Development of The Oguni Geothermal Field, Japan

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ABSTRACT

Electric Power Development Company Ltd. (EPDC) has been conducting an exploration and reservoir evaluation program in the Oguni field, central Kyushu, south-western Japan since 1983. EPDC has carried out various geophysical surveys, and has drilled 23 wells. As a result of these surveys, it has become clear that this field is characterized by the following three factors; high permeability in a wide area, moderate temperatures of 200 to 240 °C, and carbonate scale deposition in some production wells. This paper presents the characteristic features of the reservoir, and EPDC's development plan for the reservoir.

1. INTRODUCTION

Figure 1 indicates the location of the Oguni field. The Oguni geothermal field is located in the central part of Kyushu island, south-western Japan. The Hatchobaru geothermal power station (110MW) of Kyushu Electric Power Co. is located at a distance of 6 km from the Oguni field. In the Oguni area, many geothermal studies and surveys were conducted by the national government and a private company. Ministry of International Trade and Industry (MITI) surveyed a large area including the Oguni field to study the potential for large scale geothermal power development (NEDO, 1987), and identified some promising areas.

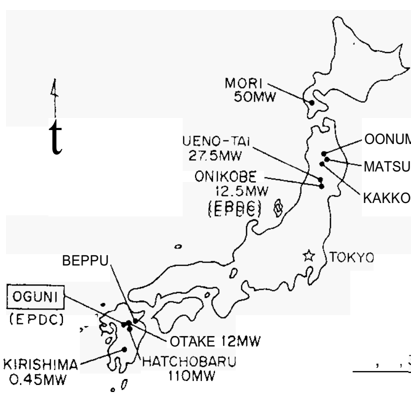


Figure 1 Location of the Oguni field and operating geothermal power plants in Japan.

EPDC, a governmental company established in 1952, has built and operates 55 hydropower stations with 7,633MW total capacity and six thermal power stations with 4,642MW total capacity, EPDC is also operating the Onikobe geothermal power plant with 12.5MW capacity since 1975.

EPDC began to survey the Oguni field, following a demand from MITI after the above mentioned national program was finished in 1983 (Fujita *et al.,* 1988). EPDC conducted an exploration program including various geophysical surveys and drilled, 12 small and 11 large diameter wells. A total discharge test using four production and five injection wells was carried out for four months from December 1991 to April 1992. Using these data and results of a reservoir simulation study, EPDC estimated the power capacity of the reservoir. EPDC is planning to start plant operation by the end of this century.

EPDC's exploration activity is characterized by the following two points. The first is the drilling of many slim holes (core drilling) in early exploration stage, which is helpful for not only reduction of exploration cost but also for detailed geological modeling and for preliminary reservoir evaluation (Garg *et al.*, 1994). Furthermore, three of the slim holes are used for the monitoring of reservoir pressure. Second point is that the mise-a-la-masse survey and CSAMT prospecting were conducted several times corresponding to the necessity of each stage of exploration (Abe, 1992). These results helped to understand the extent of the reservoir and to refine the conceptual reservoir model.

2. CONCEPTUAL MODEL OF THE OGUNI FIELD

2.1 Regional geological setting

Figure 2 shows the regional gravity map in central Kyushu (NEDO, 1987). The Oguni field lies in a regional subsidence zone referred to as the Beppu-Kuju Regional Subsidence Zone (BKSZ). BKSZ is characterized by large scale andesitic volcanic activity associated with north-south extensional stresses since the early Pliocene. Geologic structure has been influenced by continuous volcanic activity, extension and subsidence. The Oguni field is adjacent to the Shishimuta Subsidence Belt and the Kuju Uplift Belt, which are thought to have resulted from the regional volcanism and tectonics.

