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Geothermal Energy Resources, India: Country Update

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ABSTRACT

India's ambition to increase power from the present 90895 to 95895 MWe by 2015 is going result in 870 million tones of CO_2 emissions. Whether this increase will put the country on zero deficit with regard to electricity has to be seen in the next couple of years. However, India can become energy independent and be on the top of low carbon emission list within the non OECD countries if it utilizes even a fraction of the 18348 x 10^8 GWhr power available from its wet and EGS sources. As on today the building sector utilizes 33 % of thermal power and food processing industry utilizes 13% of thermal power. Geothermal energy can easily replace this energy sources in both the sectors thus earning about 2640 x 10^6 euros under CER. Major percent of electric power is generated by Public sector companies. These major industries control the socio-economic as well as political growth of the country. Hence environmental pollution is not a concern to these industries since the affected are those who have no say in the policies. Hence pollution tax will be only in the law books. Further there is no adequate structure to implement capacity building in the geothermal sector. With the new initiative taken by a few institutes and companies, the country may be put in to a situation of piling up carbon credits in the near future.

1. INTRODUCTION

During the last five years, India's power scene has not made great improvement. From the previous installed capacity of 1, 23,668 MWe, the country could enhance the installed capacity to 1,41,080 MWe till now with an increase of about 7.3 % in the year 2006-2007. But during the current year (2007-2008) the generation capacity has fallen down to 6.3% due to short supply of gas. The additional power supply is contributed by thermal power plants, whose generation capacity has increased from 82065 to 90895 MWe, and renewables that contributed additional capacity of about 4000 MWe during the same. By the year 2015, cola based thermal power is expected to reach 95895 MWe (Table 1). The Ministry of New and Renewable Energy (MNRE) claim that Wind and small hydro electric power projects contributed significantly to this increase (MNRE, 2008). It is not known how much is actually generated by these sources. With the 6.3 % power growth rate, one has to wait and see whether the country could fulfill its ambition to increase the per capita of electricity consumption from the current 631 KWhr to 1000 KWhr by the year 2012 (MOP, 2008). Coal based thermal power plants are able to meet the demand only by adding additional CO_2 in to the atmosphere. The future growth of power will be achieved at the expenses of 870 millions tone of CO_2 emission by burning 263 million tons of coal by the thermal power plants. This is the simplest way to bridge the gap between demand and supply but in future this will prove to be disaster. Energy source mix is the only way that could meet future electricity demand and control CO_2 emissions not only in India but in all the developing countries. The current demand can be achieved if the available geothermal energy resources are utilized to supply the reported shortage of electricity of the order of 78577 MWe. With the commissioning of M/s GeoSyndicate Power Private Limited, India's only geothermal power company, India could easily boast zero electricity deficits by the year 2012. Besides wet geothermal systems, the company has assessed the potential of enhanced geothermal systems in the entire country. According their assessment, India may soon emerge as one of the major leader in producing electric power from enhanced geothermal systems.

2. WET GEOTHERMAL SYSTEMS

All the wet geothermal provinces in India are either associated with major continental rifts or with subduction related tectonics (The Himalayan Geothermal Belt), characterized by high heat flow and high geothermal gradient as shown in figure 1 (Chandrasekharam, 2000, 2001, 2005).

The high heat flow and high geothermal gradient in all the major mid-continental rifts appears to be related to deep seated faults penetrating to mantle depth. This view was supported by several workers based on deep seismic sounding profiles across the Son Narmada Tapi rift (SONATA) and across the west coast fault (Kaila et al., 1981). Based on the bouguer gravity anomaly signature, presence of 1250 °C geotherm at about 18 km dept was also proposed along the coast parallel to the Cambay gulf (Negi et al, 1992). However, deep mantle signatures are not reflected in the thermal gases in any of the geothermal provinces along the west coast, SONATA and Cambay. The $^3He/^4He$ ratios (measured with reference to air and reported as R/Ra) in the thermal gases vary from (0.12 to 0.21) while the ^4He content is as high as 2 % v/v (Minissale et al., 2000, 2003). Although the helium ratio is little higher than the crustal average (0.02), this do not strongly support mantle involvement in the evolution of the thermal system in this regions.

