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TE MANATŪ PŪTAIAO

Geothermal Research

The historical role of R&D in exploiting this country's geothermal energy opportunities, the potential role in future and understanding the time-frames from research to commercial exploitation

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1 Introduction to the case study

1.1 Background

The Ministry of Research, Science and Technology, (MoRST), is commissioning a set of case studies which will inform and illustrate themes for the biotechnology, nanotechnology, energy and environment research roadmaps. Roadmaps are documents that provide an overview of an area of science activity important to Government and to New Zealand and outline the desired directions for that science activity into the future.

This report describes the findings of a brief case study on geothermal research.

1.2 The context

In its brief for the case study, the Ministry of Research, Science and Technology stated New Zealand geothermal research and development in the 1950's and 1960's led to the development of world-class geothermal capacity to utilise New Zealand's geothermal resources for electricity production and heat for timber and other industrial processing. New energy resources such as Maui gas later came on stream and over the 1980's and 1990's this R&D capacity declined. This is despite geothermal being an indigenous and renewable source of energy.

The Ministry suggests that a variety of factors including diminishing Maui gas, the need to reduce carbon emissions, a focus on sustainable development, and increases in other energy costs, has led to a resurgence in interest in geothermal energy opportunities.

1.3 The brief

The Ministry wishes to obtain an understanding of the historical role of R&D and its time-frames in the exploitation of geothermal energy. It also wishes to solicit views on the contribution that New Zealand geothermal R&D has made to international geothermal developments, the reasons for and implications of the decline in geothermal research capability, and the potential role that geothermal energy could play in a more diverse and sustainable energy future for New Zealand.

1.4 Case study method

The material which provides the basis for this case study report has been obtained through interviews with a selection of people, including research providers, consultants and several end users of research. Those interviewed face-to-face were -

Dr Ed Mroczek, Wairakei Research Centre of GNS,
Professor Michael O'Sullivan, Dept of Engineering Science, University of Auckland,
Mr Jim Lawless, Technology Coordinator at Sinclair Knight Merz (also past president of the New Zealand Geothermal Association, and one of two NZ Board members of the International Geothermal Association),
Mr Tom Powell, Geoscience Manager at Mighty River Power.

Others engaged via telephone and email exchange were -

Katherine Luketina, Geothermal Scientist at Environment Waikato,
Kevin Brown, Independent geothermal consultant, Geokem, Auckland.

Text from the interview notes and email exchanges was coded and entered into a text database for thematic sorting. Other documents were accessed as noted in the References.

2 A basic chronology of geothermal research and development in New Zealand

It is possible to trace examples of small-scale power production and direct use of geothermal heat in New Zealand to the early twentieth century (SKM, 2005, p.15). However, it was not until the 1950s and 1960s that large-scale commercial geothermal developments occurred in the form of the Wairakei power plant, commissioned in 1958, and the harnessing of geothermal energy at Kawerau to provide power to the nearby wood processing plant from 1966. Use of steam for direct process heating purposes at the Kawerau plant had begun in 1957; it was at the time, and may well still be, the world's largest user of direct geothermal heat. This early phase of geothermal development provided the foundations for a New Zealand export capability in technical services which, at its peak in the 1970s and 1980s, probably exceeded NZ$20 million per annum.

The main players in this first phase of large-scale geothermal development were New Zealand government agencies, assisted with engineering input from a UK consulting firm (Op. Cit.; also several interviews). The government agencies included the Department of Scientific and Industrial Research (DSIR) - an interesting title in itself, suggesting a close association between research and industrial development; the Ministry of Works and Development (MWD), the principal infrastructure development agency of governments of that era; and the New Zealand Electricity Division (NZED).

Although a programme of exploratory and scientific drilling of geothermal resources continued through the 1970s and 1980s[1], there was a gap of more than twenty years until the commissioning of the next commercial geothermal power plant at Ohaaki in 1989 - the last geothermal power station to be developed by the government. By the 1980s this marked a period of relative stagnation in geothermal research activity after the excitement and momentum of the previous two decades. It was no coincidence that the New Zealand governments capitalised on the accumulated geothermal research expertise by initiating several foreign aid programmes for assistance with geothermal developments in a number of Pacific nations, notably Indonesia, the Philippines and Chile (Op.Cit., p.16; also several interviews). These foreign aid programmes provided an alternative focus for some of the country's geothermal scientists to apply their knowledge, working in teams with private sector consultants from firms such as Geothermal Energy New Zealand Limited (GENZL) and Kingston Reynolds Thom and Allardice (KRTA). A number of DSIR and MWD personnel transferred to the private sector at this time

As part of the overseas aid programme, the Geothermal Institute was formed in 1979 at the University of Auckland. Its purpose was to provide post-graduate in-career professional training to senior scientists and engineers from developing countries. This extended in some cases to New Zealanders. Until the Institute was closed down in 2003 after the withdrawal of funding from the Ministry of Foreign Affairs and Trade (MFAT), it was responsible for bringing to New Zealand about 750 professionals.

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[1] Between the 1950s and 1986 there were some 120 wells drilled into 14 geothermal fields, mostly in the Taupo Volcanic Zone (Harvey, 2005)

A series of changes affecting the electricity supply sector of New Zealand around the late 1980s and early 1990s - corporatisation, privatisation and regulatory change - created the circumstances in which corporatised and private sector energy companies re-activated geothermal investment despite low power prices. Four geothermal fields were developed for power generation and commissioned in close succession - Poihipi at Wairakei (1996), Rotokawa (1997), Ngawha (1998) and Mokai (2000). The last three of these all involved participation by Māori Trusts as owners of the land (Harvey et al., 2005) and the use of old wells drilled previously by the Crown.

