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Innovative Geothermal Power Plants

THE SOLUTION TO GEOTHERMAL RESOURCE CONSTRAINTS — The Ormat Way

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1. BACKGROUND

Geothermal resources are, generally speaking, a gift for the designer/developer who desires to utilize them in order to provide reliable electrical power on a continuous and economic basis throughout the project lifetime.

After a very long "incubation" period, characterized by different approaches, it is only since the mid 80's that binary geothermal plants have become a viable commercially available solution.

The utilization of liquid (water or brine) dominated geothermal resources, at moderate temperatures, for power generation has substantial advantages including the following:

- More heat can be extracted from geothermal fluids by re-injecting them at lower temperatures than is currently possible with steam turbines operating from flashed steam.
- Use of geothermal fluids at much lower temperatures than would be economical for flash or direct steam use.
- Use of high vapor pressure working fluid results in a very compact self-starting turbine.
- Using a binary system (where the geothermal fluid is separate from the organic motive fluid) allows the use of relatively hostile geothermal fluids.
- Technical risks for the power plant equipment are now low with key system components fully developed, field proven and commercially available.

While varying considerably from KGRA to KGRA, there is certainly a limit on the flexibility in the successful utilization of any given resource. Temperature, pressure, flow rate, noncondensibles and chemical contents represent the internal set of constraints associated with a specific resource, whereby cooling system and environmental issues, being the external set of constraints, complete the picture.

The developer/designer must operate within the envelope of constraints. Once a breach of this simple principle occurs, the developer/designer is mercilessly penalized.

In the pioneering period of the industry there were numerous examples of problems created by interfering with the envelope of constraints.

As an example such problems, one can cite the case of the bi-phase system which required a very specific combination of resource parameters. Another case was that of the Raft River plant which could not support the expenses associated with the silica removal from the brine system. This plant had a very short life — from autumn 1981 to summer 1982. It was plagued by failures in the well pumps and in the cement-asbestos pipes that carried the hot water (280°F) to the plant. Chemical treatment of the spent geofluid for use as cooling tower make-up also presented problems. Another project which developed problems because of the mismatch between the plant and the resource is the Heber Binary Plant, whose designers omitted the possibility of such a huge plant having access to a lower flow rate than originally anticipated.

If there is a success side to the binary plant technology, it is found in small, modular units in a range of 600-1200 kW. These plants work — they can be built quickly and put on-line in a few months, either singly or in clusters of many units, they are flexible and can be designed to accommodate a range of geofluid temperatures, and there is a "learning curve" because these units are not "one of a kind."

It is interesting to note the trend of development of modern binary plants. It began with a simple plant (Paratunka), raced ahead with complex ones (Magmamax, Raft River), and pushed on to large plants (Heber) without ever really nailing down the "simple" technology. Then it reverted to the simple machines and amassed a lot of experience building, installing, and operating them. Now one can see a move toward refinement and improvement (e.g., the cascading concept employed by Ormat at the Steamboat and Ormesa I, II and IE plants).

2. THE TECHNICAL APPROACH

Ormat has always operated under the assumption that the power plant has, by far, a higher degree of freedom than the geothermal resource. By doing so, Ormat has consistently performed within the envelope of constraints, pushing relentlessly to optimize the combined operation of the geothermal field and the power plant.

The basic organic Rankine cycle used by Ormat binary power plants is a subcritical one. In the subcritical cycle, the working fluid will first increase in temperature to the boiling point, and then will evaporate at constant pressure and temperature. In the supercritical case, working fluid temperature will be continuously increased at constant pressure during the heat addition until it reaches the turbine inlet temperature.

The organic fluids that are used with the binary plant have the following advantages:

- for the organic fluid the whole expansion takes place outside the saturation curve, while for water, wet steam will flow through the entire turbine. This has the advantage of avoiding efficiency reduction and blade erosion (without requiring a superheater);
- the enthalpy drop is small and it is possible to design a single stage turbine having high efficiency, being at the same time subject to low stresses. For water the enthalpy drop is too high for expansion in a single stage with optimum efficiency. This requires a more complicated, expensive turbine. For a given power, the mass flowrate of organic fluid is proportionally higher, but the size of the equipment is not as large due to the high density of the vapor;
- the density of the organic fluid at the exhaust is low. The volumetric flow rate of steam is about sixteen times higher and therefore the steam turbine size is considerably larger. This is a severe economic penalty;
- the pressure of the organic fluid is always above atmospheric so air leakages into the system are avoided.

