Recent Developments and Future Prospects for Geothermal Energy in New Zealand

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ABSTRACT

The heat output above 0°C for the total geothermal resources of New Zealand is estimated to be 550 000 terajoules per year (TJ/yr). Used wholly for electrical generation at the current Wairakei utilization factor of 9%, this would produce 14.5 terawatt hours (TWh). In 1973, energy consumption in New Zealand from all sources was 86 TWh, about 20% being electrical energy.

Only about 15% of the estimated potential is proven, so that while geothermal energy could make a significant contribution to New Zealand's energy needs, planning for its utilization is hampered by lack of information. An investigation program designed to give a better appraisal of the size of the resource and of the characteristics of the individual fields has been submitted to the government for approval.

Alternative uses for geothermal energy are being considered in relation to conditions in New Zealand. This is a continuing process, but present indications are that while there is a limited use as direct heat in industry, the main potential appears to be for electrical generation.

New techniques relating to exploitation are continually being investigated and established ones updated. Installation of a multiple flash system resulting in the generation of an extra 20 MW has recently been completed at Wairakei, while possible future developments being investigated are reinjection and the binary system.

INTRODUCTION

Since investigations into the geothermal resources of New Zealand commenced in 1950, the Wairakei power scheme has been commissioned, the Kawerau geothermal field has been partially developed for use by the Tasman Pulp and Paper Company, and the Broadlands field has been proved by drilling to have an output in excess of 150 MW. Development of this field is included in present plans for electricity generation in 1981, but it could be utilized for other purposes.

Drilling and scientific investigations in other areas suggest that the development so far represents only a small proportion of the total resource, and that a considerably greater amount of geothermal energy is available. The main reason why development has not been more rapid is that there is a lack of detailed information available about the resource. Specifically, it has not been possible to say that proven amounts of energy are available at given locations, making it difficult to incorporate geothermal energy in the planning to meet the energy requirements of the country.

This is perhaps understandable in a country which has until fairly recently been able to keep pace with its electrical demand by developing hydropower, and in which a substantial natural gas field has been discovered. These factors have placed restraints on the rate of investigation of the resource and, consequently, on development. However, recent developments in the energy situation both within New Zealand and overseas have emphasized the desirability of investigating fully all resources of indigenous energy. Accordingly, the program of investigation drilling has recently been increased, and while perhaps still below the optimum, this increase, together with investigations into uses of geothermal energy other than for electricity generation, and into various techniques associated with development, will permit a more rational integration of geothermal energy into the energy supply system of New Zealand.

RESOURCE EVALUATION

The earliest estimate (Grange, 1955) gave the size of the total resource as equivalent to 250 electric megawatts (MWe). This simply converted the natural heat flow of the more accessible thermal areas into equivalent kilowatts on the basis of an assumed utilization factor. It was appreciated that this would be a minimum figure but no attempt was made to estimate any upper limit for lack of a reasonable basis. White (1970) has suggested that the artificial drawoff could exceed the natural heat flow by a factor of up to 5.

Applying this to the earliest estimate gives a resource estimate equivalent to 1250 MW, which is in reasonable agreement with present estimates, taking into account that the former covers about half the number of areas included in the latter.

Figure 1 shows the thermal areas so far located in the North Island. Only those in the Taupo-Rotorua thermal region are considered to have any significant potential, although spas and resorts are located at warm spring areas in other parts of the country. Smith (1970) describes the areas which had been investigated by drilling. Subsequent drilling has been concentrated in the Broadlands and Kawerau areas, although scientific work has been carried out elsewhere. Nevertheless, many of the areas listed have not yet been investigated to any extent, so that estimates for the total resource are subject to some uncertainty.