In parallel with the electricity sector changes came the re-structuring of science organisations in 1991, in which the DSIR was broken up and a family of Crown Research Institutes formed. The DSIR's geothermal research capabilities were divided between the Institute of Geological and Nuclear Sciences (now GNS) and Industrial Research Ltd (IRL) (SKM, 2005, p.17). It is generally agreed that this period witnessed considerable attrition in levels of geothermal research scientists; some were able to transfer to the Crown Research Institutes while others established individual or small consulting firms that remain active today (Op. Cit.; also several interviews).

3 The historical role of geothermal research in New Zealand's geothermal energy development

The initial geothermal research effort in New Zealand started seriously around 1950. It was essential in order to build the Wairakei power station, which was commissioned in 1958. The research capacity for the efforts at Wairakei - one of the first commercial geothermal developments in the world - came principally from several divisions within the DSIR, supplemented by some university research. NZED had little in-house research capacity; neither did MWD, and in the early days, private sector geothermal research capacity was minimal. (Estimates of personnel numbers involved will be discussed later, in Section 6.) DSIR supported both scientific research as well as the engineering research carried out by its staff at Wairakei. All of this geothermal research was government funded.

A coherent picture emerges from all those interviewed for this case study about the close relationship between the research activities of geothermal scientists and the development activities of geothermal engineers, and about the character of the research community during what might be referred to as the first wave of geothermal research and development in New Zealand.

As alluded to above, New Zealand pioneered much of the world's geothermal research and development activity until about 1980. Not only was Wairakei one of the first commercial geothermal electricity developments in the world, it was indeed the first time anyone had tried to drill into a water-dominated geothermal field anywhere in the world; research was required to develop the technology for liquid separation in order to make electricity generation from the Wairakei field possible.

The relationship between the research activities of geothermal scientists and the development activities of geothermal engineers was not merely a close one, it was a reciprocal relationship; in many situations it had to be. Early scientific studies guided the exploratory and development wells for the Wairakei and subsequent power developments; at the same time, the early power developments provided opportunities for developing better understandings about topics such as two-phase fluid flow and liquid separation processes. The essence of this reciprocal relationship continues to this day. Drilling is an expensive business. Latter-day geothermal drilling for commercial development has continued to draw upon the legacy of previous research results. In reciprocal fashion, any new well drilled now and in the future has the potential to provide access to additional geological and geochemical data which can be added to the body of extant data for analysis. Furthermore, as scientific and analytical methods evolve and improve, it is possible to re-visit drill-core samples and cuttings, whether they originated from scientific or commercial development activities. However, access to such data is now more difficult than it used to be, as the data are regarded as commercially sensitive.

The character of the geothermal research community during this first wave of research effort and commercial development drew consistent comments from across the group of interviewees - *" very strong - very open", "a collaborative community", "vitality", "lots of sharing of information"*, *"lack of secrecy", "meetings from all the different groups, talking about the Wairakei problems", "research creating its own priorities"*. As one interviewee remarked, *"At this stage, there were so many people involved in geothermal research and development that there were two 'geothermal coordinators' in the DSIR!"*

It appears widely recognised that the level of effort, the sense of urgency and the collaborative nature of the geothermal science community gave rise to results and reputations of world renown. A lot of geothermal technology and scientific technology and procedures emanated from this period of New Zealand's leadership in geothermal research. From the perspective of the US geothermal science community, the leading research came from New Zealand. The geochemistry section in Chemistry Division DSIR, for instance, developed techniques for high temperature fluid/rock experiments which provided essential data for the interpretation of the chemistry of the geothermal fluids. As a result, the laboratory became famous throughout the world. Geophysical methods for exploration of new geothermal fields were perfected by Geophysics Division of DSIR. Initial mathematical modeling of the behaviour of geothermal reservoirs was started at Applied Maths Division, DSIR. Contributions from the science of petrology to geothermal field development came from the University of Auckland and the Geological Survey. Other scientists developed methods for measuring fluid flows in pipelines; methods that are still in use today.

Views were also expressed by several interviewees that geothermal science, during the 1950s and 1960s, seemed to them to have been generously funded. Consequently, New Zealand built up a legacy of knowledge and skill that lasted for many years after the first wave of development activity came to an end. It was also noted that the MWD kept its drilling rig active for twenty years after the drilling programme at Wairakei, accumulating core samples from a variety of locations in the Taupo Volcanic Zone.

[Note: another important aspect of the historical role of geothermal R&D in New Zealand - its contribution to international geothermal developments - is discussed in Section 5.]

4 Time frames for the research and its uptake into commercial geothermal exploitation

The world's first major commercial geothermal power station began limited production within less than a decade of initiating the geothermal scientific research programmes. During this period, significant scientific and technological advances were made by the New Zealand geothermal research community, as described earlier. The time frame from research to uptake was very short; sometimes a matter of months, or a year or two. One person interviewed described the research and development dynamic during that period as *"almost on the run"*.

It should be remembered that the combined R&D effort referred to was the responsibility of government departments, not operating under a commercial imperative so much as a development programme determined at the time by central planning. The commercial risk environment for private-sector investment is totally different.

The geothermal research of the 1950s built the foundations for the accumulating knowledge of the geothermal resource, the technological capacity to harness that resource for power production and industrial heat, and the engineering capabilities associated with operating and maintaining the industrial-scale processes involved. Analytical techniques developed then are still in use to day.

