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THE TIWI FIELD: A CASE STUDY OF GEOTHERMAL DEVELOPMENT FOR THE NATIONAL INTEREST

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ABSTRACT

The commercial potential of the Tiwi field was established in the 1960s by the Philippine Institute on Volcanology, and development by the National Power Corporation (NPC) and Union Oil Company (now Unocal) through its subsidary Philippine Geothermal, Inc. (PGI) began in 1972. The OPEC oil price shocks and rapidly growing power demand in the mid-1970s created a critical need to reduce oil imports and add generating capacity, and development at Tiwi was accelerated. Following startup it became apparent that the field was characterized by thin layers of lateral permeability and limited reservoir storage. Subsequently, groundwater entered the reservoir from sites of natural hot springs to the northeast. Generation has since been maintained by shifting production to high enthalpy wells in the western part to the field. Selective well stimulations and steam conservation have also helped maintain generation. The field currently provides just over 10% of the power in the Luzon grid, averaging about 150 GWh/month. This is accomplished with five units operating continuously and one unit in reserve. Generation to date has more than repaid the nation's investment in power plants and steam field, as well as conserved valuable foreign exchange.

INTRODUCTION

The Tiwi Geothermal Field is located on the northeastern flank of Mt. Malinao, an eroded Quaternary stratovolcano that is part of the chain of island arc volcanoes making up the backbone of the Bicol Peninsula (Datuin & Uy 1979, see Figure 1). The geothermal resource is a hot, moderately dilute (1 wt% dissolved solids) neutral chloride brine stored in a thick section of andesitic lavas and flow breccias (Figure 2). Concentrations of non-condensible gases averaged 3 wt% in steam prior to development, with concentrations over 5 wt% along the field's southeastern and northern margins. Reservoir intervals of a corrosive, acid-sulfate brine exist along the southwestern margin, and in a north-south belt across the center of the field. Prior to development the reservoir was liquid-filled and overpressured, with an impressive area of hot springs and geysers at Naglagbong Park, its predominant surface thermal manifestation.

Today, the geothermal field covers an area of 1,200 productive hectares, with 125 wells drilled in and around the field (Figure 3). The field is divided into 4 geographic sectors; Naglagbong being the eastern coastal lowlands, Kapipihan the rugged valley to the west, and Matalibong and Bariis the high ridges to the north and far west, respectively. Production wells feed 17 separation stations where water is separated from the steam before flowing to the power plants. The Tiwi steam gathering system totals 70 kilometers of pipeline.

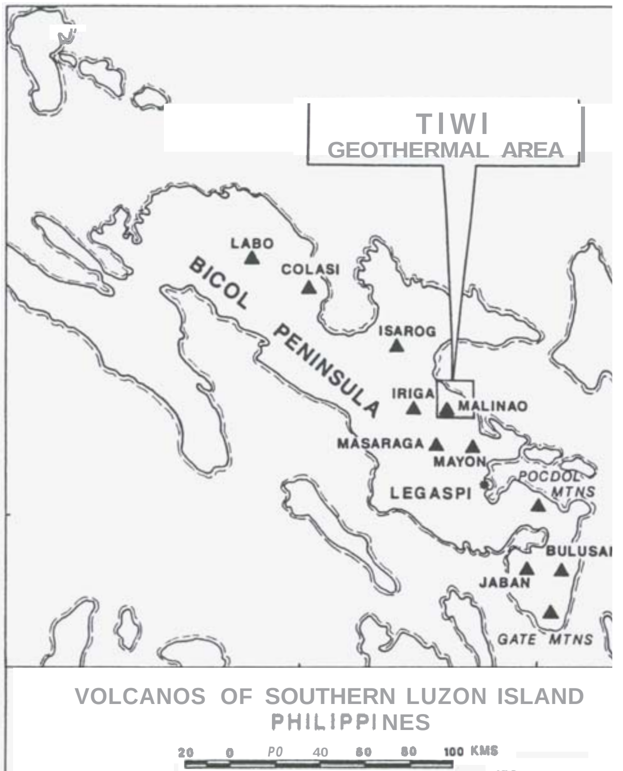


Figure 1

Approximately 50% of the field's waste brine is injected hot (185°C) into 3 wells located one kilometer southeast of the field. Waste cold brine is disposed of in a single well located on the field's eastern margin. Remaining brine is disposed of at the surface.

