FIRST TWELVE MONTHS OF OPERATION OF THE 60 MW MOKAI GEOTHERMAL PROJECT A HIGH PRESSURE, SUSTAINABLE AND ENVIRONMENTALLY BENIGN POWER PLANT

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ABSTRACT

Following the deregulation of the New Zealand electricity industry, several medium and small sized projects have started their operation. The Mokai Geothermal Project is the largest privately developed geothermal project in New Zealand. The 60 MW development has been undertaken by, the Tuaropaki Trust in Taupo / New Zealand. The Trust, who owns the majority of the land at Mokai, operates its project through its wholly owned project company the Tuaropaki Power Company.

The power plant uses the geothermal fluid captured from the production wells and reinjects the full capacity into the reinjection wells.

The plant utilises steam turbine and binary turbine technology to obtain the maximum energy from the resource with minimal environmental impact.

The electricity generated is delivered via a 20 km, 110 kV line to the Whakamaru national grid substation and is sold in to the national pool.

Financing of the development was undertaken on a non-recourse and long-term basis by a group of financing institutions with Westpack Banking Corporation acting as leader.

During the first 12 months of operation the power plant has generated an average output of above 58 MW with an availability of above 97%.

1.0 INTRODUCTION

The 60 MW Mokai geothermal project is one of a number of new geothermal projects being developed in New Zealand by the private sector following the deregulation of the electricity industry. What makes the project unique is the ownership structure, - the development is owned by Maori (indigenous people) landowners, and its technology, - which allows economic development of the high-pressure geothermal resources.

New Zealand lies in the Southwest corner of the Pacific "ring of fire"; the chain of volcanic activity which extends up through the Pacific Islands, Indonesia, the Philippines, Japan, Alaska, the West coast of the US, and down to the tip of South America. The main geothermal area is centred near the towns of Taupo and Rotorua and the geothermal activity is of volcanic origin; with some of the volcanoes still active.

Some of the world's early geothermal development was undertaken in New Zealand with the Wairakei project (currently 156 MW) being the first large-scale development of a water dominated geothermal field. Construction of the first station commenced in the mid 1950's, with the original layout of the station allowing for the installation of a plant to produce heavy water for the British nuclear programme. This was dropped before station completion, but its influence is still present in the multiple steam pressures of the older station.

2.0 THE ROTORUA-TAUPO GEOTHERMAL REGION

There is geothermal activity spread over both islands of New Zealand with the main high temperature fields associated with the volcanic activity in the Rotorua-Taupo area. Most of the other geothermal activity in the country is of tectonic origin and the heat flows and temperatures are not sufficient for commercial power generation.

The original settlers of New Zealand, the Maoris, who arrived about 800 years ago from