Geothermal science and exploration - an understanding of processes that are occurring hundreds of metres below the surface and therefore inaccessible to direct observation - is built on the ability to interpret surrogate physical and chemical indicators or images: temperature gradients; fluid pressures; chemical compositions' resistivity measures; patterns of rock fracture; and so on.

The focus during the 1950s and 1960s was on one field, Wairakei. Despite the fact that science and engineering research brought that field into production in less than a decade, the geologic, geophysical and geochemical research of that period was not sufficient to characterise the geothermal resources of the wider Taupo Volcanic Zone (TVZ) nor even to develop a sophisticated understanding of geothermal field dynamics in general. In most areas of the TVZ there remains considerable uncertainty over the physical extent of discrete geothermal fields or the extent to which one field may be connected to an adjacent field, with the result that exploitation in one affects the behaviour of its neighbour.

From the perspective of hindsight most, though not all, of the interviewees agreed that the approach to investigations into the geothermal resource associated with the TVZ can be described as driven more by project-related considerations - focused on the individual fields as they appeared from the surface - rather than the longer term strategic consideration of assembling an in-depth, comprehensive knowledge base of the geothermal resource. To this end, there is still much science to be done to prove the resource and enhance technological capacity. This will include more intensive and deeper investigations in existing geothermal fields, as well as extending investigations to other geothermal areas[2]. Because each new data set adds to the body of data collected and available for analysis and interpretation, the potential for uptake into commercial exploitation in relatively short order remains.

Ultimately, the time frames for uptake of research depend to a large extent on economic factors. In an era dominated by private-sector investment and commercial imperative, research effort and research results are important to the extent that they influence the risks faced by developers. However, they are not the only source of risk to be considered. Consequently, whether or not contemporary geothermal research facilitates immediate geothermal development depends on factors outside the realm of geothermal research. These are factors such as prevailing electricity spot price signals, investments in alternative sources of power and heat, the effect of exchange rate fluctuations on overseas technology, and not least of all the influence of regulatory uncertainty.

In summary, the time frames between future geothermal research (fundamental or applied) and subsequent commercial developments could still be relatively short, if research itself were the only constraining factor. We know from the experience of those interviewed that

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[2] A fuller discussion of research issues and priorities is presented in Section 7.4.

most of the investments which occurred during the 1990s drew upon the existing bank of knowledge gained during research and exploration in the 1970s and 1980s; knowledge that was waiting to be tapped when other economic factors made it prudent to do so.

5 The contribution that NZ geothermal R&D has made to international geothermal developments

The leadership role in geothermal research and commercial development that New Zealand occupied for several decades from the 1950s through to the 1980s has already been described. This created a substantial body of world-leading scientific knowledge and commercially applicable technology. The conduit for getting this knowledge and technology to the rest of the world was two-fold: government scientists and consultants, working initially on Overseas Development Assistance (ODA) projects delivered advice and design skills for geothermal developments in other countries; and the establishment at Auckland University of the Geothermal Institute as a professional education centre drew a steady stream of senior scientists and engineers from developing countries to New Zealand.

Overseas aid programmes providing assistance with geothermal development began in 1973. The professional expertise for these assistance programmes was drawn initially from DSIR and MWD scientists and engineers. They were also recruited by the UNDP for technology transfer to developing countries. Before long, much of this work was contracted out to the fledgling private geothermal consultancies, such as GENZL and KRTA, that worked with government agency overview (SKM, 2005, p.16). In this way, the initial geothermal power stations in the Philippines (for example, Tongonan) were developed and built by New Zealanders, as was the Kamojang power station in Indonesia. Chile and Ethiopia were other countries to benefit from New Zealand's geothermal expertise as a result of ODA programmes. The private geothermal consultancy sector continued to grow through the 1970s and early 1980s, with new entrants such as DesignPower[3] and a series of mergers and buy-outs involving major overseas companies. This growth was stimulated by the volume of overseas work which private consultancies were able to win in their own right, reflecting the international standing of New Zealand's geothermal professionals and scientists. The staff for these consultancies was initially sourced largely from the DSIR and MWD through secondments and subsequently by employing such ex-government staff (Op. Cit.; also several interviews) when the level of government's investment in geothermal research and development declined in the mid 1980s. The scale and significance of New Zealand's contribution to international geothermal developments has been such that one of the major consultancies can claim, in a recent capability statement, that its staff have worked *"on more than 100 geothermal resources, located in some 20 different countries, undertaken over the past 30 years."*

Another aspect of the overseas aid programme was the establishment of the Geothermal Institute in 1979. The Institute provided post-graduate education in geothermal science and engineering. All the industry people and scientists interviewed agreed that the Institute had a world-wide reputation which continued to attract overseas professionals to its courses until it was closed in 2003.

A joint venture between the science and engineering faculties at the University of Auckland, the Institute had four academic staff (engineers and earth scientists), and three administrative staff (manager, secretary, lab. technician). Many other people from inside the University and from outside contributed a lecture or two on their specialty and also assisted

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[3] The design division of Electricity Corporation of New Zealand (ECNZ).

with supervising student projects. The diploma course lasted nine months, during which they took six papers and undertook a research project associated with someone from the geothermal industry. Enrolments came mainly from Indonesia, Philippines, China, India, Thailand, Vietnam, USA, Mexico, El Salvador, Nicaragua, Costa Rica, Chile, Columbia, Turkey, Kenya, Ethiopia, Hungary, and Romania. Seven or eight other countries also provided a few students.