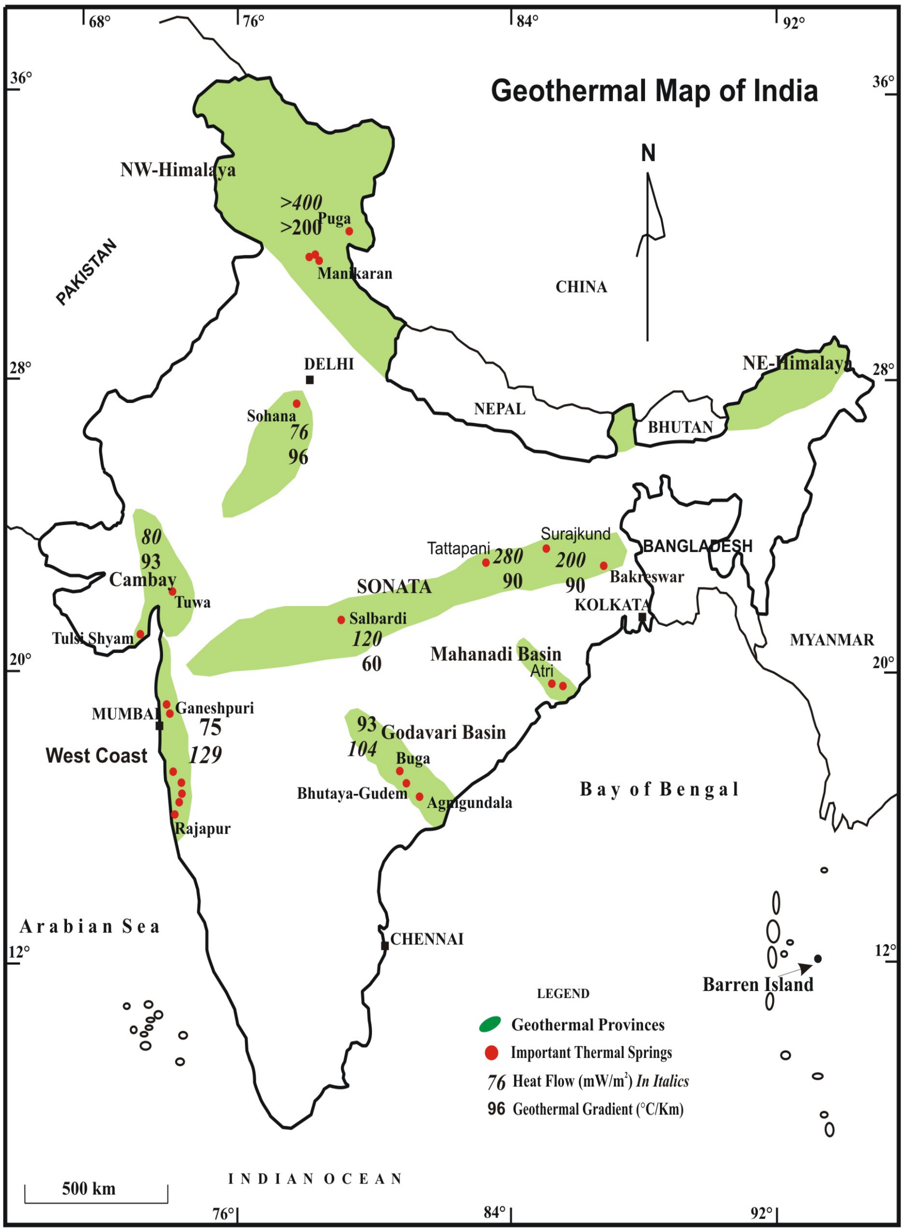

Figure 1. Geothermal provinces in India

High helium content strongly suggest radiogenic crustal rocks below the Deccan flood basalts as the main driver of hot fluids along the coast. The occurrence of granite inliers near Rajapur within the Deccan flood basalts (Ramanathan and Chandrasekharam 1997) and the recent reported occurrence of 1446 Ma granite below the Deccan flood basalts recovered from a oil well (Near Bombay High Off Shore platform certainly support a granite as the driving medium for the entire west coast thermal regime. The thorium content in this granite varies from 11 to 21 ppm (Rathore et al, 2004). Occurrence of fertile granites below the Deccan is not unusual considering the occurrence fertile granite from the SE fringes of the Deccan flood basalt province with high thorium (Th:10-43 ppm) and uranium (3-21 ppm) content (Senthilkumar and Sethuraman, 2003).