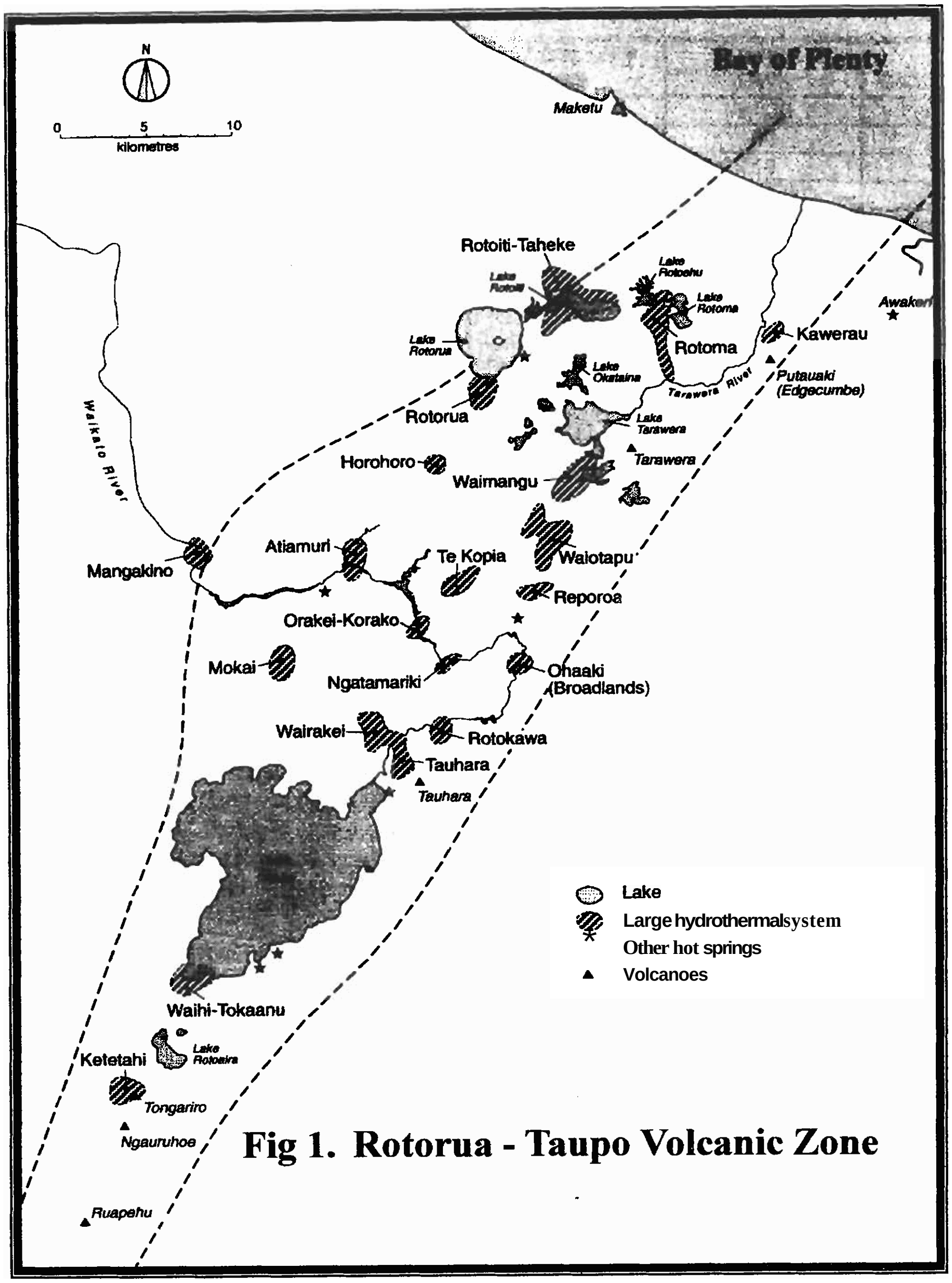

Fig 1. Rotorua - Taupo Volcanic Zone

the Island of the Central Pacific, used the natural geothermal springs for bathing and the very hot springs and geysers for cooking. There have been a number of major volcanic eruptions in the region; the most recent being the Tarawera eruption of 1886 which destroyed the world famous Pink and White Silica Terraces, and the largest being the eruption which formed Lake Taupo around 400 AD. The latter eruption was one of the largest known eruptions, with the ancient Chinese recording the impact of the emitted ash on their weather.

The major geothermal fields of the Rotorua-Taupo area are identified in Figure 1. The Wairakei, Rotokawa, Kawerau and Ohaaki fields have been developed for commercial power production as detailed in Table 1, and the Mokai field is currently being developed by an initial 60 MW plant.

Table 1. New Zealand's geothermal generating plants

Station	Location	Geothermal Field	Net Capacity MW	Output GWh	Year Commissioned
Wairakei	Taupo	Wairakei	156	1,300	1959-63
Tasman Paper	Kawerau	Kawerau	8	60	1959
TG1	Kawerau	Kawerau	2.6	18	1989
TG2	Kawerau	Kawerau	3.8	28	1993
Ohaaki	Reporoa	Broadlands	80	750	1989
McLachlan	Taupo	Wairakei	53	280	1997
Rotokawa	Taupo	Rotokawa	27	200	1997
Ngawha	Wangharei	Ngawha	12	100	1998
Mokai	Taupo	Mokai	57	475	2000
Totals			323.8	2,625	

3.0 THE MOKAI GEOTHERMAL RESOURCE

The Mokai geothermal field is a deep, high temperature field located approximately 25 km northwest of Taupo within the conspicuous western margin of a large volcanic-filled topographic depression. The investigation wells drilled in this field by the New Zealand government (the Crown) have encountered intracaldera volcaniclastics of significant vertical and horizontal permeability to a depth of over 160 m. It is generally held that the Mokai geothermal system occupies these volcaniclastic as an up flow of geothermal fluids in the vicinity of Mokai and a related northward outflow influenced by the regional groundwater hydrology.