The supercritical cycle leads to a better utilization of sensible heat sources ("pinch point" effect), but the subcritical cycle results in lower parasitic losses and lower internal pressures within the power plant than would be achieved with the more traditional supercritical cycle. The result is a design with a greater simplicity and higher reliability, due to lower stress on components.

The Cascade Principle is used to maximize the overall efficiency of the binary power plant. To illustrate and clarify this principle, let us examine the configuration of a power plant such as Ormesa I. (See Fig. 1).

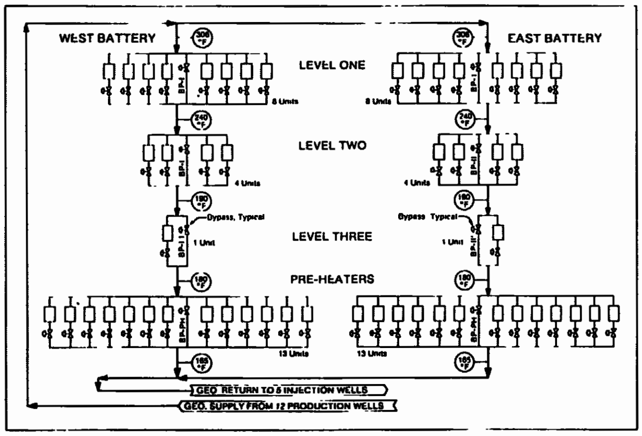

Figure 1 — Ormesa I Power Plant Configuration

The total geothermal fluid pumped from the 12 production wells enters 16 Level 1 evaporators at 306°F and exits at 240°F. The same geothermal fluid enters the eight Level 2 evaporators at 240°F and exits at 190°F. It then runs through the two Level 3 evaporators at 190°F to leave at a temperature of 165°F. Before being injected into the geothermal field, the geothermal fluid enters all 26 preheaters in parallel, to preheat the motive fluid. Consequently, the efficiency of the power plant is greatly enhanced resulting in a better steam conversion rate.

3. THE PROJECT PLANNING AND MANAGEMENT APPROACH

Ormat's approach is to integrate its interdisciplinary experience in power projects from initiation to operation through financing and construction management.

In the project planning stage, the engineering staff translates the technical and commercial parameters of the projects into an optimal conceptual design. The design becomes the foundation for selecting the project team, developing the project structure and implementing a financial plan. With a sound conceptual design, an effective project team and credible financial plan, Ormat is able to arrange financing of the project. Working with investors and banks Ormat strives to arrive at the optimal financing vehicle and negotiate power purchase agreements.

In the implementation stage, Ormat provides construction, engineering, project management and start-up services, all of which serve to reduce capital costs. The company assumes total responsibility for the project, assuring the investors that the plant will be engineered and constructed to the highest standards, will be completed in time and will pass stringent start-up tests. Ormat integrates the activities of all team members, and eliminates the work overlaps and conflicts, thereby minimizing project costs and eliminating costly overruns.

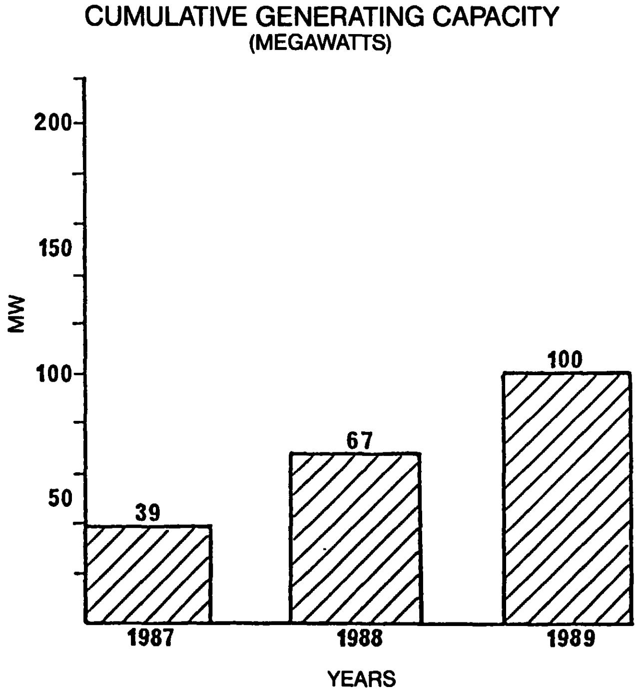

Figure 2.