A similar situation exists in the case of Cambay geothermal provinces, bounded by the two N-S trending regional faults that form the boundary of the Cambay basin. As shown in the figure 2, the basin is filled with Eocene to Miocene sedimentary sequence above 600 to 800 m thick Deccan flood basalt flows. The basalts lie over 955 Ma Godhra granite. This granite out crops at several places along the margins of the rifted basin and an excellent exposure with the thermal springs emerging from the granite is located at Tuwa on the eastern boundary of the rift (Figure 2). More than a dozen thermal springs emerge around this site. Airborne gamma ray spectrometric survey reveal high content of thorium (14 - 88 ppm) in Godhra granite. As shown in figure, a 5 km thick thermal insulation over these high heat generating granites is sufficient to circulate high temperature geothermal fluids in this region. In fact, it has been reported that some of the oil wells drilled deep into the sedimentary basement leaked high pressure steam

Similarly in the case of SONATA geothermal province, the Bundelkhand and the Baster granites form the host for thermal fluids. A thin veneer of Deccan flood basalt (500 m) underlined by thick Gondwana sedimentary formations form an ideal situation for generating high temperature fluids in this thermal province. The surface temperature of the Tattapani thermal waters, for example, is as high as 98

°C (Minissale et al 2000). Even though DSS section reveal extension of the Narmada faults to mantle depths (Kaila et al 1981), the $^3H/^4He$ ratio in Tattapani thermal gases is only about 0.02 while the He content is as high as 7 % v/v (Minissale et al., 2000). High concentration of radioactive elements in the above two types of granites is able to produce 3 to 5 µw/m^3 heat resulting in high heat flow 280 mW/m^2 along this province. The remaining geothermal provinces located in the Godavari rift valley, and the Himalayan Geothermal Belt (HGB) circulated through high heat generating granites (Chandrasekharam and Chandrasekhar, 2008a). In fact the entire wet geothermal systems shown in figure 1 above is driven by these high heat generating granites.

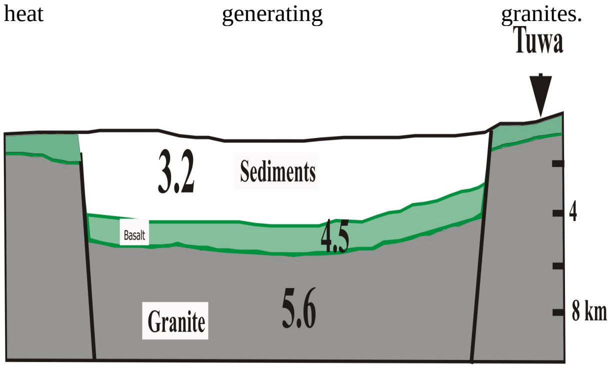

Figure 2. Subsurface geology of the Cambay basin deduced from seismic refraction and DSS profile. The numbers indicate seismic velocity in km/s (modified after Tiwari et al, 1995, Kaila et al, 1981)

3. GRANITES AND GRANITES

The surface area of exposure of granites in the Indian subcontinent is about 150,000 sq. km. These granites have evolved over a long geological time period extending from the Archean to the Recent. These granites occur as batholiths and extend to crustal depths. The heat generating capacity of these granites varies from 3 to 8 µw/m^3. Hence these granites are capable of generating the observed heat flow value and geothermal gradients in all the geothermal provinces shown in figure 1. High uranium and thorium content in these granites (5-14 and 3-101 ppm respectively, Chandrasekharam and Chandrasekhar, 2008a) are able to generate the measured helium content in the thermal (Minissale et al. 2000, 2003). Thus all the wet geothermal systems in the Indian sub continent represent deep (depth varying from 1 to 2 km, Chandrasekharam and Antu, 1995) circulating meteoric water through high heat generating granites. Thus these geothermal systems in deed represent natural enhanced geothermal systems and provide excellent clues to locate and propose future sites for enhanced geothermal systems or EGS.