The surface hydrothermal manifestation in the vicinity of the Mokai wells is relatively minor, and is confined to features characteristic of steam heating. Warm chloride springs occur in the fault-aligned Waipapa steam gorge about 5 km north of the drilled area.

A northeast-trending fault system crossing the caldera's floor has been interpreted as a major source of vertical permeability. Enthalpies measured quickly stabilised at 1450 kJ/kg and the well chemistry indicated high temperatures for the production zones, as well as for the reservoir (350°C and 325°C respectively). The field has an estimated capacity of over 250 MW, with the initial development being a 60 MW station to allow for careful monitoring of the resource before any further development is undertaken.

4.0 THE PROJECT STRUCTURE

The project is unique in its structure and technology; the former brings the indigenous Maori people into the development as a developer and owner; and the latter provides effective use of the high-pressure steam from this resource. The Tuaropaki Trust administers the Tuaropaki E land at Mokai for the benefit of its owners. Initially the iand was developed for pastoral farming under the direction of trustees and management of the Department of Maori Affairs.

In 1979 repaid the development dept and the sole responsibility for the land was vested in the trustees. The Trust purchased the Crown's interests in 1996 and decided to develop the field. After considering different options and project structures, including the lease of the land to developers or participation in a project together with other partners, the trustees decided that the Tuaropaki's best interests were kept when the Tuaropaki people, themselves, acted as the owner and developer.

The Trust undertook a thorough review of various plant configuration and technology options, and decided finally to go ahead with the Geothermal Combined Cycle configurations using both the steam and brine components of the geothermal fluid. The plant configuration selected was the more flexible and modular Geothermal Combined Cycle technology, which uses a backpressure steam turbine and binary plant to capture the best features of each technology. The turnkey contractor and supplier of the equipment for the 60 MW plant was the GRMAT Group of Companies. Mighty River Power entered into an agreement with the Trust to provide a guaranteed minimum floor price for the electricity produced and for the supply of the Operation and Maintenance services for the plant. Additional production well and reinjection wells were required for the project and a contract for well drilling and testing was awarded to Century Drilling. Westpack Banking Corporation arranged the construction and long-term finance for the development.

5.0 PROJECT DESIGN

The project has (four) 4 production wells of approximately 2000-metre depth, producing a two-phase fluid, which is piped to a separator at the station. Steam is separated from the brine at 18 bar and both the steam and the brine are used for electricity generation. The condensed steam is pumped up to the brine pressure, combined with the high-pressure brine, and reinjected with no further pumping. There are three reinjection wells of around 500-metre depth, one of which was constructed using two of the original field exploratory wells.

To maximise the benefits of the high steam pressure a General Electric backpressure turbine of 32 MW output is utilised to reduce the steam pressure to approximately 1.3 bar. This low-pressure steam is condensed in four bottoming ORMAT® ENERGY CONVERTER binary units of 6 MW output each. This configuration, referred to by ORMAT as a Geothermal Combined Cycle Unit, has the advantage of the low capital cost of a simple backpressure turbine, and of condensing the steam in a tube and shell heat exchanger where steam wetness is not a problem. Two additional ORMAT® ENERGY CONVERTER binary units, also of 6 MW output, were installed, utilising the hot brine flow and cooling it from 219°C to 150°C. The motive fluid in the binary units is pentane and cooling is effected by air-cooled condensers.

Station Parameters

Steam turbine output	31,1 MW
Binary bottoming units output	4 x 6 MW
Binary brine units output	2 x 6 MW
Net output	57 MW
Annual energy output	475 GWh

Heat and Mass Balance

The geothermal steam exiting from the separator and the brine flowing into and out of the brine binary unit have the following average conditions:

Steam flow rate	308 t/hr
NCG flow rate	4 t/hr
Steam quality ex separator	99.98%
Steam pressure; separator outlet	18 bar (a)
Steam temperature; separator outlet	208 °C
Brine flow rate	860 t/hr
Brine inlet temperature	207 °C
Brine outlet temperature	150 °C
Design ambient air temperature	12 °C

Main Equipment Description

The GE steam turbine is a backpressure, multi-stage, and reaction-type turbine. The turbine housing, shaft assembly and nozzle ring were designed to ORMAT's specification for operation with geothermal steam.