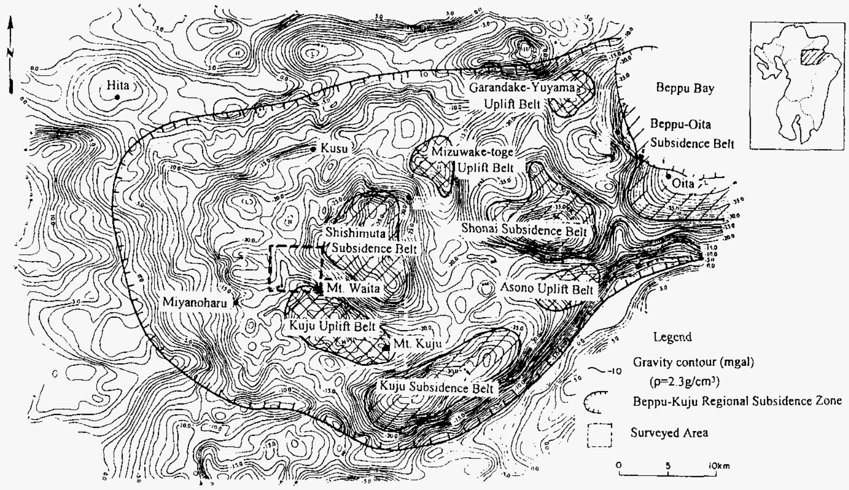


Figure 2 Regional gravity map in central part of Kyushu (NEDO, 1987)

The Oguni field lies on the northwestern boundary of the Kuju Uplift Belt, where the basement drops steeply to the northeast towards the Shishimuta Subsidence Belt. It is inferred that many faults and fracture systems are developed along the steep drop of the basement. The results of well drilling are consistent with the steep drop of the basement and the existence of a fracture system.

Geologic stratigraphy in the Oguni field is composed, in ascending order, the basement of pre-Tertiary granitic and metamorphic rocks, the Taio Formation of andesitic rocks in Neogene, Shishimuta formation of dacitic rocks in Early Quarternary, the Hohi Volcanic Rocks of pyroxene andesite in early to middle Pleistocene (2 to 0.5Ma), the Kusu Group, which is interfingered with the Hohi Volcanic Rocks, including sedimentary rocks and dacitic rocks, and the Kuju Volcanic rocks in late Pleistocene to Holocene (NEDO, 1987). The Hohi Volcanic Rocks and the Kusu Group are most important for the reservoir system. The Hohi formation is brittle such that fractures are easily developed and retained for a long time; it forms a horizontal permeable layer in the area of the steep drop of the basement. The Kusu group includes several sedimentary layers and the Nogami mudstone, the thickest one of the group, plays the role of cap rock for the reservoir.

2.2 Fault system

As the basement drops steeply towards the northeast of the field, faults are inferred to have a strike from northwest to southeast in the northern part of the field; some of the faults were encountered by geothermal wells. A representative fault with a northwest to southeast strike, called the Takenoyu fault, runs through the central part of the field as shown in Figure *3*. This fault has not been identified on the ground surface. However, several geophysical surveys and topographic features indicate its existence. Several wells were drilled on the two sides of the fault; these wells revealed that Shishimuta formation is encountered on a higher elevation on the northern side of the fault than the southern side and the vertical offset is over 400 m. Furthermore, at some distance north of the Takenoyu fault, Shishimuta formation appears at the same elevation as on the southern side of the fault. This suggests that a hidden fault lies to the north of the Takenoyu fault and that these two faults form the local horst structure (Figure 4). This horst structure might have been caused by the local uplift and subsidence of the basement; however, the exact mechanism is not been understood at present. Drillings results indicate that the Takenoyu fault is accompanied by some parallel faults; these faults form a nearly vertical high permeability zone of several hundreds meter in width.

2.3 Fluid flow

Figures 3 and 4 also show the conceptual fluid flow model in plane and vertical section respectively. Mt.Waita is one member of the Kuju volcanoes, and is composed of hornblende andesites; it is believed to have been active from 0.3 to 0.5 Ma.

