with further increases foreseen in the future. A foundation is therefore laid out in the Italian electricity market where geothermal could be rapidly developed.

Figure 9 depicts the annual installed capacity of geothermal power plants in Italy since 1946. In this graph, the number of units that were retired due to old age was not reflected, and therefore their capacities were added up to 2005. There is therefore a discrepancy in figures between those in Table 2 and this graph on some years. It is noticeable that the geothermal development took place gradually from 1940's to the 1970's and started to accelerate in the late 80's. The most rapid growth occurred in 2002 coinciding with the implementation of the law regarding the granting of incentives for the utilization of renewable energy.

3.6 Japan

The utilization of geothermal energy in Japan dates back just before the industrial Japan, and its history is always associated with the history of hot spring bathing with traces from the pre-pottery period before 11,000. The first experimental geothermal power station was built in 1925 in Beppu, Kyushu, while the first utility commercial power station started in 1966 in Matsukawa. With the oil crisis in 1973, development of new geothermal fields was accelerated resulting in the completion of 215 MW from 1974-1978.

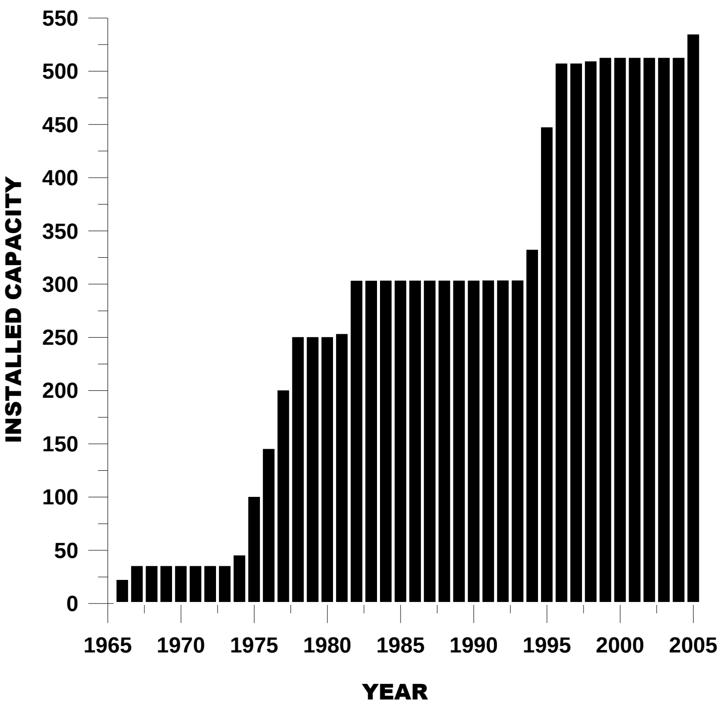

FIGURE 10: Total annual installed capacity (MWe) in Japan.

The estimated technical potential of geothermal resources in Japan is 24,600 MWe, based on the volume of geothermal water to a depth of 3 km and temperature of more than 200°C (Kawazoe and Shirakura). Fuchino (2000) reported that the potential of geothermal resources for power generation in the country is estimated at about 2,500 MWe. However, to date, the installed capacity is merely 535 MWe representing 21 percent of the country's identified geothermal resources, but only 2.1 percent of the total country's potential. When fully developed, the total share of geothermal energy in the country's total installed capacity could reach up to 9 percent compared from the existing 0.2 percent (Figure 10).

Several factors that hinder the development of geothermal resources in Japan were identified by Kawazoe and Shirakura (2005) and Fuchino (2000) which are described as follows.

- Lack of appropriate techniques necessary to reduce the uncertainty of underground geothermal structure at the exploration stage.

- Long gestation period and substantial pre-investment that discourage even the most ambitious investor to start building power plants.
- Availability of advanced technology to develop Japan´s unused geothermal resources.