4. GEOTHERMAL POTENTIAL AND POWER DEFICIT IN INDIA

According to an estimate made by M/s GeoSyndicate Power Pvt. Ltd. the EGS can easily bridge the demand-supply gap of electric power in India. For example the granites in Andhra Pradesh state have a minimum reserve of 111200 x 10^{12} kWh while the State's electricity deficit is of the order of 25 x 10^9 kWh. Similarly in the State of Madhya Pradesh the granites have a minimum reserve of 24464 x 10^{12} kWh while the State's consumption is about 33 x 10^9 kWh (Chandrasekharam and Chandrasekhar, 2008). Even a State like Tamil Nadu in south India, that has no reported wet geothermal sites, has potential EGS resources. The combined power generation capacity of the wet and EGS is estimated at 18348 10^{14} kWhr. This will wipe out the power deficit (620 x 10^9 kWhr) of India by 2030 and make India energy independent.

5. GEOTHERMAL UTILIZATION

As described in detail (Chandrasekharam, 2007), all the thermal springs sites in India are pilgrimage centers and this belief is still live and continues to be so in the futures. Since these thermal springs are considered to have divine healing power, majority of them are being used for bathing (therapeutic). Although these thermal springs are believed to heal several skin and joint related dieses, basic hygiene is not practiced in certain thermal sprigs sites. For example, the thermal springs around Vajreswari, located 80 km north of Mumbai, is visited by about 500 pilgrims every day. Even though the issuing temperature of the thermal water is about 47 °C, pilgrims brave this temperature and bathe in the ponds constructed around the emergence of the springs (Figure 3).

In other places like, Akloli, located north of Mumbai (Figure 4), small pools are constructed around the emergence of the springs. These pools are kept clean and entry is prohibited. Thermal water with temperature of about 57 °C is allowed to flow in to several large pools, where cold water is mixed to maintain optimum temperature for the pilgrims to bathe. Devotees throw coins into the pool with a wish (similar to the belief that exist for like the Tivoli fountain in Rome). Akloli is located in a remote area hence the number of pilgrims visiting this spring is small (about 50 pilgrims a day).

Figure. 3. The thermal springs at Vajreswari emerge along the banks of Tansa River. (top) Small platforms and enclosures are built around the thermal emergence for the pilgrims to have holy dip where ever the water flows to the surface. (lower). Shallow wells of 2 to 3 m deep, tapping the subsurface thermal water flow, are also common, where pilgrims get in to these wells to rinse their body with the thermal waters

Figure. 4. Akloli thermal springs. Bright silver objects are coins offered by the pilgrims. The thermal water is channeled through the base of Shivlinga, symbolizing the River Ganges flowing through the mattes of Lord Shiva (Chandrasekharam, 2007).

Thermal springs located in Basist, north of Manali in Himachal Pradesh are well protected and thermal water (62 °C) is drawn into large pools and mixed with cold water. Pilgrims visiting Basist temple follow hygiene in these pools (Figure 5). Separate pools for women exist here. Manali is located in the lower Himalayan region and hence the temperature during winter drops below zero and Manali is a popular summer resort. Basist thermal springs attract about 3000 tourists a day.

Figure 5. Devotees bathing in the thermal pool in Basist. Thermal water flows through the iron tube while cold water is supplied through the tap.

Thermal water with temperature of about 91 °C, emerging along the banks of Parbati River, in Manikaran geothermal site in Himachal Pradesh (Lower Himalayas), is used for both bathing and cooking. Temples for Hindus and Sikhs are constructed around the springs. The pilgrims cook rice in small cloth bags in the thermal waters and offer it to the deity (Figure 6) while Gurudwara (Sikh temple) use this water for cooking rice in copper vessels and feed the pilgrims. Nearly 3500 pilgrims visit this site every day (Figure 7).

Figure 6. Pilgrims cooking rice in cloth bags in the thermal pool, Manikaran, Himachal Pradesh.

Figure 7. Rice is cooked in copper vessels in the thermal pools of Manikaran. Rice is served to all the devotees in the Gurudwara.

However, thermal springs in Chumathang, south of Leh, Ladakh, is put to different use. Here the ground heated by the geothermal water is used for space heating by the Boarder Road Organization. The Chumathang geothermal site spread over a large area along the Indus River Bank and thermal water emerges at several places within this area. Thermal water with temperature varying from 85 to 87 °C emerges at about six to seven locations in this area. The ground temperature over the thermal zone is always above the ambient temperature at any time (during winter and summer). The air temperature varies from -30 °C in winter to + 29 °C in summers. The Boarder Road Organization have constructed a small guest house over the area represented by the geothermal manifestation (Figure 8a). Thus, during winters, the inside temperatures in the guesthouse rises to + 18 to 21 °C. Hot water from the thermal springs is supplied in pipes to the guest house. The local population have also constructed small houses over the thermal zone to protect themselves from the harsh winters (Figure 8b).