Apart from maintaining New Zealand's position as one of the world's two global training hubs over several decades (the other being Iceland), the Geothermal Institute provided other benefits to this country. The continuous flow of professionals from geothermal industries around the world linked New Zealand into a continuous flow of geothermal data, ideas and expertise, even though there was practically no geothermal development in this country between 1980 and 1995. In this way, the Geothermal Institute connected New Zealand geothermal scientists to the world and allowed some research to continue during this hiatus. Since the scientists and engineers coming to the Institute for further training brought some work experience with them, they were able to contribute to the New Zealand geothermal science community through the small research projects each was required to undertake. Until the Institute was closed down in 2003, it was responsible for bringing to New Zealand some seven hundred professionals for the diploma course, as well as about 20-30 others for Masters and PhDs, many of whom now occupy senior management or administrative positions in their own country. Thus – not unlike the Colombo Plan arrangements for bringing young men and women from Asian Commonwealth countries to New Zealand for their university education - twenty years later, many in these cadres of professionals had reached positions of responsibility and influence in their own countries and proved to be good friends to New Zealand in maintaining relationships and creating opportunities for delivering overseas development assistance programmes as well as opportunities for New Zealand consultancies' services.

6 The reasons for and implications of the decline in geothermal research capability

As a result of the close links between research and commercial development, the fortunes of the former were also closely tied to those of the latter. As geothermal energy, both electricity and direct heat, faced competition from cheaper sources of hydro-electricity[4] and cheap Maui gas during the early 1980s - some might argue 'artificially cheap' in hindsight - the demand for further geothermal energy investment became virtually non-existent, even though exploratory drilling continued throughout the 1970s and 1980s at the Ohaaki field, ultimately providing the information basis on which the Ohaaki geothermal power station was developed and commissioned in 1990, and the Ngawha, Mokai and Rotokawa stations later on.

There is little debate amongst those interviewed that geothermal research capacity in New Zealand declined, although some interviewees also point to the re-employment of geothermal scientists elsewhere in New Zealand - into universities, into the Taranaki oil and gas developments, into other fields of science such as vulcanology and natural hazards work, and into geothermal consulting firms doing work overseas. But there was also a cohort of geothermal scientists who started to retire in the mid-1980s and others were recruited to science overseas[5].

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[4] The Upper Waitaki hydro-electric power stations (Tekapo A & B, and Ohau A, B & C) were commissioned during the 1970s and the 1980s respectively (Minister of Energy ,1980, p.47).

[5] CSIRO in Australia and research institutes in Germany were specifically mentioned.

Basic geothermal science capacity comprises principally the disciplines of geology, geophysics, geochemistry, physical chemistry and reservoir engineering[6]. Latterly, a range of environmental sciences have become important as research interests have begun to focus on environmental issues related to geothermal development.

Detailed records of staff numbers in government agencies (DSIR, MWD) have not been available for the 1980s, with the result that the estimates included here are based entirely on the memories of those interviewed who were part of the geothermal science community at the time. It is generally agreed that peak scientist numbers occurred in the early 1980s and the decline in numbers began around 1985. During the heyday of geothermal research and development, it has been estimated that there were somewhere between 50 and 100 full-time equivalent geothermal scientist positions[7] employed by government, mostly in the DSIR, but with some employed by MWD, NZED and the universities. Until the early 1970s, the private sector consultancies had virtually no geothermal research capacity, a situation that changed progressively during the later 1970s and 1980s.

As noted in the opening paragraph of this section, geothermal electricity was supplanted in electricity supply options by hydro electricity in the 1970s and gas-fired thermal power in the 1980s. A sequence of Energy Plan documents between 1980 and 1985 indicate these relative priorities. Thus, demand for geothermal science from its companion development sector declined. This probably did not have a sudden impact on scientist numbers; that came later with the reform processes.

Two strands of the government economic reform process impacted on geothermal research capability - reforms of the energy sector and reforms of science organisation and funding. Both these sets of reforms influenced the level of research investment in geothermal research; reduced government funding, not surprisingly, led to the down-sizing or total dissolution of some of the geothermal research teams.

There is a consensus amongst those interviewed that corporatisation and privatisation of the electricity industry resulted initially in a decline of interest in geothermal development, triggering an exodus of government scientists to the private sector, either as individual independent consultants or joining one of the major consulting firms, which were becoming increasingly involved in international geothermal developments at that time. It is estimated that this may have accounted for as many 20 to 25 geothermal scientists at the time. Many of these were surprised to find greater stability and higher levels of remuneration in the private sector than they were experiencing in government employment.

The re-prioritising of energy resources (hydro and gas for geothermal) and the restructuring of the electricity sector in the late 1980s had indirect influences on the level of geothermal research capacity. Furthermore, the general retreat from mineral exploration in New Zealand over this period reduced the scope of alternative sectors in which to work.

In contrast, the most direct and immediate influences occurred when the basis of research funding and the organisational structure of research was reformed in 1991 with the creation of the Crown Research Institutes (CRIs) and the Foundation for Research, Science and Technology (FRST). Re-cast against a much wider set of national research priorities,

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[6] Although named engineering, the discipline involves active research; in New Zealand this research is mainly in the field of applied mathematics.

[7] The wide range in these estimates may be the result of some interviewees including applied science (engineering) personnel as well as basic science personnel.

geothermal research was not experienced as a FRST priority area. Declining funding (see table following) led to low morale and attrition in scientist numbers.

Government investment in R&D by FRST (excludes Technology NZ or Marsden Fund)

The 1992/93 financial year is the start of the reliable time series from FRST annual reports. Prior to 1992/93 year, FRST was not 100% responsible for PGSF. The dollar values in the table are nominal, i.e., they have not been adjusted for inflation.