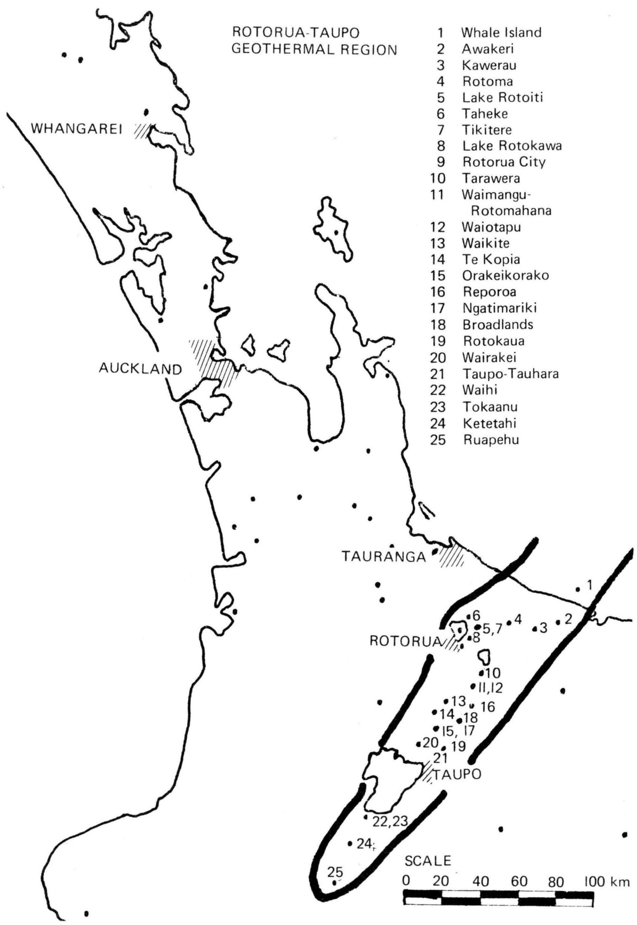

Figure 1. Location of the thermal areas in the North Island, New Zealand. (Adapted from Department of Scientific and Industrial Research Report 380, New Zealand Geological Survey.)

However, assuming that all fields have generally similar characteristics to Wairakei but taking into account any relevant information referring to individual fields, the total potential heat output above 0°C is estimated to be 550 000 TJ/yr. Used wholly for electrical generation at the current Wairakei utilization factor of 9%, this would produce about 14.5 TWh/yr. With some improvement in the utilization factor, it is possible that the resource could support a total installed capacity approaching 2000 MW.

An alternative method of obtaining an indication of the magnitude of the resource is on the basis of energy in place. As with other underground energy resources, the method of extraction is important, and for all of them the energy available for use will be only a fraction of that in place. Similarly, for any estimate of energy in place to be meaningful, the assumptions on which it is based should be clear. In the case of geothermal energy, the factor presenting most difficulty is perhaps depth because even in a producing field, the effective depth could well exceed the drilled depth. However, on the assumptions that the effective depth is 1 km, that, as before, the physical characteristics of all fields are comparable to those at Wairakei, although modified by information available concerning individual fields, and that only the heat above 80°C is of interest, the total geothermal energy in place is in excess of 37×10^{12} MJ.

ENERGY REQUIREMENTS OF NEW ZEALAND

In 1973, the total energy requirements of New Zealand exluding food but including transport was equivalent to 86 TWh of electricity (Kibblewhite, 1974). This energy was derived from oil and natural gas—60%, coal—16%, and electricity—24%.

Oil and natural gas and coal used for the generation of electricity are included in the electricity figure, which may be further broken down into hydro electricity—80%, thermal electricity—12%, and geothermal electricity—8%.

Assuming that all the geothermal energy estimated to be available was used for electrical generation, it would thus be capable of generating about 70% of our present total requirements for electrical energy. The full potential is of course not yet available but even compared with the estimated demand in 20 years' time, it still represents 25 to 30% of the expected electrical requirements, a useful proportion.