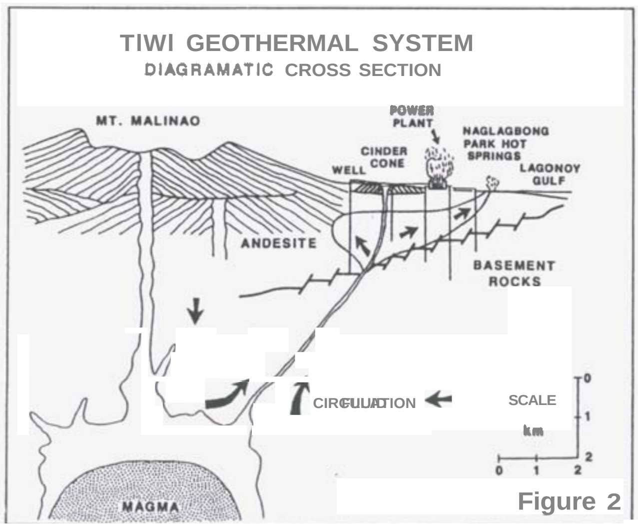
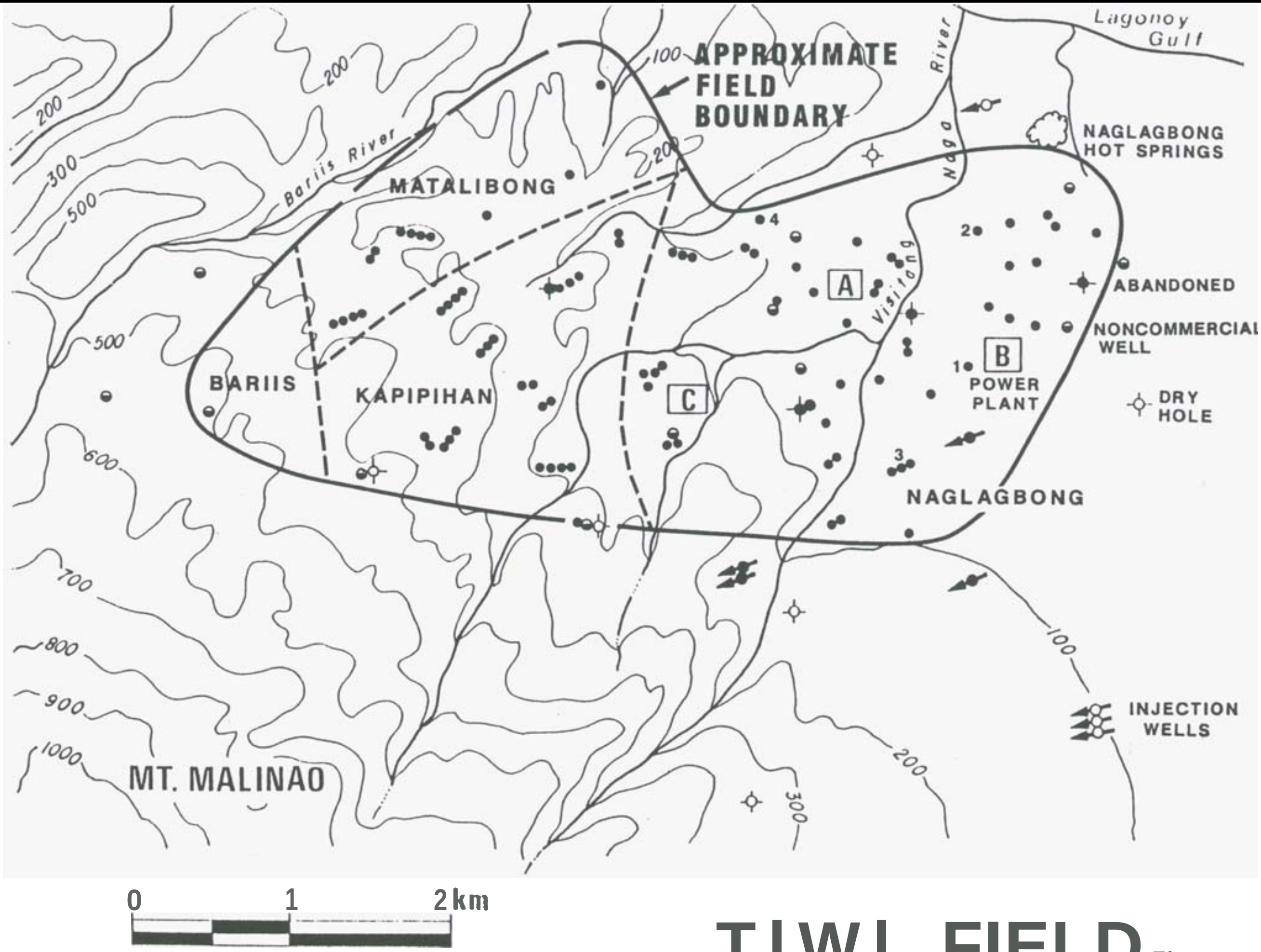