<u>Level I Steam Turbine and Generator</u>

Steam turbine type	GE multi stage, single cylinder reaction
Steam inlet pressure	18.6 bar(a)
Steam outlet pressure	1.3 bar(a)
Speed	3000 rpm
Construction	Horizontal split casing
Generator rated output	32 MW
Voltage	11 kV, 3 phase, 50 Hz
Power factor	0.85 (lagging)
Efficiency	97.5%
Manufacturer	GE

<u>Level II ORMAT® Energy Converter</u>

Organic vapour turbine type	Impulse
Speed	1500 rpm
Construction	Horizontal (overhung) vertical split casing
Number of stages	2
Motive fluid	Pentane

Generator rated output	6 MW
Voltage	11 kV, 3 phase, 50 Hz
Speed	1500 rpm
Efficiency	97%

The power plant consists of the geothermal combined cycle unit, the brine driven OEC unit, plus the following main systems:

- Power plant geothermal fluid gathering and reinjection system
- Auxiliary systems
- Electrical systems
- Main station control
- Fire fighting systems
- Auxiliary buildings
- High voltage T-line

The generator circuit breaker, control and auxiliary electrical equipment for each binary unit is housed in a container, and was delivered to site fully wired and pretested. This reduced construction time, and speeds up commissioning on site. The overall station control is from a control room attached to the steam turbine building. The central station control computer utilizes software and graphics developed by ORMAT.

Construction Programme

The modular nature of this plant allowed a very short construction period on site. All the binary turbines are mounted on simple low-level foundations. As the steam turbine has no attached condenser it too is mounted on a low level foundation, allowing a simple turbine building of modest size. The binary plant components were designed to be shipped in packages of standard container size and within days of the shipment arrival the main components were bolted down and the air-cooled condenser erection was under way. The overall time programme for the plant development was as follows:

Notice to Proceed	**February 1998**
Delivery of turbine-generator	**February 1999**
Commissioned	**December 1999**

6.0 ENVIRONMENTAL IMPACT

The station was designed to have minimal environmental impact. Under normal operating conditions the geothermal fluid is completely contained from production to reinjection, with the only emissions being negligible quantities of steam emitted by the steam traps and the non-condensable gases emitted above the air coolers. The plant has a relatively larger footprint, but a much lower profile than a conventional condensing steam turbine, with an under slung condenser. The air cooler structures have a significantly lower profile than wet cooling towers, and have the advantage of never producing a visible plume. In addition to its low profile, the plant has no water or chemical consumption and no blow-down of contaminated cooling tower water. The power generation technology implemented at Mokai fully complies with the resource consents and is dedicated to the needs of a sustainable, environmentally benign and reliable geothermal power plant.

Because the development is small relative to the ultimate capacity of the very deep resource, it is expected that there will be little impact on the surface features. A comprehensive baseline-monitoring programme was undertaken prior to project operation and an ongoing programme monitors the field behaviour.

7.0 OPERATION AND MAINTENANCE

Operation of the station was contracted to Mighty River Power to provide 24-hour operator coverage on a 12-hour shift basis. Only one operator is on duty during the day shift and one at night. Operators are required to undertake routine and emergency minor maintenance work as well as operational duties. An Operations Manager, who is also involved in the ROTOKAWA geothermal power station (a 27 MW geothermal combined cycle power plant supplied by ORMAT in 1997), supervises the station. During the first 12 months of operation the power plant and the geothermal resource fulfilled the owners' expectations with an availability exceeding 97 % and a generated an output of over 58 MW.

8.0 FUTURE DEVELOPMENT

The Mokai field has been assessed as having a development potential of greater than 250 MW. This initial conservative development of 60 MW is not expected to have any significant effect on the resource, neither from a temperature/pressure perspective nor from a surface environment perspective. However, before the joint venture partners embark on any further development, a programme of environmental and reservoir monitoring is being undertaken to monitor reservoir and environmental changes. Subject to these impacts being within acceptable limits, the partners will look to the next stage of development.

9.0 CONCLUSION

The Mokai Geothermal Project is a working example of the indigenous landowners developing their own resources through a .partnership with a power company.

In addition to the scientific resource modelling and resource behaviour projections there were two essential comfort factors, which were taken into consideration by the project developers:

- The use of a power generation technology which ensures the sustainability of the geothermal reservoir and avoids drainage of the resource and assures long term maintenance of the fluid level and characteristics of the field; and

- The option of a power plant configuration, which maximises the use of the geothermal energy, minimises the risk factors for the equity partners, and generates the highest possible income at the lowest possible operation and maintenance cost.