From the alternative viewpoint of energy in place, geothermal energy also represents a substantial resource. The estimated 37×10^{12} MJ is equivalent to some 1700 million tonnes of coal which compares with measured, indicated, and inferred total coal reserves in excess of 1000 million tonnes. Currently, coal production is approximately 2 million tonnes/yr.

Clearly, geothermal energy can make a useful contribution to New Zealand's energy requirements. There are a number of reasons why greater use has not been made of the resource. There has been an abundance of hydropower and, more recently, the discovery of substantial reserves of natural gas. Because so little is known about New Zealand's geothermal resources, it has been considered unwise to include it in the planning to meet energy demand. This has resulted in a moderate approach to investigation of the total resource. However, the recent energy crisis has pointed up the desirability of utilizing indigenous energy to the fullest extent possible and both investigation and utilization are now receiving considerably more attention than has been the case in the recent past.

INVESTIGATION DRILLING PROGRAM

A period of relative inactivity in geothermal investigations occurred between early 1971 and early 1973. The reason was that substantial quantities of electricity were expected to be available from natural gas, and there was some question as to the need for alternative forms of generation. Scientific work continued in a number of fields, but drilling was temporarily suspended. However, in 1973, the need to continue with investigation drilling was recognized and a program of 4 wells/yr was established. The object was to complete the investigation of the Broadlands field in about 2 to 3 years, and then move into new areas. Subsequently, in 1974, the oil crisis pointed to the desirability of establishing the full potential of the Kawerau field, so that the Tasman Pulp and Paper Company's dependence on imported fuels could be lessened. Accordingly, in October, 1974, approval was given for investigation of the Kawerau field to be undertaken concurrently with the Broadlands work. This is equivalent to a 7 to 8 well/yr drilling program.

If the total geothermal resource was to be evaluated over a 20 year period, and for a number of reasons, this appears to be a reasonable time scale, a drilling program of 16 wells/yr is required. This is about twice the present program, and is based on appraisal requiring about two-thirds of the total number of wells for full development, including an allowance for nonproductive drilling and rundown in well output. A proposal incorporating such a program was submitted to the government for approval, but in view of the present economic situation, this has been deferred.

While the current program may not be the optimum from the point of view of determining the place of the total resource in meeting the country's energy needs, it will still be making a useful contribution. The possibility of increasing the rate will be raised again at a more propitious time.

DEVELOPMENT PROGRAM

In the Broadlands field (Fig. 2), 28 wells have now been drilled, of which 17 produce a total of 3600 tonnes/hr at a wellhead pressure of 8-8.5 atg. The average enthalpy of the discharge is 1156 kJ/kg, so that utilizing steam at both 5 atg and 0.1 atg, these wells would produce 165 MW at the present time. Figure 3 shows BR20, one of the larger wells at Broadlands. The number of wells drilled in relation to the area of the field as delineated by resistivity surveys indicates that the field could support an initial drawoff in excess of this figure, but until a reasonable amount of operating experience has been obtained, the field would not be committed for more than 150 MW.

In its 1974 report, the Power Planning Committee, which advises the government on methods of meeting the electricity demand in the country, recommended a 150 MW geothermal station to be commissioned in 1981. To meet this date, the environmental report will be required by early 1976, environmental clearance and financial authorization by mid to late 1976, with design starting as soon as authorization is received. While a lot of the preliminary design will have been covered in the preparation of the environmental report, Wairakei experience, in conjunction with the present materials and equipment supply situation, suggest that a 4 to 4-1/2 year period for design and construction would not be unreasonable.

It should be noted that incorporation in the Power Planning Committee report is not a final committal of the Broadlands field for electrical production. It is, of course, an expression of intent and does allow preliminary planning to proceed. However, the field could be used for other purposes, but it would have to be clearly demonstrated that any alternative proposal was more favorable than the production of electricity, taking all circumstances into account.

Preliminary work already completed relates mainly to the preparation of the environmental report. For effluent treat-

Figure 2. Broadlands geothermal field (1972).

