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PRESENT STATUS OF GEOTHERMAL DEVELOPMENT IN EL SALVADOR AND CONTRIBUTION OF UNU FELLOWS IN THE GEOTHERMAL SCENARIO AND MANAGEMENT

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ABSTRACT

El Salvador has commercially exploited geothermal resources for 23 years. Development began in 1975 when a 30 MWe condensing type power unit went on line in the Ahuachapán field. Since then development has slowed due to low investment during the civil war, but in 1990-1992, a new investment cycle beganwith the running of two large projects Ahuachapán and Berlín, At the moment both projects are ongoing, the net increase being almost 70%, and they are expected to be finished by next year. The total installed geothermal power capacity will be 90 MWe in the Ahuachapán field and 55 MWe in the Berlín field by the year 2000. New government policies will affect the future development of geothermal resources due to the privatization of public service companies, anticipated levels of profit and the impact of environmental laws. Former UNU Fellows are playing an important role in field management and providing technical advice for these projects.

1. INTRODUCTION

El Salvador is located in Central America where the Cocos Plate is being subducted under the Caribbean Plate. This has formed a tectonic graben, which runs almost E-W through the country. Along the southern margin of the graben are the young andesitic volcanic chains which characterize the high-temperature geothermal fields (180-300°C). Five major fields have been identified lying on the northern flanks of the young volcanoes. Geothermal evaluation in El Salvador began in 1953 when the National Energy Company, CEL, carried out reconnaissance level geology, geochemistry, and geophysics studies as well as drilling of small diameter exploration and gradient wells in several geothermal prospects including Ahuachapán, Chipilapa, Berlín, San Vicente and Chinameca. Further exploration headed by the United Nations Development Programme (UNDP) during 1968-1971 characterized resources and established priorities for developing geothermal fields.

The first field to be developed was Ahuachapán, which is located in the western part of the country where it forms a geothermal area of about 100 km^2. It is associated with the Pleistocene age Laguna Verde volcanic group where the heat source of the system is believed to be located. Two major fault systems funnel fluids from the upflow zone located underneath the Laguna Verde, where fluids are believed to have temperatures close to 250°C (LBL, 1988). In the borefield, the geothermal wells produce almost single-phase fluid with temperatures of 220-240°C from depth 400 to 800 m. The geothermal fluid is then transported through the NNE-SSW faults to the main outflow zone, known as El Salitre spring. This spring had an initial discharge of almost 1000 l/s of 65-70°C fluid. The commercial production of the Ahuachapán field began in July 1975 when a 30 MWe power plant went on line. In order to complete the 95 MWe installed capacity, two additional power units were commissioned in October 1975 and March 1981.

The second field of the geothermal development programme was Chipilapa, which is located to the east of the Ahuachapán field. During geothermal exploration conducted by the UNDP, drilling of well CH-1 was undertaken but due to low production capacity observed in this well the commercial development was moved to Ahuachapán. In 1986, CEL again began exploration of the field in order to install two 5 MWe backpressure units. Seven wells were drilled from 1988 to 1991, two showed very low permeability, and four of them presented good permeability, but quite low temperature (180-200°C) and low well head pressure (WHP). Due to the lack of high WHP wells (6-10 bar-g) the project was stopped and the units were stored in CEL's warehouse.

The third prospect to be developed was the Berlín field, which is located in the eastern part of the country. It is associated with the Tecapa volcanic group, where the most recent activity has been dated by C^{14} as 700 years old (GENZL, 1994) and the Berlín caldera of Pleistocene age. Geophysical anomalies (MT and Schlumberger sounding) cover an area of about 50 km^2. A small NW-SE graben cuts through the northern part of the Berlín caldera and it is believed that the faults that form the graben, along with the conjugated NE-SW faults, transport the geothermal fluid from the upflow zone close to the young craters, towards the wellfield. This fluid is believed to discharge through several hot springs close to the Lempa river. The wells in the Berlín field discharge fluids with temperatures in the range of 280 to 310°C, chloride contents of about 6000 ppm, and dryness close to 30% from depths of about 1800 to 2300 m (Monterrosa, 1993). Geothermal exploration in the Berlín field began at the same time as in Ahuachapán. During the geoscientific investigation carried out by the UNDP, well TR-1 was drilled to a depth of 1458 m identifying a geothermal resource of at least 250°C. During 1976-1981 CEL conducted a resistivity survey and five wells were drilled which proved the production potential to be close to 24 MWe. A feasibility study was carried out in order to assess the power potential of the field. Further development was suspended at the field as most of CEL's work was concentrated at Ahuachapán field and because of the civil war period. From 1990-1992 two well head back pressure units were installed, but due to the lack of injection wells, only one unit went on line (TR-2) for production, and well TR-9 as an injection well.