Financial year beginning July	**Geothermal production**	**Geothermal impacts**	**Total**	**Total contracted ($m)**
1992	$2,139,750	-	$2,139,750	$2.14
1993	$1,488,000	-	$1,488,000	$1.49
1994	$1,572,000	$107,000	$1,679,000	$1.68
1995	$1,517,000	$140,000	$1,657,000	$1.66
1996	$1,369,000	$200,000	$1,569,000	$1.57
1997	$1,817,000	$200,000	$2,017,000	$2.02
1998	$1,510,000	$123,000	$1,633,000	$1.63
1999	$1,510,000	$123,000	$1,633,000	$1.63
2000	$945,198	$134,802	$1,080,000	$1.08
2001	$945,198	$134,802	$1,080,000	$1.08
2002	$965,198	$134,802	$1,100,000	$1.10
2003	$1,145,198	$134,802	$1,280,000	$1.28
2004	$1,145,198	$134,802	$1,280,000	$1.28
2005	$1,145,198	$134,802	$1,280,000	$1.28

Source: MoRST

Given the change of circumstances during the 1980s and 1990s, interviewees pointed to a range of implications for geothermal research in this country.

First and foremost in people's minds is the fact that, in many areas, New Zealand is no longer at the forefront of geothermal research internationally. Nevertheless, individuals continue to make contributions of an international standard.

The wind down in public research investment to current relatively low levels has resulted in private sector scientists becoming a more significant component of the present research capacity - *"there are a lot of the luminaries we now hire as consultants".* An industry survey for the Energy Efficiency and Conservation Authority (EECA) in 2005 put the geothermal science capacity available in New Zealand in the disciplines mentioned previously[8] at some 57 scientists in total, of whom 27 were in CRIs[9], 20 in the private sector, 5 in universities and 5 employed by companies which operate geothermal power stations (SKM, 2005, p.33). Furthermore, while GNS may have as many as 26 scientists with some geothermal experience, only 3 to 4 full-time equivalents work in the geothermal research programme at the present time due to the low level of government funding. However, it is conceivable that some of the scientists who have diverted to natural hazards work could re-deploy to geothermal research if priorities and funding justified this.

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[8] Ie, geologists, geophysicists, geochemists and other physical chemists.

[9] With one exception, these were employed by GNS.

With privatisation of the power sector in NZ, and with the CRI scientists also working within a competitive funding regime, there is no longer the same advantage to sharing new scientific knowledge or technological advances - as used to happen so freely and openly during the first wave of geothermal research and development. As a result, *"many advances are not publicised"*. This was observed to be a world-wide problem[10]. Furthermore, private sector research is *"no longer on the government's radar; FRST and MoRST are unlikely to know about recent geothermal research in the private sector."*

In terms of the current body of research, there appears to be the absence of a strategic approach to national geothermal research effort. To an outsider, the total picture[11] of present research could be described as *"piece-meal and under-funded"*. It was suggested that the current research environment favours 'evolutionary' low-risk research rather than 'revolutionary' higher risk research. This is evident in the differing research priorities expressed by the interviewees. Furthermore, it would not be unexpected that private-sector and public good research should reflect different degrees and aspects of risk in research.

In summary, some research capacity remains, but a major new investment in geothermal research now (ie, increasing demand for geological, geophysical and geochemical scientists) would probably require some recruitment of scientists from overseas to bolster current local science capacity; even the reservoir of scientific experience in related fields (eg, vulcanology, oil and gas exploration, natural hazards) is unlikely to provide sufficient expertise to fill the immediate gap in capacity. It should be noted that, over the past ten years, the former trend for the private sector to recruit geothermal expertise from the public sector has in some instances been reversed. There is also the alternative that new graduates could be recruited but it would take time for them to gain practical experience.

The interviews for this case study encountered a lively debate between public and private sector geothermal research interests regarding research funding. The extent to which the private sector could in future contribute to public good research is in some measure dependent on its perception of the financial attractiveness of this area of work relative to commercial consulting and research work. However, it is unlikely that the involvement of this research capacity would satisfy totally the additional demands for geothermal research capacity associated with a substantially increased level of investment in geothermal research and development activity.

7 The potential role that geothermal energy could play in a more diverse and sustainable energy future for New Zealand

7.1 The circumstances for geothermal development have changed markedly

The circumstances for future geothermal development are markedly different from the circumstances which prevailed during the first wave of geothermal development in the 1950s and 1960s. During the first wave of geothermal development, both research and development activities were driven by central government as part of a co-ordinated programme of expansion in energy (electricity) infrastructure. Since that time, electricity

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[10] The editor of a geothermal science journal reported that the number of articles submitted for publication has dropped dramatically in the last decade.

[11] That is to say, all geothermal research activity; private sector as well as government-funded research. This comment is not a reflection on public good research in isolation.

supply has largely been privatised, the legislative framework has changed substantially, resource-use decisions have been devolved from central government to regional councils, and competing uses for geothermal resources are making these resource-use decisions more complex.

The 2005 review of the industry (SKM, 2005, pp.20-30) demonstrates the extent to which the simple, central government-driven model of geothermal development has changed. Industry players include as many as eight energy companies[12] with some degree of involvement in existing geothermal power development or prospecting. The extent to which Māori trusts have become active in commercial geothermal development is also evident[13].