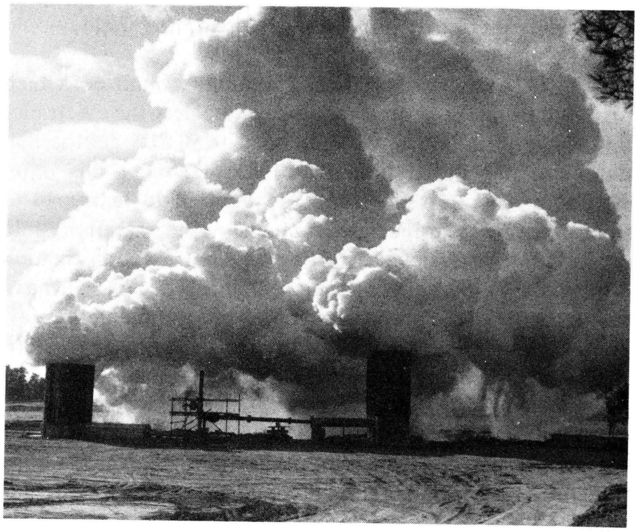

Figure 3. Well BR20. Capable of producing 375 tonnes per hour total mass at an enthalpy of 1300 kJ/kg.

ment, the Department of Scientific and Industrial Research is investigating a method of silica removal. The results of this are promising, one of the benefits being the removal of arsenic as well as silica.

A reinjection test program has been initiated. In the first instance, this program will be testing measurement and operational techniques as much as the effects of reinjection. While this program is related primarily to Broadlands, the technique is of wide interest. We are, therefore, cooperating with the United States Bureau of Reclamation, which has a similar program under way, in the exchange of data, and information and ideas on reinjection.

More straightforward design aspects which are being looked at are corrosion and foundation conditions. As far as the former is concerned, a static test rig is in operation, and a dynamic rig is to be installed as soon as practicable. Some foundation investigation work has been done for powerhouse location, but this has to be extended to cover alternative sites, and also sites for a bridge, and other major structures.

UTILIZATION FACTOR

This is defined as the energy utilized as a proportion of the total energy discharged by the field. For Wairakei the figure was initially 4.7%, but as a result of modifications to the steam collection and transmission system it is now 8.9% (McKenzie, 1974). The utilization factor depends largely on the dryness or enthalpy of the discharge, and for a new field of similar characteristics to those of Wairakei, used for electrical generation, a factor of about 10% could be expected. For Broadlands, which has a somewhat higher enthalpy than Wairakei, the factor will be nearly 13%, while for a dry steam field, a figure of 25% or more could be expected.

The improvement in the utilization factor at Wairakei has resulted from the recovery of energy which was otherwise being wasted. Wairakei was originally designed to combine the production of heavy water with the generation of electricity. The heavy water plant was dropped, but left the legacy of a two-pressure steam collection and transmission system with substantial quantities of water at about 12.5 atg and 5.5 atg being wasted. Recently completed modifications utilize this water but have resulted in the addition of a third pressure.

Very briefly, in the modified system, the separated water from a number of high-pressure wells is collected and flashed at the intermediate pressure. The steam gained is combined with steam direct from intermediate-pressure wells, and transmitted to the powerhouse. The water from the flash vessels is combined with intermediate-pressure water from the wells and flashed at the low pressure of 1.7 atg. This flashed steam is combined with direct steam from low-pressure wells, and transmitted to the powerhouse where it is reduced to about 0.1 atg and used as pass-in steam. The recently completed work has resulted in a gain of 20 MW, representing energy which would otherwise have been wasted and, as mentioned, resulted in a considerably improved utilization factor. Figure 4 illustrates one of the major flash units.

The circumstances leading to the multiple pressure system at Wairakei will not be repeated, and improvements in the utilization factor for future schemes will come from improved techniques, or from the use of the geothermal energy as direct heat.