2. POWER PRODUCTION AND FUTURE DEMAND

By late 1997, the total installed capacity of the country was around 943 MWe from several power sources but the available capacity was 787 MWe, which corresponds to 83 % of the installed capacity. The total electrical energy produced was 2600 GWh with an income of US$ 254 millions (Table 1). The average cost of electricity was close to 7.17 US cents. However, the same year demand was 3,600 GWh, which means an 8.2% increase, compared to the 1996 demand and the total power demand was 666 MWe, which corresponded to an increase of 6.4%.

Table 1: Installed and available capacity

Source	Installed (MWe)	Available (MWe)	Net energy (GWh)
Hydroelectric	388 (41 %)	342 (44 %)	1424 (40 %)
Geothermal	105 (11 %)	61 (8 %)	453 (13.%)
Thermal	305 (33 %)	257 (32 %)	745 (21 %)
Private generator	144 (15 %)	127 (16 %)	925 (26 %)
Total	943 (100 %)	787 (100%)	3600 (100%)

According to CEL's studies the demand of the country is rising between 8-9% every year, which means in the year 2000 the power capacity required will be close to 753 MWe and the total energy consumption will be 4214 GWh per year. Figure 1 shows the behaviour of the demand and the power production. During the last three years, CEL's total production has declined due to production of private generators with long term contracts. However the geothermal energy produced is almost stable. After the peace agreement (1992), total demand has risen every year.

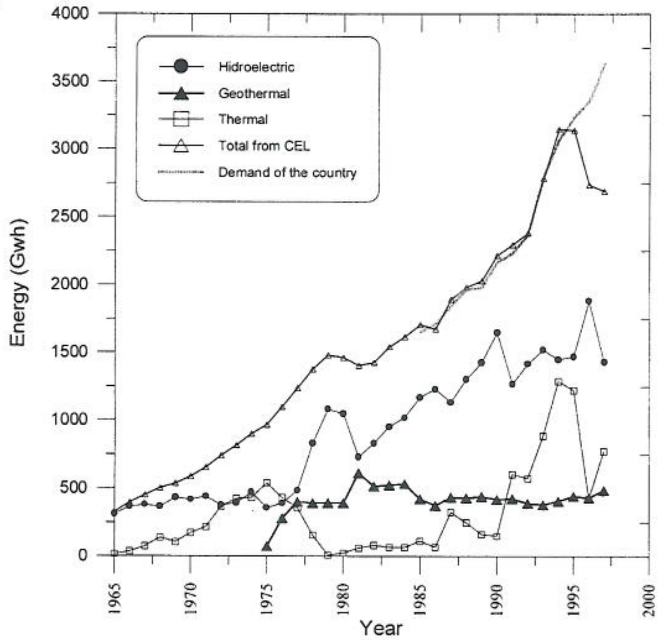

Figure 1: CEL's electricity power production history

3. PRESENT STATUS OF THE GEOTHERMAL DEVELOPMENT

In 1985, CEL presented a 1985-2000 Energy Plan proposal in order to increase power production in response to rising demand. In this proposal the main development of the power production must be undertaken by geothermal resources. Later, with loans of almost US$ 110,000,000 coming from the Inter-American Development Bank (IDB), CEL was able to carry out two main geothermal projects: "Stabilization of Ahuachapán geothermal field" and the "First condensing development of the Berlín geothermal field."

The Ahuachapán project includes the following activities:

1. Drilling of 10 production wells at the inferred upflow zone in the southern part of the wellfield;
2. 4-6 km injection line, from the power plant to the Chipilapa wells;
3. Gathering system for new production wells;
4. Optimizing of ejector system in order to increase the efficiency of the power plant;
5. Upgrade of electrical equipment in power plant.