Although geothermal development is heavily reliant on drilling and exploration activities, it does not come under Crown Minerals or Petroleum Legislation. Instead, geothermal development proposals are covered by the Resource Management Act, with its effects-based framework and sustainable management imperatives. This situation has distinct disadvantages for developers' rights during the exploration phase, which in turn has implications for the Intellectual Property associated with exploration results. Within the minerals exploration framework, in exchange for a priority right to develop the resource commercially, the developer is legally required to provide exploration data to the public domain. In the case of geothermal exploration under the RMA, there are no exploration licenses; there are consents for exploratory drilling, but these have limited obligation to publish the resulting data, because much of the data is not relevant to environmental effects assessments. Under the RMA, in the absence of a priority right to develop, there is a strong dis-incentive to share geothermal exploration results in the public domain. In this way, the present regulatory environment for geothermal developers acts as a constraint on the level of exploration undertaken.

All but one of the nation's high-temperature geothermal systems are found within or adjacent to the active volcanic band known as the Taupo Volcanic Zone stretching from Mt Ruapehu to White Island and beyond. Waikato Regional Council and Bay of Plenty Regional Council administer almost all of the geothermal resource within this area, although a part of the Tongariro geothermal system extends into the Manawatu Region. The other high-temperature system is the Ngawha geothermal system found in Northland.

Low-temperature geothermal systems are found in various parts of the country but are generally more likely to be found in areas of active faulting. The Waikato, Bay of Plenty, and Westland Regions account for approximately three-quarters of the isolated sets of hot springs that make up the nation's low-temperature geothermal resource. While these generally do not have significant geothermal features and ecosystems associated with them, they can be used for tourism-oriented bathing facilities or direct use industrial applications.

Three regional councils' areas account for all the major commercial geothermal development in New Zealand at the present time. This situation is unlikely to change as further commercial development proceeds.

7.2 The potential role for geothermal development

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[12] Contact Energy, Mighty River Power, Top Energy, Tuaropaki Power Company, Bay of Plenty Electricity, TrustPower, Norske Skog Tasman, the Geotherm Group.

[13] Tuaropaki Trust, Putauaki Trust,Tauhara North No2 Trust, Ngati Tuwharetoa Geothermal Assets Ltd, Tikitere Trust.

While the mix of uses of geothermal resources has always been varied - tourism and natural features, small-scale domestic usage, electricity generation and large-scale direct heat applications – it is the latter that have dominated in terms of scale, effort and prominence. Traditionally there has been much more effort on research into these extractive uses and therefore more quantitative data on estimates of future potential exist.

An estimate of untapped electricity-generating potential, based on the shallow, high-temperature geothermal resource economically accessible with current technology was provided by Lawless (2005, p.1) *"Using only current technology, and ignoring environmental and regulatory constraints, the median value of New Zealand's high temperature resource capacity is estimated to be about 3,600 MW of electrical equivalent. That is about 65 % of New Zealand's current total peak demand for electricity. Taking environmental and regulatory constraints into account reduces the figure to 898 MW."* Commentators view these estimates as either conservative or optimistic, depending on their perspective. However, the order of magnitude of the estimate is likely to be correct given the common perception of a potentially very large resource.

To put this in context, 898MW of new electrical equivalent (MWe) is twice the total existing installed capacity of geothermal electricity generating stations in New Zealand (SKM, 2005, p.21). Since geothermal power stations are capable of being operated at varying loads without too much operational difficulty, such development could complement other renewable electricity options such as wind farms. However, several interviewees, expressed the view that the cautious approach by regional authorities to resource consenting will mean that incremental additions to installed geothermal power generation on their own would not be capable of forestalling the country's looming electricity crisis.

Estimates of existing direct heating uses total just over 300MW thermal equivalent (MWt) (White, 2006, Table 2, p.11) comprising 181MW of industrial process heat, 84MW used in bathing complexes, 9MW for fish and animal farming, 5MW in heating greenhouses, and 1MW in space heating. Environment Waikato points out that New Zealand does not have one single geothermal district heating scheme operating despite having several towns and cities in close proximity to geothermally active zones, such as Rotorua, Taupo, and Tokaanu.

Environment Waikato highlights non-extractive uses of geothermal resources for tourism and 'cultural' use, and in support of plant and animal biodiversity and micro-organism biodiversity. These are uses that also need to be considered in development decisions. They note that a survey in 2001[14] reported 2 million visits to geothermal attractions in the Waikato region alone, including Orakeikorako, Waiotapu, and at Wairakei-Tauhara Craters of the Moon, Wairakei Terraces, The Prawn Farm, Geyser Valley, and Taupo Hot Springs. They point out that, until the building of Auckland's Sky Tower, Whakarewarewa in the Bay of Plenty was New Zealand's most-visited tourist site. Regarding animal and plant bio-diversity, Environment Waikato notes that: there are approximately 1000 hectares of geothermal terrestrial vegetation in New Zealand and a much smaller area of geothermal aquatic habitat; that the 500 hectares of geothermal terrestrial habitat found in the Waikato Region amounts to 0.02% of the land area of the Region; that many of the plants found on geothermal ecosystems are extremely rare[15] and may be found in only a few locations in New Zealand; and that some of the invertebrate species adapted to aquatic geothermal habitats are known only in a single location. Regarding micro-organism bio-diversity, Environment Waikato notes geothermal pools and springs containing water hotter than ~50°C are home to many species of thermophilic micro-organisms not yet found anywhere else, and about which very

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[14] A new survey is scheduled for 2006-07.

[15] Although not necessarily rare in geothermal areas.

little is currently known. Furthermore, they express the view that thermophilic micro-organisms are an important repository of national and international bio-diversity and many are being studied for medical and commercial applications or are already being commercially used for industrial processes[16].