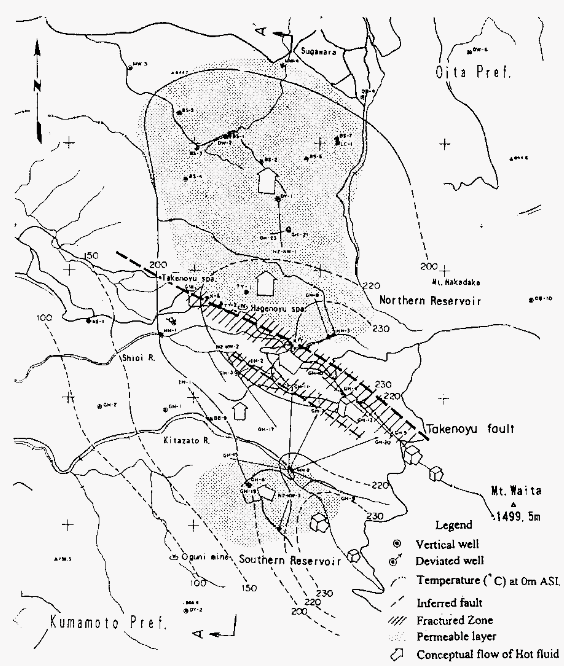


Figure 3 Conceptual model of the Oguni reservoir

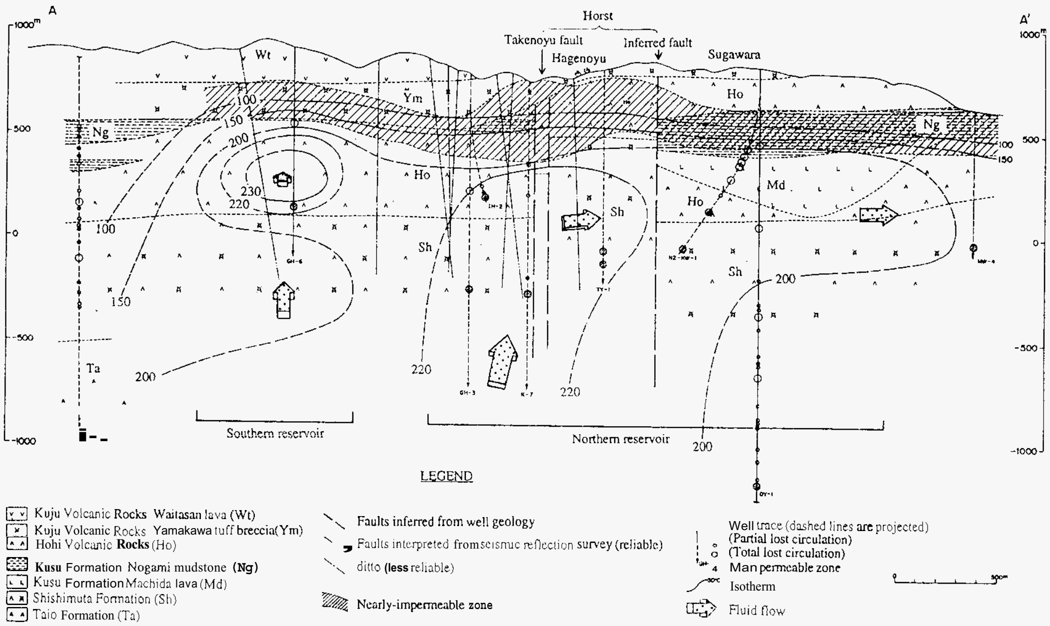


Figure 4 A vertical section the Oguni geothermal field

The residual magma of Mt.Waita is possibly the heat source of the Oguni geothermal system. The geothermal fluid is heated by the residual magma at depth under Mt.Waita, and flows in a northwest direction along the Takenoyu fault zone. The geothermal fluid then flows laterally northwards passing through the high permeability layer of the Hohi Volcanic Rocks and the upper part of the Shishimuta formation.

The Oguni reservoir is to be separated in two parts, i.e., a northern and a southern part. The northern reservoir covers a large area in the north (including the Takenoyu fault zone), whereas the southern reservoir is restricted to a small area. Figure *5* shows the correlation between reservoir pressure and elevations of feedpoint in the wells. The southern reservoir has a higher pressure (one MPa) than the northern reservoir. The reason as to why the reservoir is divided into two areas is not understood in detail. A nearly-impermeable zone is considered to exist between the two zones.