According to feasibility studies, an expansion of the production zone to the southeast of the field was needed in order to increase the power capacity of the field up to 95 MWe, and injection had to be implemented in order to maintain the reservoir pressure (LBL, 1988; Electroconsult, 1994). Figure 2 shows the well locations and the make-up expansion.

The aim of the new wells is to intersect the main faults where the thermal fluids are moving from the upflow to outflow zones. At well site AH-34 three production wells were located. The vertical one has the fault Los Ausoles as its target and wells AH-34 A and AH-34 B the La Planta Fault. Well site AH-33, located 150 m away from AH-18, was included due to high temperatures observed in well AH-18 (240°C). Wells AH-4bis and AH-16-A were drilled in order to recover the original production of AH-4, and to reach the reservoir, respectively. The drilling programme began in 1997; at the moment 9 wells have been drilled. Table 2 presents the results for these wells:

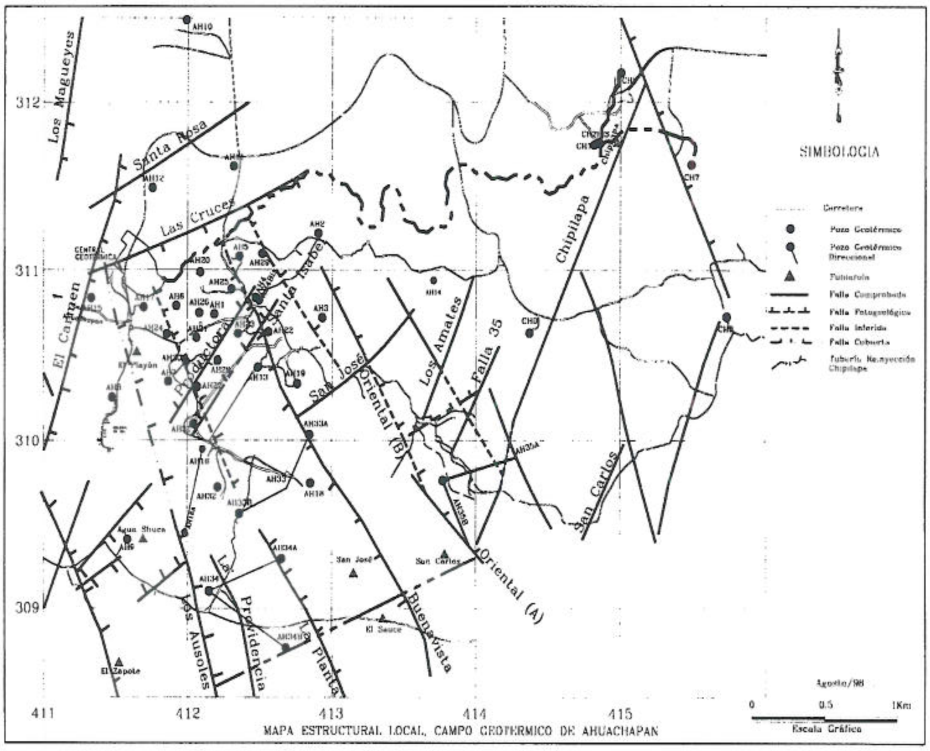

Figure 2: Structural map of the Ahuachapán geothermal field

Table 2: Results for new Ahuachapán wells

Well No.	Drilling period	Depth (m)	Results
AH-4bis	April-May 1997	650	Good production well, total flow rate 80 ks/s, enthalpy 1300 kJ/kg, 15 MWe power production, at the moment production is declining
AH-34	May-June 1997	1601	Feed zone temperature is around 250°C, good permeability observed (II=4 l/s/bar), presently highest temperature of the field but the main feed zone is deeper (1200-1300 m); the production is only 20 kg/s at WHP 4.5 bar
AH-34 A	July-Sept. 1997	1628 (MD)	Same results as AH-34
AH-34 B	Oct-Dec 1997	1645 (MD)	Same results as AH-34
AH-33 A	June-Aug 1997	1608 (MD)	Low permeability was observed (II=2 l/s/bar), temperature almost 250°C, production quite low
AH-33 B	Aug-Oct 1997	1600 (MD)	Feed zone temperature close to 250°C, good permeability observed (II>10 l/s/bar), the total mass flow rate 60 kg/s
AH-16 A	Jan-Mar 1998	1460 (MD)	Feed zone temperature is 225°C, High permeability (II>10 l/s/bar), total flow rate 60 kg/s
AH-35 A	April-June 1998	1507 (MD)	Fair permeability was observed, feed zone temperature 240°C, the total flow rate is close to 40 kg/s at 5 bar
AH-35 B	June-Sep 1998	1500 (MD)	Similar results as for AH-35 A but quite low permeability observed
AH-35 C	Drilling suspended		