Figure 2



TIWI FIELD Figure 3

DEVELOPMENT HISTORY

A chronology of significant events in the development of Tiwi is presented in the form of a vertical timeline in Figure 4. Overlain on this is the concurrent history of spot market prices for Indonesian light crude oil.

The Commission on Volcanology, a Philippine government research agency, chose Tiwi as the pioneer area of investigation for geothermal energy and initiated studies in 1962. On April 12, 1967, a successful demonstration was made on the use of geothermal energy for power generation by piping steam from a shallow exploratory well to a small turbo-generator.

By 1970, the Philippine Government, recognizing the potential benefits from geothermal development and realizing that Tiwi had reached the stage for commercial development, directed the National Power Corporation (NPC) to develop and exploit the field. For this purpose an agreement was reached with Union Oil Company of California (now Unocal) to develop the Tiwi geothermal field through its local subsidiary, Philippine Geothermal Inc. (PGI).

A service contract to this effect was modeled after Unocal's contract with Pacific Gas and Electric Company on The Geysers steam field in California. The NPC-PGI agreement was duly signed in Los Angeles, California on September 10, 1971. The contract basically provided that for certain considerations, PGI would undertake the development of the Tiwi field and deliver the necessary steam to a power plant that NPC would construct to utilize the geothermal energy. Further, the economic viability of a geothermal power plant compared to an equivalent alternative energy source would have to be demonstrated in the first plant in Tiwi. Otherwise, the expenditures of PGI in the development of the field would not be reimbursed. The NPC's risk in the steam field development was limited to their initial 25% share in the investment. The contract was revised in 1975 to increase this share to 55%.

The first deep exploratory well, Naglagbong No. 1, was drilled in early 1972 and discovered a deep high temperature resource suitable for commercial development (Alcaraz, 1976). Drilling then concentrated on delineating the resource. The deliverability and inferred reservoir volume proven by the initial 4 wells were encouraging enough for PGI to recommend that the NPC commit to the first 110 MW plant (Units 1 & 2 at Plant A) in December 1974 (Horton et al., 1981).

The wisdom and timeliness of the decision to develop Tiwi was demonstrated in 1973 when the shock of the first OPEC oil price increase came. The Philippines then was 95% dependent on imported oil for its power generation needs (Malixi, 1982) and the three-fold increase in oil prices put severe stress on the national economy. Nuclear and fossil plant construction could not keep pace with surging energy demand in the mid-1970's, resulting in power shortages in Luzon. The national energy situation thus demanded an acceleration of NPC's capacity expansion plans. NPC decided to order four additional units of 55MW capacity ahead of reserves confirmation.