To promote geothermal energy development, incentives in the form of technical and financial assistance are provided by the Japanese government from resource exploration to construction of power plants as follows:

- Grant of 50% of the drilling cost of exploratory wells intended for power generation.
- Grant of 20% of tangible costs such as drilling of production and reinjection wells, construction of production facilities and steam turbines.
- Funding to take out inevitable risks during early stage of development such as research on small geothermal power units, small Binary Geothermal Power Generation systems, development of Reservoir Evaluation Technology, Confirmation Study of Effectiveness of Prospecting Techniques for Deep Resources, survey of Deep-seated Geothermal Resources, Hot Dry Rock Power Generation System, development of 10 MW Binary Cycle Power Plant.

Despite these incentives and technical and financial assistance, the growth of geothermal development in Japan is at a very slow pace, compared with its technical and financial capabilities.

3.7 New Zealand

New Zealand was the second country in the world to demonstrate the use of geothermal energy for power generation and the first country to develop a liquid or water dominated type of geothermal system. Initial geothermal production in Italy is mainly from the dry steam field of Larderello.

The most comprehensive recent assessment of the New Zealand's high temperature geothermal resources was conducted by Lawless (2002), indicating that the country's total potential could be equivalent to a average value of 3,600 MWe using existing technology. McDonalds and Grant (1978) earlier estimated that New Zealand's geothermal potential for power generation was about 1300-2500 MWe based on the similarity of features of most geothermal fields with Wairakei and Broadlands. Based on its installed capacity in 2005 (Figure 11), New Zealand currently utilizes 12 percent of its accessible resources and forecasts that geothermal will make a significant contribution to their energy requirements. However, regulatory constraints and cost of other alternative sources of power are perceived to be hampering New Zealand's full geothermal development.

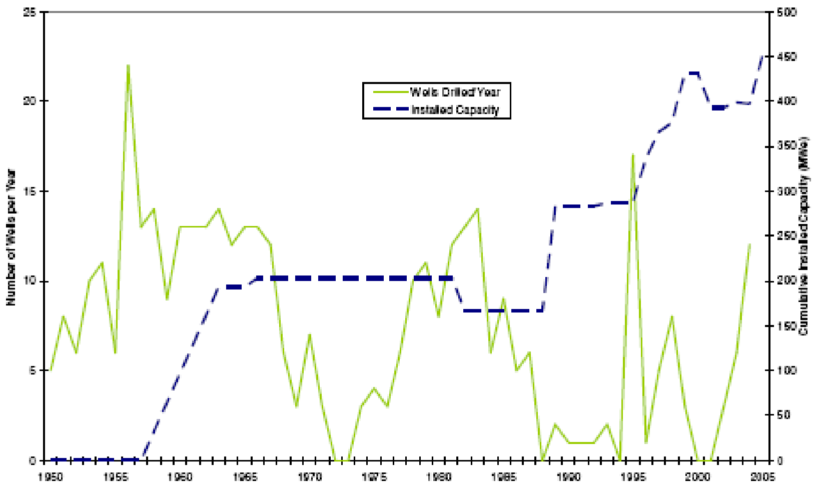

FIGURE 11: Total annual installed capacity in New Zealand (After White, 2006).

Geothermal development In New Zealand is presently regulated by the Resource Management Act of 1991 which regulate power development for geothermal resources in the 12 regional counties in the country. These councils are required to oversee the sustainable management, development and protection of physical resources for the well being of the people while providing the needs of future generations. Since most of the geothermal systems are located in the Waikato region, most of the regulations governing geothermal development are initiated through the Waikato regional Councils. Lawless has reviewed possible constraints imposed by Regional Councils which has set some rules to protect the unique natural geothermal features while allowing controlled development of some fields. According to Luketina (2000) the days of the government's Think Big projects are gone, i.e., when the goal of national power generation was pursued with little or no regard to value of geothermal characteristics for native traditional use, biodiversity, tourism, environmental amenity values and the needs of future generations.