3.1 **Soda Lake Geothermal, Nevada** (Fig. 3)

Located in Nevada, this 3.6 MW (gross) power plant is a fully constructed and tested geothermal power station. Financing for the project was arranged by Ormat, who constructed and now operates the plant. Chevron Resources developed the field and owns the geothermal resource which contains proven production and reinjection wells.

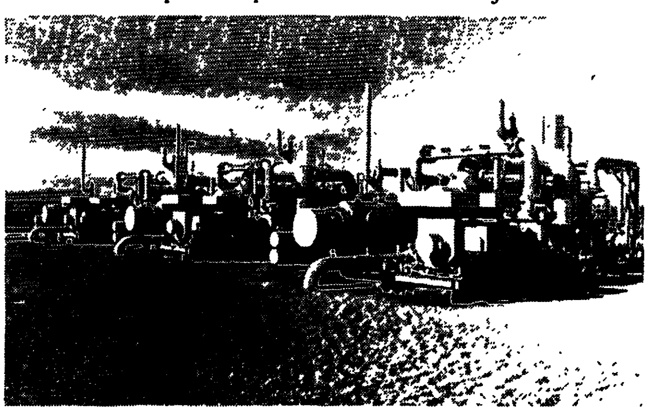

Figure 3 — Soda Lake Geothermal Power Plant

400,000 pounds of geothermal fluid per hour at 360°F is delivered to three Ormat Energy Converters (OECs). The 2.75 MW net generated power is sold to Sierra Pacific Power Co. under a 30-year Power Purchase Agreement. The project became operational in December 1987 and has been fully operational since then. Ormat is a 50% owner of this power plant.

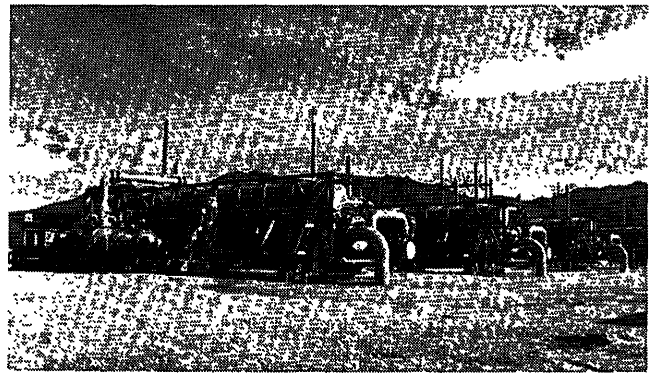

Figure 4 — Empire Geothermal Power Plant

3.3 **Steamboat Springs, Nevada** (Fig. 5)

The plant incorporates seven OEC modules in a proprietary cascading process, to generate 6,700 kW gross power with a capacity for sale to the utility of 5,200 kW. The temperature of geothermal fluid is 334°F. Due to the lack of make-up water, air cooling condensers were used. The project was constructed under a fast track schedule for initial start-up in 1985 with full commercial operation by June 1986. This construction schedule was feasible because of the utilization of the Ormat modular concept using factory integrated power units.

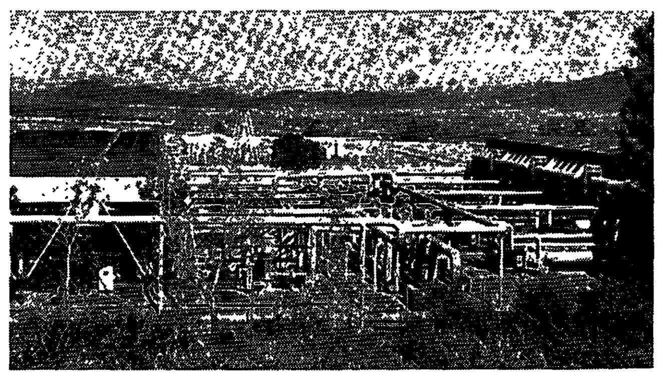

Figure 5 — Steamboat Springs Power Plant

3.4 **Steamboat Springs 1A, Nevada**

Two additional OEC modules were added in 1988 to increase the plant gross power to 8,700 kW.

3.5 **Ormesa Geothermal I** (Fig. 6)

Located in Imperial Valley, California, the 30

MW (gross) geothermal power plant constitutes the largest project developed by Ormat to date. Ormat arranged the $88 million financing for the project, developed the field which contains the geothermal resources, including drilling, piping and installation of the pumps.