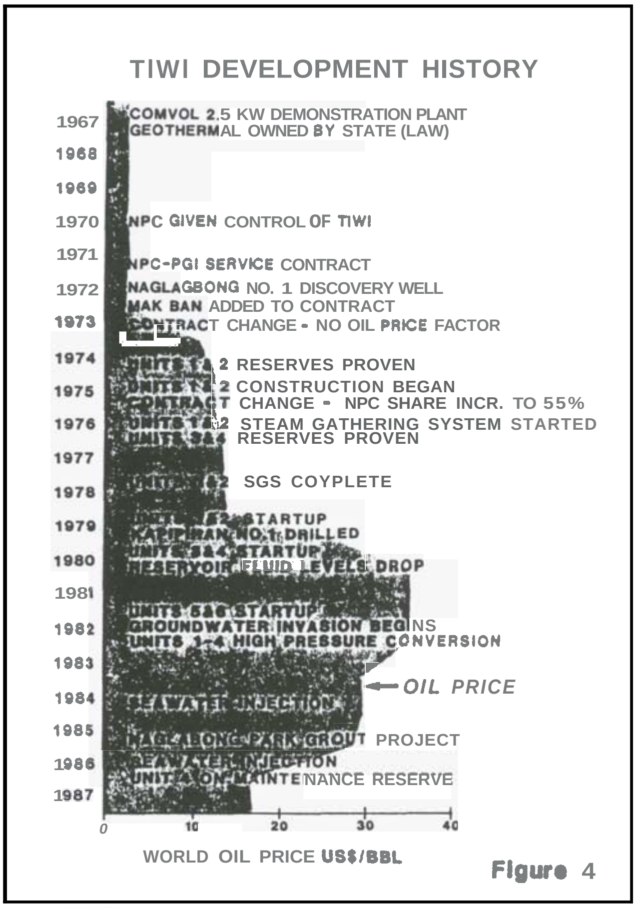


Figure 4

When oil prices rose in 1973, both partners recognized that the extraordinary leap was unanticipated. To restore the intended equitability of the original agreement, the NPC-PGI service contract was renegotiated. The steam pricing formula relying on oil prices was replaced by one reflecting more general economic conditions. Units 1 & 2 began commercial operation in mid-1979, just as the second round of OPEC price increases began.

Information available for preproduction reservoir evaluation did not discourage accelerated development. Well deliverabilities were consistently high and step-out drilling continued to find additional reservoir area in the Kapipihan and Matalibong sectors to the west of Naglagbong.

By 1979, exploratory drilling had proved 420 hectares of productive area at Tiwi, with in-field wells producing an average of 65 T/h steam. At the time of Unit 6 startup in 1982 Tiwi's drilled steam supply was 3840 T/h, 25% more steam than was needed to supply the 6 units.

Several of the early wells were drilled to more than 2.5 km depth to determine reservoir thickness, and found hydrothermal alteration, lost circulation and high temperatures over wide intervals. The few temperature reversals that were measured did not clearly indicate any problem areas. A year-long, four-well flow test was conducted during 1976, in part to obtain pressure interference data. Analysis showed the pressure behavior was also consistent with the model of a deep, hot reservoir suggested by drilling results (Gulati, 1977).

RESERVOIR RESPONSE

When Units 3 and 4 began operation in early 1980, the reservoir pressure and liquid level dropped, and production enthalpy increased. At that time Units 1-4 had dual entry turbines fed by high and low pressure separation facilities. The resulting shortage of water for low pressure steam required that the turbines be converted to single entry in 1982.

In response to the reservoir pressure and deliverability declines observed in 1980-81, a reservoir reevaluation program was implemented. The program included drilling additional deep wells and coring during drilling to collect intact rock samples of the reservoir for analysis. At about this time a new generation of high-temperature spinner surveying tools was introduced which allowed the direct identification of permeable zones in wellbores during injection testing. These in combination with other surveys showed that a large volume of high temperature rock at depth in the area dedicated to Units 3 and 4 was not contributing significantly to the fluid reserves of the field. The reservoir thickness in most of the Naglagbong area was shown to be less than 600 meters, perhaps a fourth of that previously indicated by the interference analysis and by drilling indicators.