Under these highly restrictive conditions, it is forecasted that 400-600 MW of new generation capacity may be possible for the next 10 years. Whilst the government is encouraging geothermal development in its policies, the 600 MWe in the pipeline is still not enough to demonstrate that it is making the best use of its geothermal resources. Lawless (2002) suggests that by reducing regulatory constraints, reasonable environmental, recreational and conservation values, would allow another 800 MWe for development. And by releasing the development of unused wells and assets to the private sectors, there is a medium probability that about 1,335 MWe could proceed by the year 2025.

3.8 Iceland

Iceland lies on the mid Atlantic ridge and an active rift zone of volcanism crosses the country from southwest to northeast. More than 200 volcanoes are found in the volcanic belt and eruptions are frequent and seem to have occurred on average every five to ten years for the last centuries. The geothermal resources of Iceland are associated with the volcanism and the high heat flow through the young crust of the country. In the volcanic zone, more than 25 high temperature fields have been identified, fields where temperature exceeding 200°C at 1 km depth is expected. The high temperature fields are linked to the active volcanic systems and draw their energy from magmatic intrusives and magma chambers in the roots of the volcanoes. Outside the volcanic belt, numerous low temperature fields are found with temperature less than 150°C in the uppermost one kilometre. The low temperature activity is highest at the flanks of the volcanic zone but some geothermal activity is found in most parts of the country. Figure 12 shows a geothermal map of Iceland. It shows the high temperature fields in the volcanic zone and the hot spring areas in the low temperature regions.

The geothermal potential of the Icelandic geothermal fields has been studied during the last decades in association with their utilization. A general resource assessment for the country as a whole was, however, carried out in the 1980s, using volumetric methods (Palmason et at.; 1985). The stored heat was estimated to 10 km depth (resource base) but was assumed only accessible by drilling to 3 km depth (accessible resources base). The volcanic zone was divided into three parts (1) the high temperature fields, (2) other volcanically active areas, and (3) other parts of volcanic zone. The rest of the country was divided into six geographical regions. The main results of the resource assessment for Iceland the following:

Resource base (<10 km):	1.2×10^{-24} Joule
Accessible resource base (<3 km):	0.1×10^{-24} Joule
Resources (Technically possible to extract):	3.5×10^{-21} Joule
Possible power generating capacity:	68×10^{-18} Joule

A part of the assessment was to estimate the stored heat in each of the high temperature fields and estimate their potential for electricity generation, excluding fields in inaccessible location, i.e. underneath the glaciers. The result was that, using existing technology, these fields can produce 5.6×10^{-18} J of electric energy which corresponds to 175 GW-years or 3500 MW for 50 years generation assuming 8% plant efficiency and full year operation. This potential has later been re-evaluated taking into account environmental restrictions to the utilization of some of the field. The present estimate is 20 TWh/y corresponding to about 2500 MWe.