As an active participant in this project, Ormat constructed the power plant (with Atkinson Mechanical as the general contractor) using 26 Ormat Energy Converters (OECs), as well as cooling towers, transformers and interconnections. All the OECs are computer controlled. The plant operates continuously to produce a total output of 30 MW. The project sells electricity to Southern California Edison (SCE) under a 30 year Power Purchase Agreement.

A subsidiary of Ormat has a 4 year O & M Agreement for Ormesa I and Ormesa IE projects.

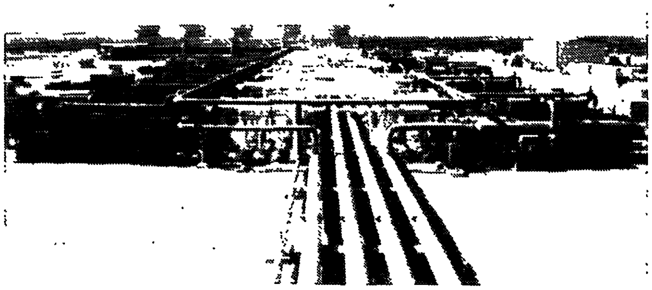

Figure 6 — Ormesa Geothermal I Power Plant

3.6 Ormesa Geothermal II (Fig. 7)

Located in Imperial Valley, California, this 20 MW (gross) facility is the sister project to Ormesa I. The financing of $66 million for this project was based solely on the private capital market arranged by Ormat. This project was funded as a non-recourse lease. A subsidiary of Ormat and Harbert International (also the general contractor) act as the lessee and as operator of both the field and the power plant, which consists of 20 OECs as well as cooling towers, pumps and piping, transformers and interconnections, all of which are computer controlled. The project declared firm operation in March 1988.

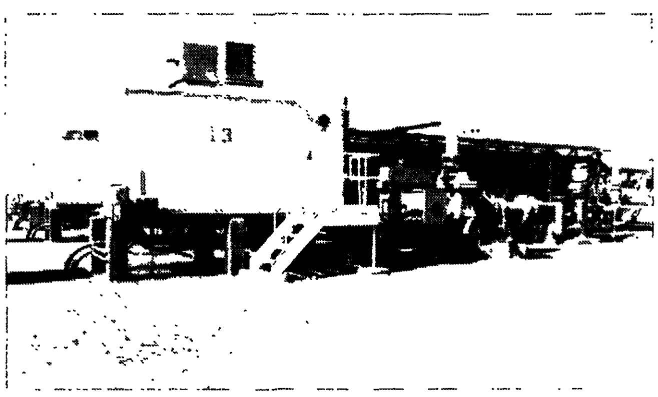

Figure 7 — Ormesa Geothermal II Power Plant

3.7 Ormesa Geothermal IE (Fig. 8)

Located in Imperial Valley, California, Ormesa Geothermal IE consists of an interconnected array of ten (10) OEC units which provide Southern California Edison (SCE) with a base load capacity of 8 MW (net).

The geothermal fluid is pumped from four production wells, with the water cooled condensers being supplied from a three cell cooling system. All the OECs are computer controlled. The generated electricity after being interconnected with Ormesa I, is sold to SCE Company under a standard offer No. 4 sales agreement.

The geothermal resources provide the project with 2.8 million lbs/hr of fluid at a temperature of 293°F.

Figure 8 — Ormesa Geothermal IE Power Plant

3.8 Stillwater Geothermal I (Fig. 9)

Ormat has acquired geothermal resource rights in the Stillwater KGRA, located in Churchill County, Nevada, which are capable of supporting a series of power plants. Stillwater Geothermal I is the first project which Ormat developed in the Stillwater KGRA, consisting of 14 OECs at a total project cost of $36 million. It was placed in service in March 1989 and passed acceptance test in June 1989.

A subsidiary of Ormat supplies the project with geothermal fluid. Ormat will provide long-term operation and maintenance services for both the geothermal field and power plant.

Stillwater Geothermal I holds a 30-year power purchase agreement with Sierra Pacific Power Ormat (SPPC) and will supply the utility with over 90 million kWh per year.