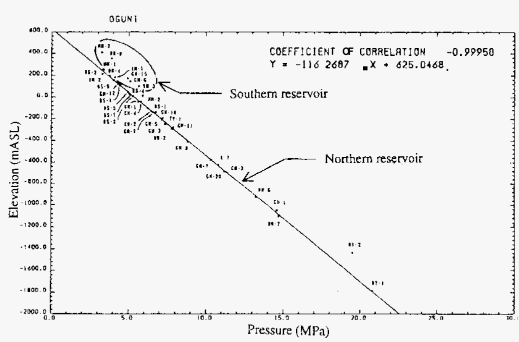


Figure 5 Reservoir pressure profile in the Oguni field

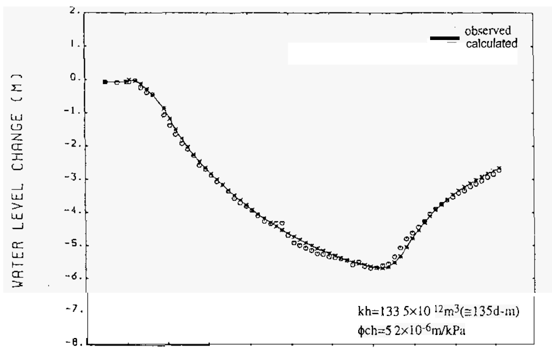
This separation is confirmed by the results of interference tests. A pressure response corresponding to production from the northern reservoir has never been observed in the southern reservoir.

The geothermal fluid in the southern reservoir also rises from depth and flows laterally in the Hohi Volcanic Rocks. The direction of lateral flow in the southern reservoir is not clear; it is possible that the hot fluid flows northwards through a narrow flow channel in the impermeable zone (Figure 3). The drilling data imply that the southern boundary of the southern reservoir is almost impermeable. Two natural hot springs are located on the western side of the southern reservoir; however the source fluid for these hot springs, which is characterized by sulfate ion, is considered not to be related to the southern reservoir fluid characterized by sodium-chloride.

There are several natural springs and fumaroles in Takenoyu and Hagenoyu area in central part of the field. Surface discharge fluid is geochemically characterized by bicarbonate ion, and is considered to come from meteoric water and is heated by either conductive heat and/or a steam leak from the reservoir. Fumaroles are especially valuable for the residents in that area, and are used for house heating, steam cooking, heating water for bath and drying of agricultural products. Therefore, it is important not to adversely affect these natural discharges.

3. RESERVOIR PERMEABILITY

In the Oguni field, the reservoir pressure is observed in six wells (NEDO, 1992) and the water level is observed in three wells (NEDO, 1988). These wells are used as observation wells in interference tests in discharge test in the Oguni field. From the analysis of pressure interference data, it became clear that the reservoir has high permeability in a wide area. Figure 6 shows the water level response, which is almost equal to reservoir pressure response, observed in well MW-4 in the northern most part of the field. Well MW-4 is 2.5 km distant from the main production zone. This response was observed during the 1991 total discharge test (four months in duration). Figure 6 also shows the match obtained using the line source solution. Analysis of these data imply a very high permeability-thickness product (kh) of 135 darcy-meter. Figure 7 shows the kh distribution obtained using all the interference data. The high kh area extends over 3 km in a north-south direction. Furthermore, an area along the Takenoyu fault has a permeability-thickness of 300 darcy-meter. High permeability over a wide area is one of the characteristics of the Oguni geothermal field. This is an important factor in the plant design.