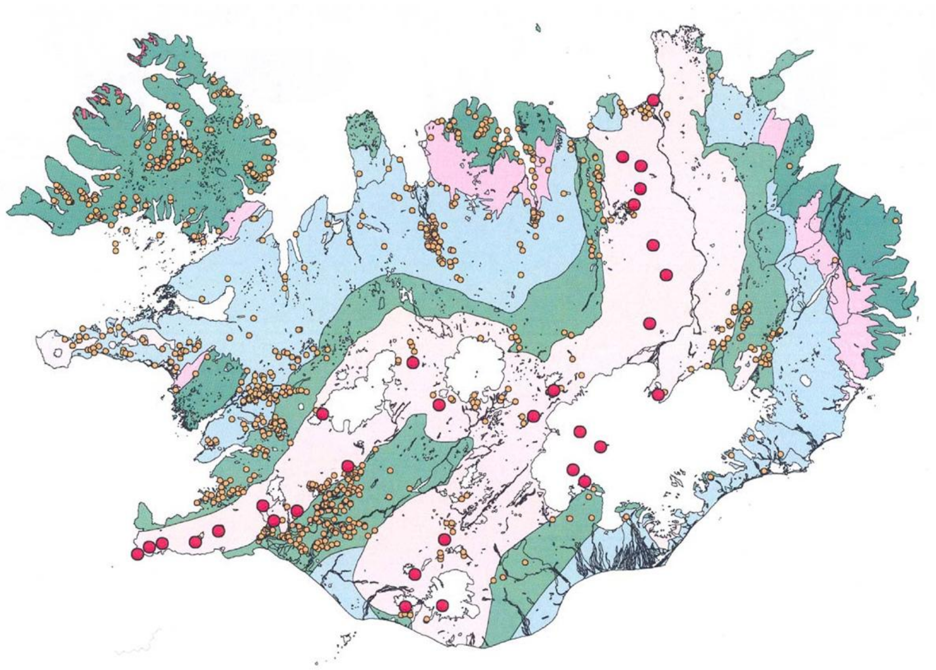

FIGURE 12: Geothermal map of Iceland. High temperature fields inside the active volcanic zone are shown as red circles, and hot and warm springs as yellow circles

The utilization of the Icelandic geothermal sources was very limited through the centuries and it was not until the early part of the last century that Icelanders started systematically to use geothermal energy, first for space heating but later for power generation. Figure 13 shows how the consumption of geothermal energy has grown during the last 65 years. During this period, Iceland has become one of the world leaders in direct use of geothermal energy and ranks in the top ten in geothermal power decades as geothermal district heating services started operations utilizing easily accessible low temperature geothermal areas close to populated areas. When the oil crisis struck in 1973 and oil prices almost doubled, about 40% of houses in Iceland were already heated by geothermal energy and about 50% by oil. This called for a change in energy policy and the government launched a major effort to replace oil in space heating by geothermal energy. This led to exploration of new fields, exploration and production drilling in new areas and use of submersible pumps where artesian flow was not sufficient. The effort had very successful and in 1985 oil heating served less than 5% of the population and geothermal was grown to 85%. This development explains the dramatic increase in geothermal energy consumption around 1980 (figure 13). The share of geothermal energy in heating of households has continued to grow and is at present 89%, electric heating is about 10%, and the share of oil heating is down to 1%. The market for geothermal energy for space heating has been more or less saturated during the last twenty years apart from that to meet the growth of the population.

The increase in geothermal energy consumption seen in figure 13 during the last ten years is due to geothermal power development. Icelanders were rather slow in developing the high temperature fields for electricity generation, the reason being the abundance of hydro resources for power generation. The first geothermal power plant with 3.2 MW installed capacity was commissioned in 1969. The next development was the Krafla power plant which started production in 1978 and the Svartsengi plant a year later. The installed capacity of these three plants was about 50 MW in 1995 (Table 2). Figure 14 shows the power generation from geothermal steam in Iceland from 1970 to the end of last year. It also