By this time in 1982, an influx of cold groundwater began to affect the Tiwi steam supply. Reservoir pressure decline allowed cold groundwater to enter the reservoir through the conduits to the hot springs in the Naglagbong area. The cold water mixed with reservoir brine in shallow reservoir intervals, causing a number of wells to lose enthalpy and become non-commercial. Between 1981 and 1987, cold water influx spread through most of Naglagbong and into the eastern edge of Kapipihan. Figure 5 shows the progress of the front as defined by chloride dilution.

Efforts were made to identify the precise source of the intruding cold water and to limit the flow. Shallow wells drilled in the Naglagbong Hot Springs area delineated a groundwater sink; and a cementation program was completed in 1985 to block this suspected source. In addition, treated seawater was injected into the downflow in an attempt to slow cold water influx with mineral precipitation. Neither of these programs was measurably successful.

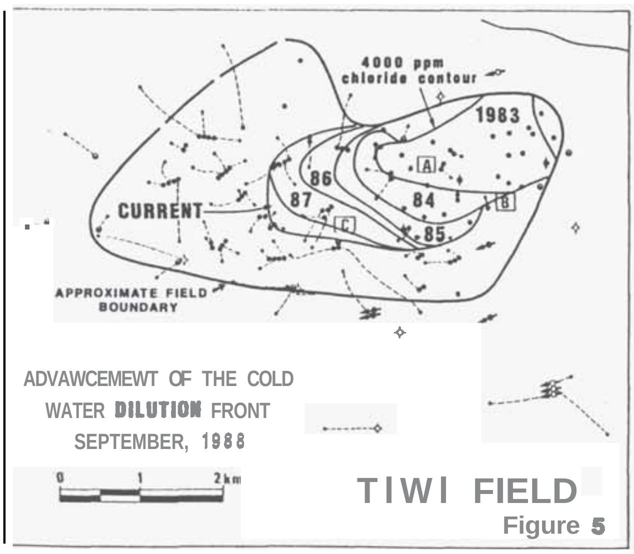


Figure 5

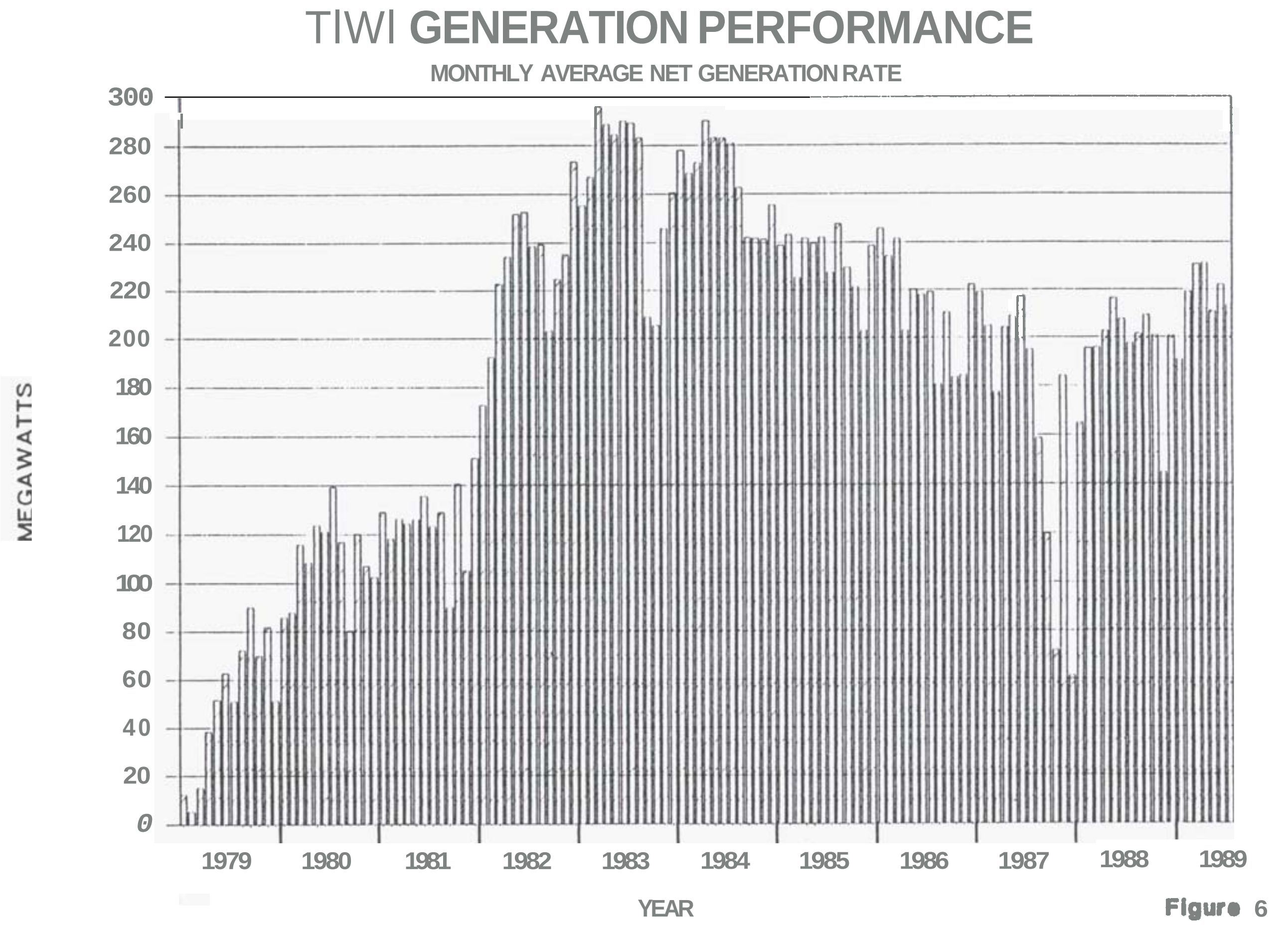


Figure 6

The ultimate recovery of heat from the influx-affected area does not appear to be greatly influenced by the rate of exploitation. Numerical modelling indicates that the inflow is essentially invariant under any commercial exploitation scenario. This is confirmed by the observation (Figure 5) that the spreading rate of cold water during 1984-87 did not decrease even while Naglagbong area production was being reduced by half. It is also consistent with the geologic model of the reservoir consisting of flat-lying permeable zones linked by vertical pathways. As hot liquid is produced from each interval the piezometric potential gradient favors its refilling with cold water. A lower production rate may actually reduce recovery from some zones by promoting greater mixing of cold and hot water.