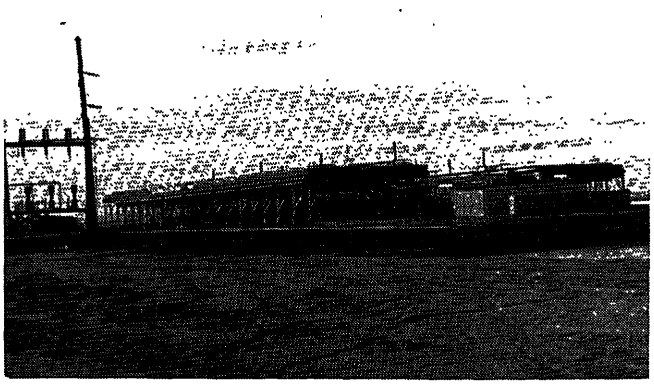

Figure 9 — Stillwater Geothermal Power Plant

3.9 Puna Geothermal - Island of Hawaii

Ormat has acquired development rights for a geothermal project on the Island of Hawaii in the Puna District, approximately 21 miles southeast of the City of Hilo. The Puna District contains proven geothermal reserves and offers tremendous development potential. The State of Hawaii has identified the development of this resource as essential to achieving the State's goal of decreasing energy dependence and has passed legislation designed to encourage the development of the Puna reserves.

Ormat's first power plant will have a total project cost of approximately $100 million and will be designed to use two phase geothermal steam and water to drive a hybrid turbine generator with a gross capacity rating of 30 MW. The electrical output will be sold to Hawaiian Electric Light Company (HELCO) pursuant to a 35-year power purchase agreement. The plan of operation has been approved and the project is now in the detailed permitting phase. According to the schedule, the construction will begin in the third quarter of 1989.

4. THE OPERATION AND MAINTENANCE APPROACH

In the operating stage of the plant, Ormat's team pays attention to every detail of operation which affects the costs. It purchases consumables and manages the inventory. It performs preventive and emergency maintenance, and conducts major overhauls. It supervises operations and maintenance.

A complete staff includes a Director of Operations, Staff Engineers, Maintenance Personnel, and Administrative Support. All Nevada activities are centralized at Ormat's headquarters in Sparks, which also provides specialized administrative, technical and training support for the California plants.

Each Nevada power plant is staffed with operators who also perform the routine maintenance.

List of Geothermal Power Plants Operated by Ormat

Project	Number of OECs	Hours of Operation (aggregated)	Comments
Soda Lake Geothermal	3	31,000	In commercial operation
Empire Geothermal	4	22,000	In commercial operation
Steamboat	7	139,000	Air cooled OECs. In commercial operation
Steamboat 1A	2	10,000	Air cooled OECs. In commercial operation
Ormesa I	26	400,000	In commercial operation
Ormesa II	20	209,000	In commercial operation.
Ormesa IE	10	35,000	In commercial operation
Stillwater I	14	5,000	Air cooled. In commercial operation started in June 1989

Staff engineers use computers to off-site-monitor the Nevada installations from the Sparks headquarters.

Ormesa I and Ormesa IE power plants in East Mesa California, are operated by Trigor Geothermal Corporation, a wholly owned subsidiary of Ormat. The local staff includes a plant engineer and a plant superintendent who reports to the Sparks office. The facility includes a well equipped workshop.

Once a plant develops a performance track record, its operation is analyzed with a view to

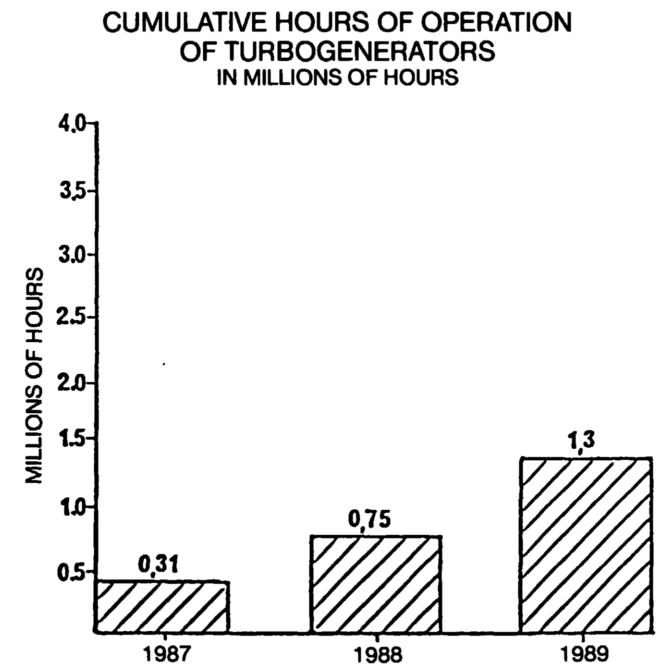

Figure 10

improving the capacity factor, and with it, plant profits. Enhancements may include equipment upgrading and modification, adjustments to operating or maintenance procedures and measures to reduce parasitic loads and increase plant output. The full spectrum of plant activity is covered, from cost and adequacy of maintenance and plant safety to cost of operation, staff training, regulatory and contractual compliance and power output.