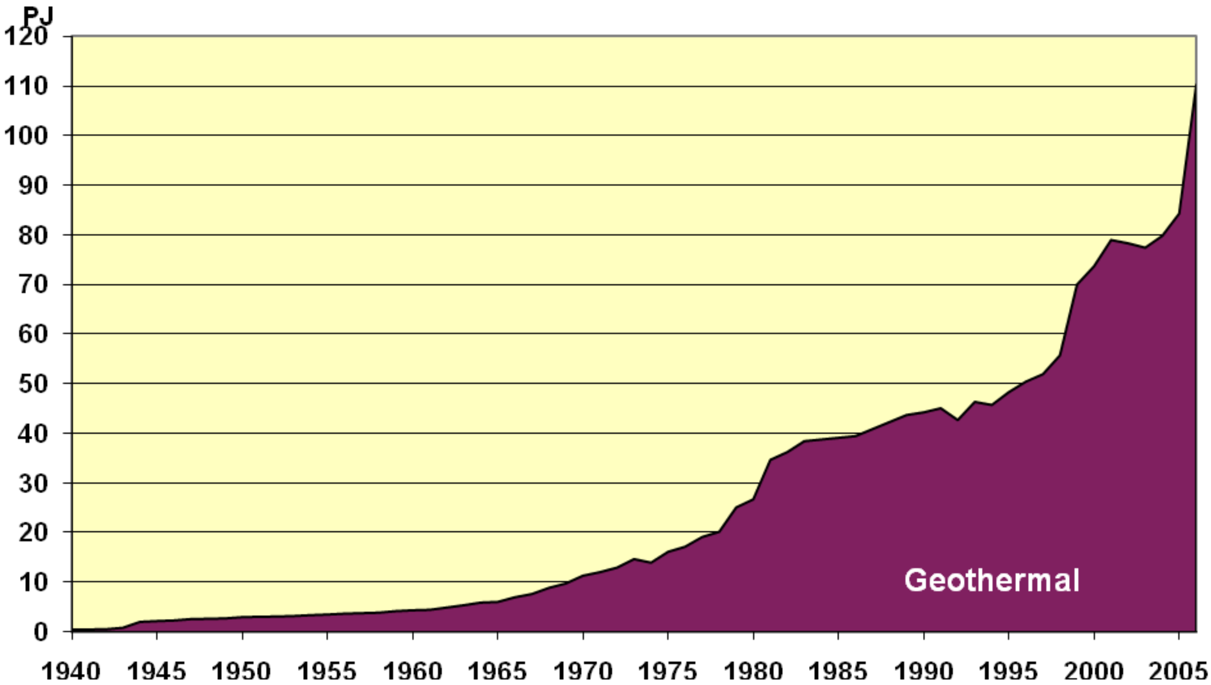

FIGURE 13: Geothermal energy use in Iceland 1940-2006 (primary energy).

shows that the present installed capacity of the six power plants in operation by the end of 2006 was 422 MW. This rapid growth of the electric market is due to large expansion of the power intensive industry after 1995 and has been met not only by geothermal power plants but hydro power as well.

The future of geothermal developments is bright in Iceland. There is a high demand for electricity for the intensive power industry and several geothermal fields are being explored and developed. In 2007, some 30 MW will be added to the existing plant in Svartsengi and 33 MW to the Hellisheidi power plant followed by 90 MW in 2008. If all plans of the energy companies will be realized the installed geothermal power in Iceland may be close to 1000 MWe by 2012. This is still less than 50% of the estimated power potential of the known high temperature fields.