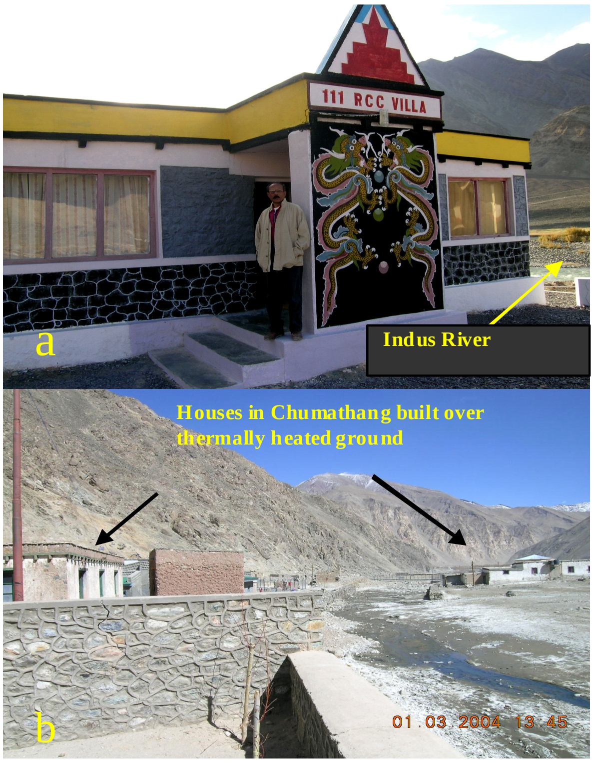

Figure 8. Army guest house (a) and local houses (b) built over thermally heated ground in the Chumathang geothermal site, Leh, Ladakh.

It is realized beyond doubt the healing powers of these thermal waters. But under the current world situation, India has to go further beyond the myth and use this energy sources for the betterment of the rural population. Currently, only 265 MWt energy for direct applications (Tables 3 and 5) from a handful of thermal springs is being utilized. In fact all the 400 thermal springs are accessible for utilization and if exploited will provide > 10 fold the current utilization (Chandrasekhar and Chandrasekharam, 2010)

Due to the pressure from the UNFCC to control CO_2 emission, during the last couple of years India has taken geothermal seriously and considering its potential as carbon credit earner and control growing carbon credit with "less" CO_2 emitting European countries. At present two states have realized its importance and surging ahead with implementing project to generates a modest 25 to 50 MWe (from wet geothermal systems alone). Like Australia, the geology and tectonic regime of India is well suited to exploit hot dry granites and reduce power deficit considerable in the future and reduce its CO_2 emissions to the levels prescribed by the Kyoto Protocol. Generation of power from the Puga geothermal site (with a potential of generating > 250 MWe; about 2 x 10^9 kWhr)will make a huge difference to the Leh community and its environment. The CO_2 emitted by the diesel generators in generating 8 MWe is about 41 x 10^6 kg CO_2 (Chandrasekharam and Chandrasekhar 2008b). Geothermal can save the currently retreating Gangotri glacier (retreating at the rate of 18 m per year, Chandrasekharam and Chandrasekhar, 2008b) and preserve the pristine ecosystem of the Himalayas. The retreating glaciers of the Himalayas could present the most far-reaching challenge to the region by changing the monsoon dynamics of the entire Asia (IEA, 2007).

6. DISCUSSIONS

The Kyoto Protocol which entered into force on 16th Feb 2005 aimed at developed countries for emission targets and is open to developing countries through Clean Development Mechanism (CDM). CDM is an excellent instrument for India to develop its geothermal energy resources (both wet and EGS) and become the leader among no-OECD countries in terms reducing carbon emissions and earning hug carbon credits (Chandrasekharam and Bundschuh, 2008). By utilizing geothermal energy as a primary source mix, India can reduce emissions of the order of 396 x 10^9 kg of CO_2.thus earning an amount of 396 x 10^7 euros under Certified Emission Rate (CER) from the European countries (@ ~ 10 euros /tCO_2). In fact, the building sector and the food processing sector can also be a part of CDM. The food processing sector uses about 13 % of the electricity (IEA, 2007) amounting to 63 x 10^6 MWhr (from coal fired thermal power plants). By increasing direct application of geothermal energy an amount of 600 x 10^6 euros can be raised through CDM and ploughed into this industry for creating the necessary infrastructure and implement state of art processing technology (Chandrasekharam, 2001, Chandrasekhar and Chandrasekharam, 2010 MFP. 2008). Similarly, building sector can utilize geothermal energy and reduce about 234 x 10^9 kg CO_2 emission. Building sector (commercial and residential) utilizes about 33 % (245 x 10^6 MWhr, only coal power) for air conditioning, refrigeration and hot water (UNEP, 2008). If India utilizes low enthalpy geothermal sources (through Ground source Heat pumps: GHPs) it can earn an additional revenue of 234 x 10^7 euros under CER.