This activity includes:

- Productivity improvement studies
- Comprehensive spare parts program
- Preventive maintenance
- Operations and maintenance cost analysis
- Preparation of operations and maintenance procedure manuals
- Training
- Security analysis
- Contract analysis
- Records management
- Betterment modifications and retrofits

Ormat currently operates and maintains 8 power plants, including the field, the deep well pumps, the gathering system and the wells themselves.

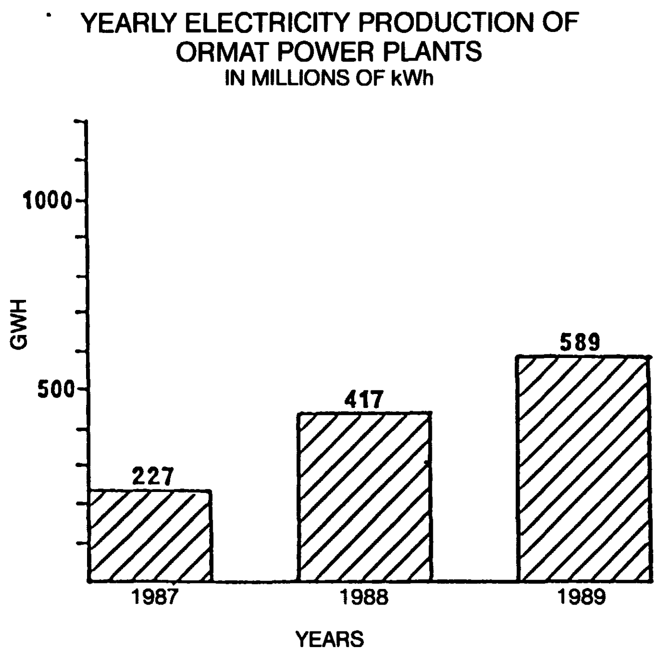

Figure 11

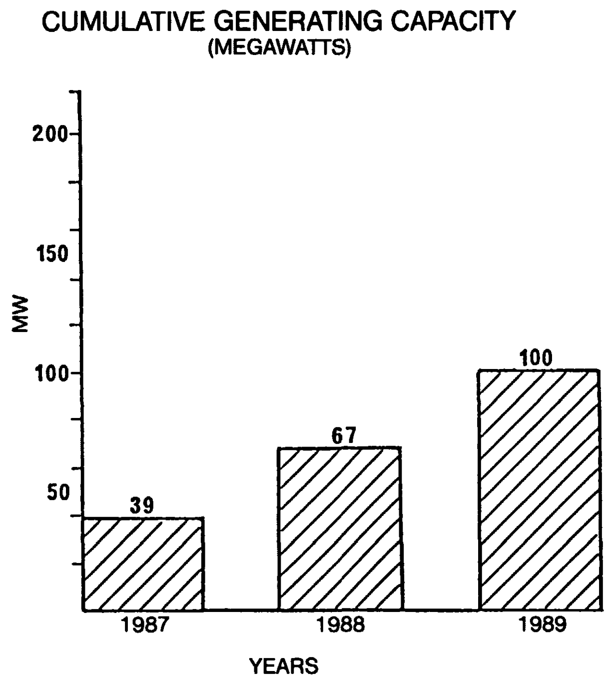

Figure 12

5. CONCLUSION

Large amounts of geothermal energy are available from low and moderate enthalpy liquid dominated geothermal sources in many parts of the world.

After a long trial and error process, the binary power plant technology with its integrated multidisciplinary approach made this resource viable inspite of its thermodynamic limitations.

The experience accumulated over the past years shows that the binary system has now been developed into a well proven technology. The Ormat modular OEC units have already accumulated hundreds of thousands of operating hours in actual field operation, proving the reliability, availability and inherent long life of the binary geothermal power systems.