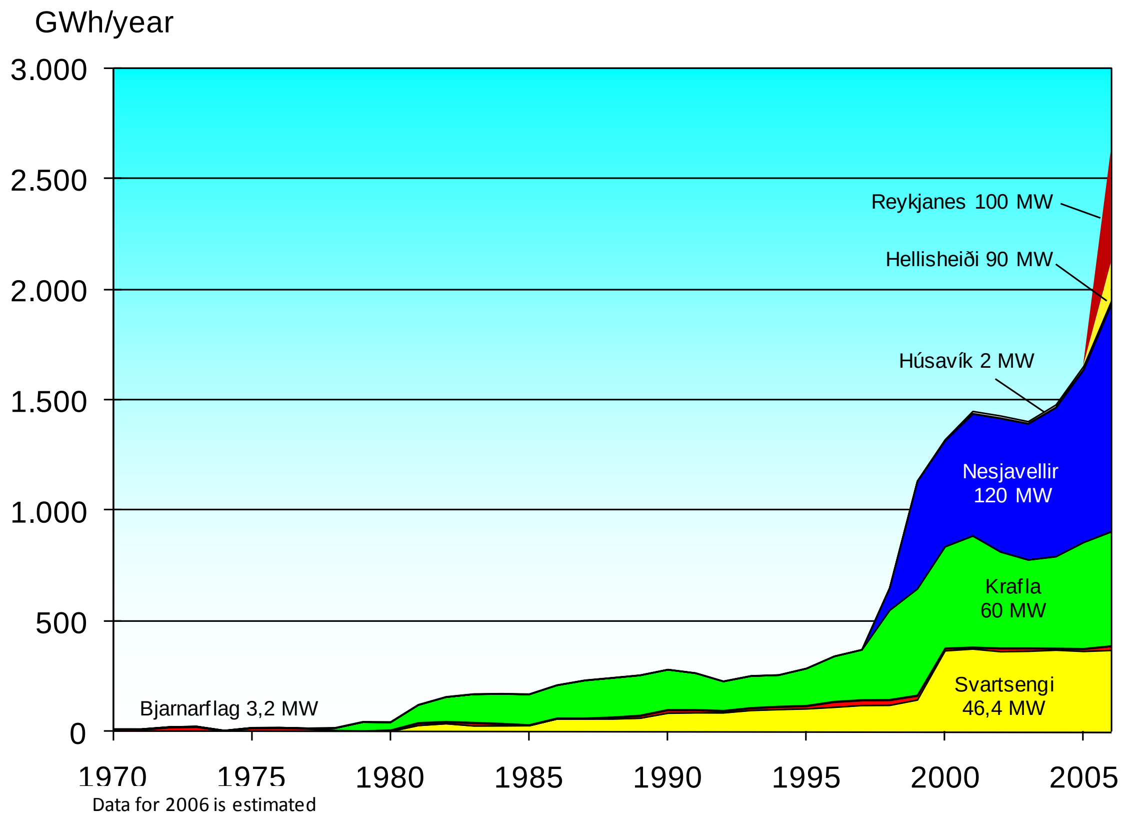

FIGURE 14: Power generation from geothermal steam 1970-2006 in Iceland

4. SUMMARY AND CONCLUSION

The development of geothermal resources in the leading geothermal countries indicates that substantial work is required to fully tap the potential of their geothermal resources. Several factors influence the phasing of geothermal development in each of the countries. The following factors contribute in the accelerated development of this indigenous resource:

- High geothermal potential.
- Full government support and strong political will.
- Availability of funding either domestic or thru international banks and lending institutions.
- Reduction of each country's reliance on imported fossil fuels.
- CDM under the Kyoto Protocol on reduction of GHG.
- Power crisis.
- Government incentives to minimize exploration, development and management risks.

On the other hand, the following factors are perceived to be hindering the development of this resource in many countries:

- Availability of more competitive and traditional sources of energy like fossil fuels.
- Strict environmental rules and regulations.
- Lack of legal framework and structure to protect private and foreign investors.

- State monopoly.
- State of economy and/or financial crisis.
- Low quality of resources for newly explored areas.
- Resource depletion.
- Long gestation period.
- High risks and initial development costs.
- Additional costs due to transmission lines.

Despite the presence of many of these factors in these countries, individual countries have adopted different strategies in developing their geothermal resources. The most aggressive of these countries appears to be the Philippines which recorded the fastest growth since the oil crisis in 1973. The Philippines have no other recourse but to develop this indigenous resource because of its limited fossil fuel source, and it has shown its political will despite many constraints in financing, technology, and the enormous risks associated with early exploration and drilling. The Philippines have not shown any hesitation, especially during the late 70's and the early 80's to tap this abundant energy source. When a power crisis struck its main capital region, further accelerated geothermal development was obtained by tapping international companies to engage in BOT contracts for the building of power plants. All these plants have already been transferred to the government in 2007 except the 2x54 MW units that will be transferred in 2009.

Development in Japan is mostly concentrated in areas where there is existing production, thereby gaining only a small amount of power. Indonesia could have surpassed the Philippines and probably the USA by this time if their programs were not scuttled by the 1997 financial crisis. The lack of a strong legal framework to protect the private investors is still affecting the inflow of needed capital in their geothermal sector. USA and Mexico allow market driven forces to influence when to develop geothermal resources although there are programs and incentives targeted on supporting geothermal development. The restoration of the lost capacities in the Geysers is rekindling geothermal activity in the area. The outlook for the United States geothermal program is seen to be very promising, especially in the Western states. The improvement on the EGS technology is seen to enhance further the development of geothermal not only in the USA but also in all other countries that have stopped developing high temperature areas because of lack of permeability. In New Zealand the restrictive Resource Management Act constrained further development of geothermal resources to ensure their sustainable management and use during the last 10 years. The highest pace in geothermal developments has been in Iceland due to great demand for electric power for power intensive industries.

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