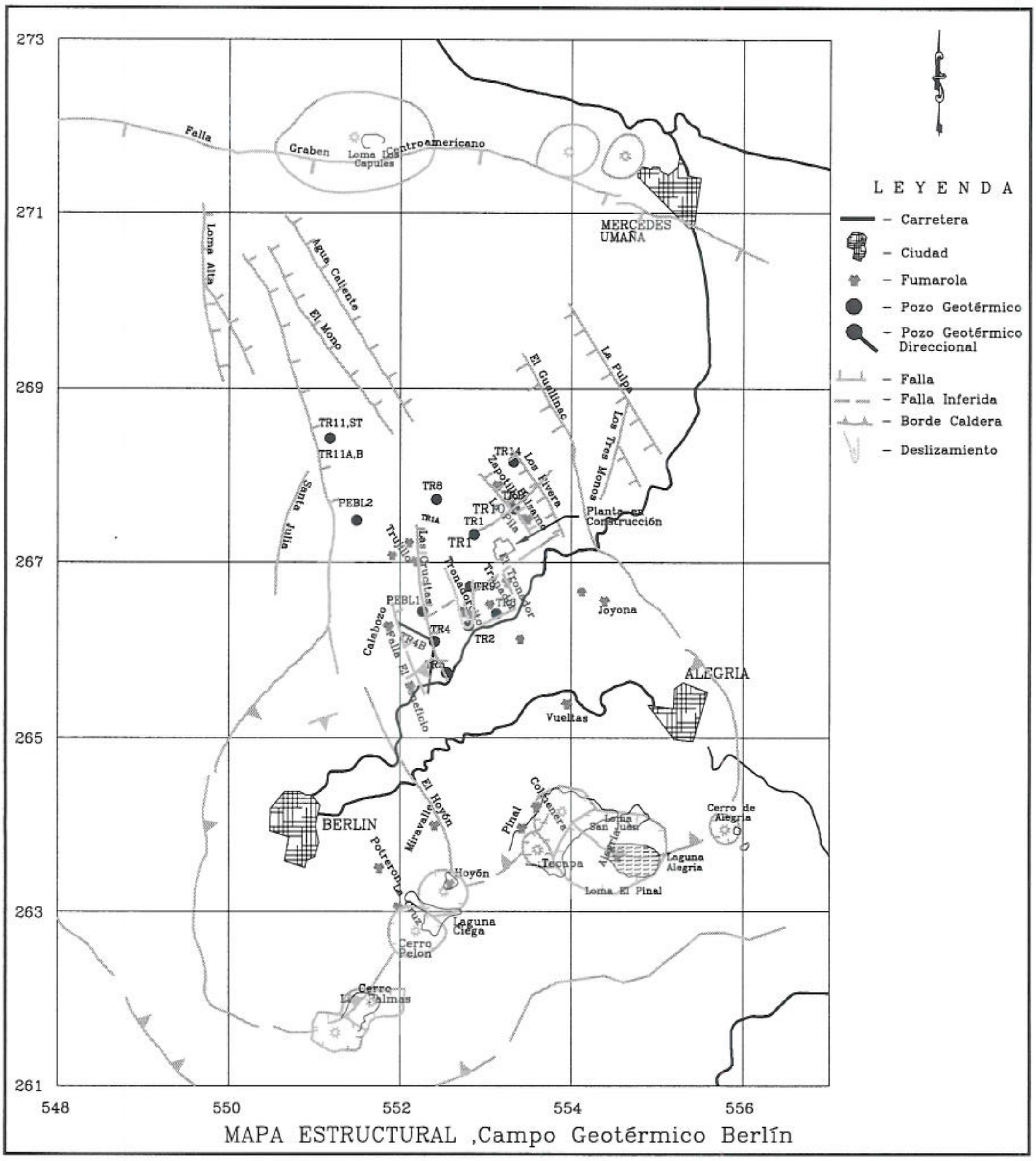

Figure 3: Structural map of the Berlín geothermal field

The injection line to the Chipilapa wells is under construction and is expected to be finished in late February 1999. However, it will not be until year 2000 that the effects of the injection into the reservoir can be evaluated. The change of ejector and up-grading of the electrical equipment in the power station is now under bidding process and it is expected to be finished early next year.

The Berlín project includes the following activities:

1. Construction and putting on-line two condensing type units of 27.5 MWe each;
2. Collection system and injection line;
3. Drilling of 14 production and injection wells.

At present, 8 wells have been drilled. Figure 3 presents the well locations at the Berlín field. Table 3 presents a summary of the results. The results of the new and existing wells at the Berlín field indicate that available steam is sufficient to operate the two condensing units (2x27.5 MWe) which require close to 100 kg/s of steam; with an efficiency 1.9 kg/s/MWe (Sumitomo/Fuji data), the injection capacity of the field must be around 245 kg/s. Table 4 summarizes the steam and injection capacity.

Table 3: Well results in the Berlín geothermal field

Well	Drilling period	Depth (m)	Results
TR-11	June - October 1997	2500	No permeability was observed, only at the shallow aquifer water loss circulation was observed
TR-11 ST	October - Nov. 1997	2050	A side track hole, drilled from TR-11 at 1450 m oriented to S78W with horizontal drift of 200 m; low permeability was observed, injection capacity 23 l/s at 500 psi
TR-11 A	Dec. 1997 - Jan. 1998	504 (MD)	Intersects a permeable zone at 490 m in accordance with shallow aquifer, injection capacity 70 l/s (II= 3 l/s/bar)
TR-11 B	Jan. - Feb. 1998	614 (MD)	Well located 45 m south of TR-11 A; it is a deviated well oriented N17W; No permeability was observed