IMPROVED UTILIZATION TECHNIQUES

Insofar as electrical generation is concerned, the two major improvements in techniques being considered are two-phase transmission, and the use of alternative methods of generation which enable energy in the water below 100°C to be recovered.

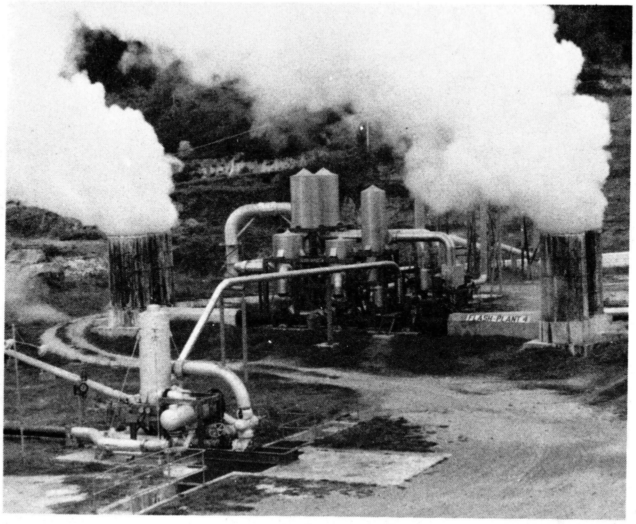

Figure 4. Flash plant 4, Wairakei. Separated water from high-pressure wells 30, 70, 71, 72, 82, and 83 enters the single 106 mm diameter intermediate-pressure separator (center). Steam at 5.5 atg feeds the intermediate-pressure mains. The water is combined with that from the separator of intermediate-pressure well 46 (left foreground), and enters the twin 137 mm diameter low-pressure separators at the left. Steam from these is fed to the low-pressure mains at 1.7 atg, while the water is discharged to waste through the two twin tower silencers at the left and right. This plant produces 47 tonnes per hour of intermediate-pressure steam and 47 tonnes per hour of low-pressure steam from hot water which would otherwise be wasted. This is equivalent to approximately 10 MW of electricity.

Two-phase transmission has been used in a number of places, although as far as is known has not yet been used for a major power station. However, there appear to be no insuperable difficulties in a major application of this nature, although there are one or two areas where further investigation is necessary. One of these is cold start-up. This will require careful procedures to avoid a combination of thermal and mechanical shock which could damage various parts of the system. A possible solution would be a two-stage operation, in which the system is first heated by steam only.

For an installation of any magnitude, flexibility of operation, and the volumes to be handled will almost certainly dictate the need to separate in a number of vessels. This will require splitting the two-phase flow, a phenomenon about which little is known at present. A further factor is that with separation in the field, the steam mains act as very efficient scrubbers. This advantage is lost with separators or flash vessels at the powerhouse; therefore, additional vessels for scrubbing will be required. Alternatively, the scrubbing characteristics of a pipeline could be utilized and the flash vessels located some distance from the powerhouse. However, minimum lengths of line for efficient scrubbing have yet to be investigated.

Of the alternative methods of generation which are being developed overseas, the binary system is the only one being investigated seriously in New Zealand. The main advantage this technique has is that the technology is widely known, and although some development work is required to adapt the system for use with geothermal energy, there is little doubt that it is technically feasible. The main question to be decided is the economic feasibility, and this must be assessed for each geothermal field individually.

A study is underway to determine what benefit it may have in conditions in New Zealand. No firm conclusions have been reached yet, although there is some indication that the energy gain may not be as great as had been expected. However, if justified by the feasibility study, a pilot binary scheme of about 10 MW is proposed.

The other main area of interest in this connection is the development of the total flow type of turbine of which a number are being investigated. Limited funds preclude the testing of other turbines at the present time. However, at some time in the future, depending on the stage of development reached, and on the availability of supporting data to enable an assessment to be made, there would be interest in testing the performance of these turbines under conditions in New Zealand.