In contrast to Naglagbong, the western half of the field has performed better than expected since 1982. It now produces two-thirds of the Tiwi steam supply. Pipeline cross-overs have been built to carry surplus steam from this area to the power plants in Naglagbong, maintaining generation during periods of peak demand and during power plant overhauls. The high enthalpy of wells in the west makes them amenable to throttling for steam conservation and field management flexibility.

Make-up drilling in the western sectors has been fruitful, with the 3 wells drilled in 1988 averaging 58 T/h steam. Additional make-up drilling, principally in Matalibong, is planned. Matalibong wells had previously had high concentrations of non-condensible gases (5-10 wt%), but these have dropped to acceptable levels in recent years. A program of step-out drilling is under way to develop additional reservoir north of the producing field.

GENERATION PERFORMANCE

Generation began at Tiwi with testing in December 1978. Commercial service started in 1979 with Unit 1 on May 15 and Unit 2 on August 29. Figure 6 shows the average gross generation achieved since then. Units 1 and 2 reached an average gross capacity factor of 93% in that first year. With the startup of Units 3 and 4 generation increased but could not be fully used because of transmission line limitations, resulting in a drop in capacity factor. By 1983 the average capacity factor reached 72% with the construction of a new 230 kV transmission line and the commissioning of Units 5 and 6. Field capacity factor has since declined, principally due to decreased field deliverability, and is now stable at approximately 62%.