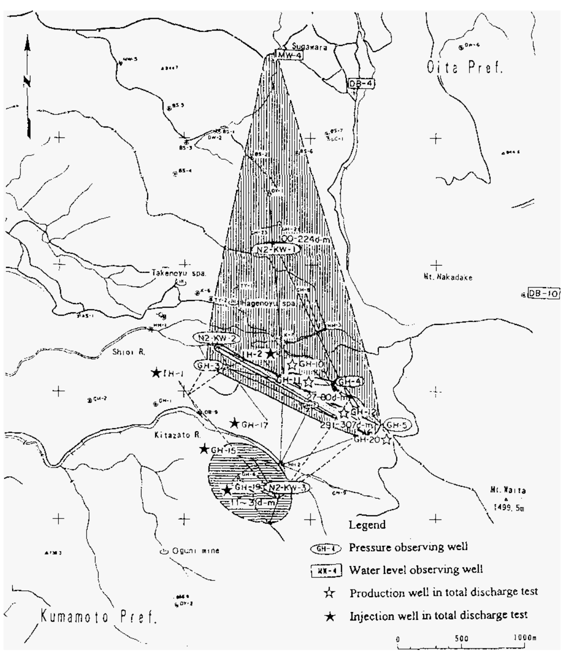


Figure 7 kh Distribution in the Oguni field

4. SCALING PROBLEM

Prior to the total discharge test, EPDC conducted single well discharge tests using two production wells to obtain accurate kh values for the region between the production and pressure observation wells. In these discharge tests, a wire line was set in each production well during discharge to examine the occurrence of carbonate scaling. After one week to ten days discharge, the wires were pulled out and the deposition of carbonate scale was confirmed. As a result, it is planned to inject a chemical downhole to prevent scaling in the plant. The appropriate chemical has already been developed and used in the Mori geothermal power plant operated by the Hokkaido Electric Power Co.; Mori is the first Japanese geothermal field with carbonate scaling problems (Fujii, 1988). In the Oguni field, however, it is not known if carbonate scaling occurs in all of the production wells; also the appropriate rate of the chemical injection needs to be determined. EPDC is conducting a research and development program for solving the scale problem. The carbonate scale deposition in the Oguni field is described by Todaka *et al.* (1995).

Table 1 shows chemical composition of discharged fluids from four production wells in the total discharge test. As for Ca content, it is not as high as that of the Mori geothermal field with the chemical injection. The Oguni samples were collected without injection of the chemical; however, Ca content of the Oguni fluids did not change in samples obtained before and after stopping the chemical injection. It is therefore likely that the Ca concentration lies on the critical line for carbonate scaling.

Table 1 Chemical composition of discharged fluid in The Oguni field

(separated water)

Well	GH-IO	GH-11	GH-12	GH-20
Date	Apr.8,'92	Apr.9,'92	Apr.9,'92	Apr.9,'92
pH	8.8	8.9	9.0	8.8
TSM	3420	3350	3260	3560
EC(μs/cm)	5100	5000	4900	5300
Na	929	900	879	950
K	129	124	121	134
Ca	23.2	25.0	23.4	22.0
Mg	0.01	0.01	<0.01	0.01
T-Fe	0.01	0.02	0.01	0.01
Al	0.62	0.69	0.79	0.77
Li	5.01	4.16	4.71	5.22
NH4	0.19	0.21	0.23	0.22
SO4	53	59	65	58
Cl	1590	1530	1430	1620
T-CO2	54.7	41.2	57.3	56.9
I	0.25	0.24	0.28	0.29
Br	3.06	3.07	3.08	3.50
F	3.85	3.45	3.58	3.78
T-Hg	<0.0005	<0.0005	<0.0005	<0.0005
As	2.03	2.04	1.72	2.11
B	21.8	20.1	19.9	20.8
T-SiO2	595	576	580	615
H2S	0.07	0.11	0.05	0.05
δD(‰)	-52.8	-53.5	-52.0	-51.5
$\delta^{18}O$(‰)	-6.1	-6.1	-6.1	-6.1

(condensed water)

pH	4.4	4.5	4.4	4.6
δD(‰)	-70.3	-68.3	-70.7	-69.3
$\delta^{18}O$(‰)	-10.0	-10.1	-10.3	-9.9

(non-condensable gas)

gas/water%	0.063	0.053	0.075	0.054
CO2(%)	93.0	95.1	94.9	93.0
H2S(%)	4.6	2.2	3.0	2.5
R-gas(%)	2.4	2.7	2.1	4.5

*units (mg/l) except described, (%): vol.%

Silica contents shown in Table 1 may possibly cause silica scale deposition in injection pipe lines and inside of injection wells. Because a double flashed type system is planned for the power plant, the temperature of the secondary flashed water is below 100°C. The above mentioned research program will also deal with the silica scaling problem, because a fairly long pipe line for reinjection of water is planned as discussed below. EPDC has so far investigated retaining tank system and pH control methods in order to reduce silica scale. The retaining tank system, which makes use of the fact that the poly-silicate has deposition problems than the mono-silicate, is effective in the high silica content systems (Hirowatari, 1988). In the Oguni field, however, silica content is not as high as the case of Hirowatari (1988). In the case of Oguni waters, it takes two to three hours to attain the equilibrium between mono-silicate and poly-silicate, and the retaining tank system is not effective.

5. RESERVOIR CAPACITY

EPDC evaluated the capacity of the Oguni reservoir by means of a three dimensional numerical reservoir simulation. In the simulation, *32* cases were studied corresponding to various production-injection strategies and power plant sizes. Figure 8 indicates the makeup well requirements for production. Hatched area in Figure 8 denotes the existing five wells in the northern reservoir. These wells are sufficient to supply a *27* MW plant at the beginning of plant operation; just *3* makeup wells can produce the necessary amount of the fluid for 30 years. In this case, the southern reservoir is not used for either production or injection. However, our detailed study revealed that the southern area is suitable for small amounts of production.