Thus geothermal energy can be a part of the primary sources mix. But the country needs human resources to support the growing needs in the geothermal energy sector. At the existing rate of capacity building (Table 7) it will take several years to bridge the gap between demand and supply as for as trained manpower in this energy sector is concerned. (Table 7). India has to create adequate structure at university level to for capacity building. Several developing countries are encouraging this field as is evident from the number of countries participating in the course offered by the UN University in Iceland. As on today Only one institute have a structured course in geothermal energy (IITB). Even the Power Ministries have no expertise in geothermal and this is often handled either by an electrical engineer (e,g, in Central Electricity Authority) or by a biologists (e,g, Ministry of New and Renewable Energy) or by a Civil Engineer with poor knowledge in geothermal system. A major policy shift with respect to use of primary energy source mix. With the initiative taken by M/s GeoSyndicate Power Pvt. Ltd, utilization of geothermal energy for purposes other than direct use will see a substantial growth in the coming few years. Perhaps this initiative will change the data in the entire table appended in future.

7. ACKNOWLEDGEMENTS

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APPENDIX: STANDARD COUNTRY UPDATE TABLES

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	Nil	Nil	90895	477744	32135	197052	3310	23196	6158	10789	123668	708781
Under construction in December 2009	Nil	Nil	2000	10512	100	613	ND	ND	ND	ND	1100	11125
Funds committed, but not yet under construction in December 2009	100	850##	3000	15768	500	3066	ND	ND	100	175	2700	19009
Total projected use by 2015	100	850	95895	504024	32735	200731	3310	23196	6258	10964	127468	738915

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2009 (other than heat pumps)

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)

Enthalpy information is given only if there is steam or two-phase flow

Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 ($MW = 10^6$ W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°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

Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1)]	Maximum Utilization Flow Rate (kg/s)	Temperature (°C) Inlet	Temperature (°C) Outlet	Enthalpy[2)] (kJ/kg) Inlet	Enthalpy[2)] (kJ/kg) Outlet	Capacity[3)] (MWt)	Annual Utilization Ave. Flow (kg/s)	Energy[4)] (TJ/yr)	Capacity Factor[5)]
Himalayas	B,O	400[a]	95	15			134	100	1055.2	0.087
Cambay	B	100[b]	85	25			25	15	118.71	0.15
West coast	B	100[c]	72	30			22	10	55.39	0.098
SONATA	B	100[e]	95	25			18	100	923.3	1
Bakreswar(W.Benga	B	90[f]	66	30			13	22	104.46	1
Godavari	B	150[g]	58	30			17	28	103.4	0.925
Bihar	B	250[d]	65	30			36	40	184.66	1
TOTAL		1190	536	185			265	315	2545.12	4.26

O: Cooking
a: cumulative discharge of 4 springs
b: cumulative discharge of 10 springs
c: cumulative discharge of 16 springs
d: cumulative discharge from 6 springs
e: discharge from two bore wells
f: cumulative discharge from 4 springs
g: cumulative discharge from 6 spirings

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. (°C) - outlet temp. (°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. (°C) - outlet temp. (°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]	265	2545	0.3045
Other Uses (specify)			
Subtotal			
Geothermal Heat Pumps			
TOTAL			

[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)]	(all)	31		73		0-2-0.6
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total		31		73		0.2-0.6

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 Progra
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	2		15		4	
2006	4		15		4	
2007	4		15		4	
2008	4		15		4	
2009	4		15		4	
Total	18		75		20	

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	0.022		0.00816			100
2000-2004	0.133		0.0122		70	30
2005-2009	0.503		0.0321		75	25