TR-11 C	Feb.- March 1998	800 (MD)	Same as above, this deviated well was oriented S68W; no permeability was observed
TR-4 A	May - Dec. 1997	2156 (MD)	After much sticking and fishing, the well reached the reservoir (II= 5-6 l/s/bar); the well was oriented S20W, the temperature is close to 300°C and total flow rate is 30 l/s; more than 4 MWe are expected.; no more discharge tests have been carried out at present
TR-4 B	Dec. 1997 - Mar. 1998	2292 (MD)	Well was oriented N56W, intersecting the reservoir (II=4-5 l/s/bar), temperature close to 300°C, total flow rate is 30 l/s; more than 4 MWe are expected; no more discharge tests have been carried at present
TR-4 C	March - Aug.1998	2179 (MD)	Well was oriented N6E, intersecting the reservoir (II= 2-3 l/s/bar), total flow rate 27 l/s; more than 4 MWe are expected; no more discharge tests have been carried out at present
TR-5 A	March - Aug. 1998	2321 (MD)	Well was oriented straight to the south, intersecting the reservoir (II=7 l/s/bar), total flow rate 25 l/s; more than 7 MWe are expected; no more discharge tests have been carried out at present
TR-5 B	Sept. 1998		Drilling of well is going on at present; well oriented N17E
TR-1 A	Sept. 1998		Drilling of well is going on at present, well is oriented N5E

Table 4: Well production and injection capacities

Steam availability		Injection capacity	
Well	**Steam at 10 bar-a (kg/s)**	**Well**	**Injection (kg/s)**
TR-2	20	TR-8	60
TR-9	12	TR-14	40
TR-5	16	TR-10	15
TR-5 A	15	TR-11A	70
TR-4	10	TR-1 A	50*
TR-4 A	10	TR-1B	50*
TR-4 B	12		
TR-4 C	12		
TR-3	10		
Total	**117**	**Total**	**285**

* Estimated data

At the Berlín field, the main goal of the drilling strategy is to achieve the complete injection capacity required to operate the power station. At the moment the power station is under construction and is expected to be finished in late 1998.