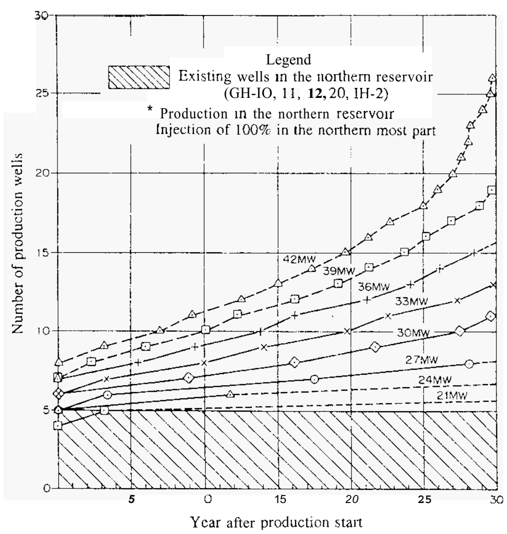


Figure 8 Increasing pattern of production makeup wells

The injection area is planned in the northern most part. If the injection area is nearby the main production area along Takenoyu fault, injected water might invade and rapidly cool down the production zone. Therefore the injection area should be located far enough from the production zone. The best production strategy is to produce large part of the necessary fluid from the northern reservoir along Takenoyu fault, and a small part of the fluid the southern reservoir, and to inject the waste brine in the northern most part. One production well has already been drilled in the southern reservoir, and six production wells are available at present. EPDC also studied the reservoir capacity from an economic view point and concluded that the maximum sustainable capacity is *30* MW.

Figure 9 shows a plan view of the Oguni project. The Oguni plant uses long pipe lines from the power station to each of the production and injection pads. This is dictated by the topographic features, the national park restrictions, and the reservoir characteristics. As the area of Mt.Waita is the special reserve area of the National park, any industrial development is prohibited in the area. As shown in Figure 9, the main production pads (pads **A** and B) are located at the bottom of steep valleys. The power station is situated on the ridge between these two production pads. The total length of pipe line is *3.2* km for production and 2.6 km for injection, respectively. Although the long pipe line raises the cost of electricity, this feature is expected to contribute to sustaining production from the Oguni field.

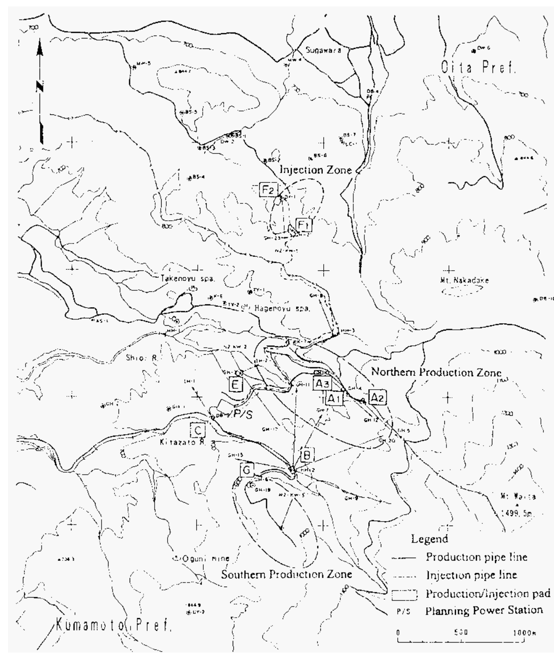


Figure 9 Plane view of the Oguni project

Fluid transport in fractured geothermal reservoir has been studied recently by many researchers. EPDC has initiated a study of fluid transport in fractured reservoirs based on the Oguni field data. The study of the fractured system should be useful for an accurate prediction of the behavior of injected water in the northern area. This work is described in Nakanishi ***et al.*** (1995).

6. CONCLUSIONS

After overcoming several problems associated with reservoir characteristics, topography, the national park restrictions and costs, the Oguni project is approaching the final stage. EPDC is presently (1994) negotiating the electricity price with the client.

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