Improvements in steam usage have made contributions toward maintaining generation. Efforts to reduce steam wastage, such as throttling wells during curtailments and piping otherwise unusable, high-gas steam to power plant ejectors have resulted in steady improvements in steam usage. Steam usage factors are also affected by periods of operation below optimum plant capacity, some of which are required by external grid considerations. Plans are underway to replace steam ejectors on some of the Tiwi plants with gas compressors, to further improve steam efficiency.

A successful well workover and stimulation program, aimed principally at the Naglagbong sector has also helped maintain generation. In 1987 it accounted for 20% of the steam supplied to the plants. Most of these workovers have been routine scale drill-outs, with acid stimulations and well recompletions performed where needed. More recently, a number of flooded, low enthalpy wells have been found to respond favorably to a "huff and puff" strategy of alternating production and shut-in.

Today, with one 55 MW turbine operated in reserve, monthly net generation averages about 150 GWh, representing just over 10% of the electricity supplied to the Luzon grid. Outside of a series of transmission line difficulties in late 1987, generation has remained relatively constant at this level since the second half of 1986. Enough steam is currently available to generate 250 MW fieldwide for a theoretical peak generation of 180 GWh. This compares with the historical peak generation of 216 GWh for June 1983.

Total generation through 1987 has been 14,550 GWh. This has replaced approximately 22 million barrels of fuel oil with an estimated cost of US$630 million. A financial study done for the Asian Development Bank in Manila (ELC, 1987) found that the net cash flows including avoided oil cost had paid for the project by 1986.

CONCLUSIONS

The Tiwi Geothermal Power Project is a good example of a successful partnership between a private resource developer and a state-owned utility to achieve national objectives. Several observations from the Tiwi experience may apply to developing country situations in general.

1. The Philippine government's decision to push through with developing a promising but unconventional indigenous energy source near the bottom of a fossil energy price cycle was most astute. When the NPC-PGI service contract was signed, oil sold for less than US$4/bbl. By the time of first electricity sales the price had quadrupled.

2. Both parties have shown their adaptability to changing circumstances. NPC was able to respond to demand increases by altering its investment plans. PGI was able to work with NPC to get through the Philippine foreign exchange crisis of 1983-86. They worked together to evolve a contract beneficial to both.

3. NPC recognized that expeditious development is critical to the economic performance of a geothermal plant. Because the geothermal plant relies on a single, depleting energy source, excessive preproduction investment creates a drag on potential profitability (Stefansson, 1987). Unlike a traditional plant which draws on a world fuel market, operation of the geothermal plant at high capacity cannot be extended indefinitely to make up for failure to achieve an early payout.

4. Each party was responsible for an area where it had a comparative advantage.

   Unocal's long experience in energy resource development enabled it to shoulder the exploration risk and guide steam field development. This reduced NPC's risk to that appropriate for a utility, and gave them stable fuel costs.

   NPC, on the other hand, enjoyed access to government financing and aid, as well as many years of experience in the generation business. This allowed it to make the heavy infrastructure investments with the least risk and on the best terms.

5. NPC and PGI have made the transition from expansion to optimization of field operation. This is attested to by continuing improvement in steam utilization and operating coordination, which has resulted in substantial stabilization of generation for the past three years.

From the early years of accelerated development and changing economic climate to more recent times of modified development and production strategy, the Tiwi experience has required adaptation and cooperation between a philosophically distinct corporate producer and government utility. The results of this adaptation and cooperation are reflected in the relatively quick development of the field and stable generation in the face of declining steam supply. In 1987 Tiwi ranked fifth in capacity factor among NPC's generation facilities. The National Power Corporation and Philippine Geothermal, Inc. look forward to the many more years of teamwork needed to maintain Tiwi's role in the Philippine energy supply.

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