ALTERNATIVE METHODS

Undoubtedly, the use of geothermal energy as direct heat is the most efficient way of using the energy. This is a possibility being looked at in connection with many of the geothermal fields in the world, and New Zealand is no exception. Armstead et al. (1974) describe many of the possible alternative uses but clearly not all of these would apply to all fields.

Examination of this question has led to the conclusion that for an industry in New Zealand to be able to use geothermal energy as direct heat, it must satisfy the conditions that it has a need for a reasonably large block of energy of the quality available and that transport and establishment costs do not offset the cost advantages to be gained from the use of this energy. Establishment costs are important, of course, because most of the fields are in relatively remote locations.

The timber industry is a fairly obvious choice, as one of the largest man-made forests in the world is located in the thermal belt. Indeed, the Tasman Pulp and Paper Company mill was located on the Kawerau geothermal field because of the availability of geothermal energy there. However, even in this case, the use of geothermal energy as direct heat is not as extensive as may be thought at first. The total energy needs of the company are met from:

oil	1.3%
electricity from the national grid	63.0%
geothermal energy	10.7%
combustible wastes	25.0%

In other words, the need to dispose of combustible wastes reduces appreciably the use of geothermal energy as direct heat, even though useful quantities of the latter are available. The obvious use of any available geothermal energy is the generation of electricity to reduce the drawoff from the national grid. The oil usage, incidentally, is the minimum considered necessary for the safe operation of the boilers producing high pressure steam.

Another industry requiring fairly substantial quantities of energy is the manufacture of heavy water. In this case, while overall production costs are high, the transport and establishment contribution to these costs is small. Yet another possibility is certain aspects of the dairy industry. The manufacture of milk powder, cheese, butter, casein, and other dairy products requires reasonably large quantities of energy. The dairy industry is also well established in the thermal belt. However, a certain amount of rationalization in the industry would be necessary to enable it to take advantage of the benefits of geothermal energy.

An experimental plant has just been installed at the Broadlands field for drying and pelletizing lucerne. The product is very clean compared with other methods of drying lucerne and the operation so far is quite encouraging. However, the energy requirements are relatively small and perhaps 10% of the Broadlands output could cope with all the lucerne that could be grown within reasonable transport range of the field.

There is a considerable use of geothermal energy on the small scale both domestically and commercially. This is almost entirely on an individual basis with a multitude of shallow, privately owned wells. Because of this there is no extensive hot water reticulation scheme in the thermal region, although the possibility exists at both Rotorua and Taupo.

Other possible uses such as the production of fresh water or extraction of chemicals from the geothermal fluids are not relevant to New Zealand conditions. For the foreseeable future there will be sufficient water for New Zealand's needs although care will be needed in its management. So far as chemical extraction is concerned, the concentration of chemicals in New Zealand geothermal water is low and, in general, recovery of any of them would be uneconomical on its own account. However, should pretreatment of the waste water be necessary before disposal, recovery of some of the chemicals may then be justified.

While there are undoubtedly industries which could make use of geothermal energy as a direct source of energy, and efforts to investigate these will continue, the extent to which this will be possible appears to be limited. In the conditions obtaining in New Zealand, it appears that the best use of geothermal energy on a large scale will be for the generation of electricity.

CONCLUSION

The two factors which emerge as the most important in controlling the development of geothermal energy in New Zealand are that it must be integrated into an energy system which, although small, is fairly complex, and that the integration is dependent on a more detailed knowledge of the individual fields that is at present available. There is a fairly close parallel here with oil exploration in that a lot of work is necessary before any indication of the real potential of a discovery is established and development can proceed. Within the limits of the economic restraints imposed, the current program, including the ongoing investigations into techniques and methods of utilization, will ensure that geothermal energy assists in meeting the energy requirements of New Zealand.

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