4. NEW POLICY OF NATIONAL POWER PRODUCTION AND ITS EFFECT ON GEOTHERMAL DEVELOPMENT

The new policy of the National government is the privatization of the main public service companies. Power production is going to become the independent product of companies without any governmental subsidies perhaps as a joint venture with international investment companies. If the market for electricity generation is going to be open and competitive, then the power generators must reduce production costs in order to be "economically attractive" to the main buyer (distribution companies).

The big task of the geothermal power companies is to reduce the cost. The main aspects that could affect the general cost are:

1. Thermal efficiency of the system is close to 40% according to exergy analysis (Quijano, 1998);
2. Internal power consumption in the power plant is close to 15-20% of the gross power generation;
3. The capital risk to investment in make up and injection wells increases the total cost of the project and the future operation cost of the power station;
4. The knowledge of trained experts on the conceptual model of the fields must be an important part in the decision process (uncertainty vs. making decision);
5. The environmental law doesn't represent any direct advantage for geothermal operators; for this reason, there must be a focus on international agreements such as the Kyoto Protocol (CO_2 bonus);
6. The low price of oil will have an important effect on geothermal development in the whole world.

The main and initial strategy is to reduce production cost by reducing the man power that could be less efficient or unnecessary according to the new requirements of the company. The immediate results are declining motivation and the unstable situation for workers.

Anyway, in the globalized world the new tendencies for the government do not stop. National geothermal operators must change into private companies which means work, looking for profits but taking care of the environment, and using this as an advantage against oil energy.

5. THE ROLE OF UNU FELLOWS IN GEOTHERMAL DEVELOPMENT AND MANAGEMENT

El Salvador has at present 15 former UNU Fellows which did receive training in, wellbore geology (2), geology (1), reservoir engineering (3), drilling (3), geophysics (2), geothermal engineering (1), geochemistry (1), data base management (1) and environmental studies (1). Thirteen are still working for CEL, where the Fellows have worked within their respective area of training. The work due to new projects requires more trained experts. In that sense, all the UNU Fellows are taking part in the development of geothermal resources. Examples of the roles of UNU Fellows: CEL formed an advisory team for the decision making process of the drilling strategy which included three UNU Fellows, the diary making decision on drilling at the rig is also carried out by two UNU Fellows, and finally, the new exploitation and field management is also carried out by UNU Fellows.

6. CONCLUSIONS

Exploitation for commercial purposes of geothermal resources in developing countries is becoming more difficult, taking into account the highly competitive price of oil as an alternative energy resource. In order to be more competitive, we must try to make the international environmental agreement a profitable advantage.

The development of geothermal resources in El Salvador as a part of the globalized media must be more cost efficient on a daily basis in order to be competitive against the oil-thermal generators. We must try to

1. Increase the efficiency of the system field-power station;
2. Optimize the exploitation-injection strategies by using numerical modelling;
3. Carry out an analysis of the "uncertainty vs. making decision" and how it effects the high cost of geothermal projects.

The main results of the two current geothermal projects in El Salvador are as follows:

1. The Ahuachapán geothermal field can perhaps be operated at up to 90 MWe but injection must be implemented as soon as possible in order to increase the reservoir pressure. Extraction from the newly drilled zone shows a direct effect on the production field, due to low recharge and pressure drawdown. The injection strategy must be flexible in order to make changes depending on the response of the reservoir.
2. The Berlín geothermal project looks to be in good shape. The 55 MWe power plant will go on-line in late December 1998. The results of the production wells seem to be successful. Injection will be a crucial point for the project. At this time, the injection capacity is almost 60% of the total injection capacity and we are expecting success for the injection wells which are now being drilled.

The UNU Geothermal Training Programme has made an important contribution to the geothermal development of our country, and the role of UNU fellows is becoming more important everyday, especially in the decision making processes of the geothermal projects.

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