Many of these potential uses of geothermal resources have not been investigated, quantified or assessed for their economic value.

As competition grows over uses of the geothermal resource and the associated decision-making complexity increases, so does caution in granting resource consents. In the rest of the world, geothermal power developments have become larger over time and therefore benefited from economies of scale. In New Zealand, the trend has gone the other way. Regulatory authorities have been cautious about what they have permitted, with recent applications being granted for considerably less extraction than was applied for[17]. Furthermore, consents have tended to be granted for less than the maximum 35-year period.

7.3 Constraints on geothermal development

The interviews conducted for this case study suggest that the principal constraints on geothermal development arise from a combination of economic drivers, regulatory framework and the state of knowledge about the resource and the effects of its use, in a situation of potentially competing uses. These three factors are inter-related, since regulatory processes and scientific uncertainty both influence commercial risks and costs faced by developers. The influence of operating under an RMA framework rather than a Crown Minerals framework has already been discussed.

The present state of knowledge reflects both the limits of what was achieved through earlier research and exploration as well as scientific uncertainty about environmental issues that are now given greater significance than they used to be.

Economic drivers are important for private sector geothermal developers. While they suggest that geothermal power stations *“are relatively expensive to build but cheap to run”* their anticipated life-cycle costs at the present time make them only borderline investments in today’s electricity supply market (Harvey et al., 2005). The costs of importing capital items, the effect of planning delays on returns to capital, and the need for developers to compete on the international market for expertise if New Zealand does not re-vitalise its own research support are suggested as some of the factors which influence the competitiveness of geothermal power developments.

What defines sustainability when sanctioning extractive uses of geothermal resources is a major challenge for regulators. Operators do not deny that *“extraction of the fluid and energy in a geothermal system beyond the natural rate of discharge depletes the usable resource found within the upper aquifers”*. However, expectations of recovery times of depleted geothermal fields are based on existing reservoir models, not on real system experience.

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[16] Citing as an example the DNA identification technique used in forensic applications which relies on a thermophilic micro-organism discovered at Yellowstone National Park, USA.

[17] At Ngawha, the application was for 35,000 Tonnes/day fluid draw-off, with 10,000 Tonnes/day granted; at Poihipi the corresponding figures were 44,000 Tonnes/day and 11,800 Tonnes/day respectively; while at Tauhara, one-third of the quantity applied for was granted in the consent (65,000 Tonnes/day vs 20,000 Tonnes/day).

Similar limitations apply to the current level of knowledge about how sub-surface extractions affect other surface phenomena or how inter-connected geothermal systems are[18].

As the pressure for further commercial development mounts, after an extended period of minimal research effort, the combination of recently adopted policy principles and considerable scientific uncertainty results in very cautious decision making. This situation is not helped by the fact that the regional councils themselves have negligible geothermal expertise. Environment Waikato does not consider *"the depletion of the available energy and fluid in a geothermal reservoir within one or two generations to be sustainable management of the resource."* Some scientists suggest that important questions remain to be asked as to whether this has to be the scenario. Some also suggest that New Zealand seems out of step with trends in other countries[19], where regulators *"are tougher on environmental effects but less stringent about imposing a sustainability requirement on geothermal developments."*

What most interviewees seem to agree on is that the limitations of the existing scientific knowledge base for the geothermal resource and the effects of its use are a critical constraint both for commercial development and for sustainable management.

One regulatory response adopted by Environment Waikato has been to divide the Region's 15 high- temperature geothermal systems into four use categories. *"Seven systems are available for large-scale extractive uses, two for limited uses, and five are protected. There is one system, Reporoa, in the research category, where not enough is known about that system to put it into one of the other categories. This category is also for any undiscovered geothermal systems that may exist."*

7.4 Research issues and priorities

Compared with the first wave of geothermal development in the 1950s and 1960s, the scope of research effort required has broadened and expanded considerably, although the threads of analytical and investigative methods and resource proving continue. Rather than being driven exclusively by the immediacy of specific commercial developments, the need now is for strategic research in the sense of building the knowledge base about the whole resource systematically, as well as being able to inform strategic decisions about competing uses and environmental effects. It should be remembered that many developmental problems were only partially solved by the previous research. It was also suggested that, in some cases, it might be better to promote more collaboration[20] with overseas researchers and put some funding into applying overseas knowledge to New Zealand situations. Furthermore, there is now a more diverse range of end users for the research.

The interviews for this case study canvassed views on critical research priorities for realising the potential role of geothermal energy in a more diverse and sustainable energy future. Responses have been summarized under a series of bullet points below (with more elaboration of some topics provided in Appendix 1). It should be noted that the listing below does not indicate priorities; nor did all those interviewed agree on the importance of every item. There was strongest consensus regarding the need for research on sustainability issues, other environmental effects, and improving levels of energy extraction in existing

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[18] The example was given of the Reporoa geothermal system and whether its boundaries are sufficiently accurately understood.

[19] Cited as Italy, US, Japan, Iceland and the Philippines.

[20] Some research collaborations already operate, e.g. GNS collaborating with Iceland deep drilling work.

electricity generation plants. The strongest polarisation of views was associated with interests in deep drilling. However, this polarisation did not reflect a simple private- versus public-perspective dichotomy.

Summary of critical research priorities:

- Geothermal system knowledge and resource proving – shallow as well as deep resources
    - A strategic approach to basic geothermal studies
    - Better drilling techniques
    - The chemical composition of fluids
    - Improved computer modeling methods

- Existing electricity generation – improving the efficiency of energy extraction
- Sustainability issues
- Other environmental issues
    - Subsidence
    - Destruction of surface features
    - Reducing thermal and chemical pollution

- Analytical and investigative methods
- Other uses of geothermal energy
    - Low-temperature direct uses
    - Heat pump applications

7.5 Conclusions

The first wave of geothermal research and development in New Zealand generated a body of knowledge and expertise that delivered economic returns to the country for several decades after geothermal development was halted. There is still a core of knowledge and expertise (albeit somewhat reduced in scale and world-wide currency) as well as a substantial geothermal resource which has only ever been investigated in a preliminary and partial manner. However, the drivers for re-vitalising the research activity appear confused and the prospects for further commercial geothermal development, substantial as they are, seem hampered by a challenging regulatory environment and a limited body of scientific knowledge.

It has been recorded that a close relationship between geothermal research activities and geothermal development activities was extremely beneficial to both parties in the past and is likely to continue to be beneficial to both parties in the future. The country's geothermal research capability is no longer the sole preserve of the public sector. These two facts are not contradictory, nor do they imply that the research priorities for public good science and the research priorities for commercial developers are identical. They point towards complementarity.

It could be concluded from this case study that increased levels of investment and greater strategic coordination of the national research effort are necessary, both for facilitating further extractive uses in an efficient manner and for balancing the interests of extractive and non-extractive uses in a manner appropriate to sustainable management. Improvements in the knowledge base are critical to both the efficiency of commercial development and the efficacy of regulatory principles. If, on current estimates, environmental and regulatory concerns over resource sustainability lead to a reduction of the technical potential for future geothermal electricity generation from 3600MW of electrical equivalent to 900MWe, then it might be argued that there is much to be gained from directing research effort towards addressing the scientific uncertainties that give rise to such a reduction.

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Appendix 1 Comments on research priorities

1 Geothermal system knowledge and resource proving - shallow as well as deep

(a) A strategic approach to basic geothermal system studies is very important; *"there are some glaring gaps in our knowledge - we haven't studied enough systems in enough detail to* *identify all the common themes, even though there are relatively few different types of geothermal system"* For example, geothermal systems tend to be highly fractured *"and yet we don't have a good explanation why; this causes us to go out and drill not knowing quite what we're looking for".* While *"full development relies on site-specific understanding"*, a strategic approach to basic geothermal systems research can help reduce costly drilling mistakes. A better understanding of the geologic controls of geothermal systems will allow more accurate drilling targets; *"you pay $5 million for the first well; because we don't have enough fundamental research to cover enough of the territory, it's still very risky; with more fundamental research we could bring the risk down."*; *"just understanding the active tectonic regime in our geothermal systems; how faults move episodically"*

(b) Better drilling techniques, including directional drilling and the use of different drilling fluids to make exploration and recovery more efficient; developing the ability to drill deeper to access the geothermal resource; if you could reduce the risks associated with targeting of deep drilling, this would open up possibilities for development that might be less likely to exhibit any changes in surface phenomena; *"New Zealand is a good place to do deep wells; geologically easy drilling - shallow high temperature resources; some of the hottest temperatures at 2km; not many other places are doing it - Japanese have a deep well; Iceland is drilling deep too".*

(c)The chemical composition of fluids in geothermal fields is very varied, even in different parts of a single field like Wairakei; there remains a need to be able to interpret what chemical composition data indicates about changes in field properties over time.

(d) Improved computer modelling methods for determining the scale of the resource; also for predicting future behaviour of a reservoir under various extractive regimes.

2 Existing electricity generation - improving efficiency of energy extraction

How to make better use of geothermal fluids which are brought to the surface; at present there is ~50 degrees C of temperature which is not being used at many projects; using this would have no incremental environmental effects; more work done on pushing the rejection temperature lower on real New Zealand fluids and in a New Zealand industry context; there is scope for more binary plants; more sophisticated thermodynamic Kalina binary plants, although it is not practical for New Zealand to do basic research on such technologies but the research to apply them in New Zealand conditions; also the research on downstream liquid treatment - these are the sites of environmental issues - silica deposition, pilot plant work again, this work tends at the moment to be done on a project-by-project basis; needs a more strategic approach which could then have more diverse application.

3 Sustainability issues - different perspectives

Investigations to determine the factors affecting responses of a range of geothermal fields - some appear to be depleted by extraction while others are replenished by recharge from below as field pressures reduce.

4 Other environmental issues

Since environmental effects are the focus of many regulatory constraints, research should be aimed at addressing these.

(a) Subsidence - *"this is poorly understood"; "you have technical experts disagreeing with each other at consent hearings - and what's the evidence?"*; need a sound theoretical basis for determining what suitable mitigation would be; there is still a level of uncertainty about subsidence modelling - very relevant to subsidence issues; *"there are other dynamic processes of ground movement that are important - why is the inflation/deflation happening? where is it happening?"*; need more knowledge of micro-earthquakes, nuisance seismicity - *"has shut down projects in France".*

(b) Destruction of surface features - *"no one is managing hot springs from beneath - this could be done"*; a better understanding of the subsurface hydrology of hot spring systems would help operators avoid and remedy adverse effects on surface features; characterisation of the extent of microbial biodiversity in geothermal surface systems; currently very little is known about this. *"You have to know what you have before you can know how to use it."*

(c) Research into ways of reducing thermal and chemical pollution of rivers from discharges.

5 Analytical and investigative methods

New technologies and better methods for analysing deep[21] geothermal fields such as magneto-tellurics which has the promise of being a lower-cost, non-invasive method of investigation.

Improved instrumentation for down-well data capture to enable better characterisation of the resource.

Renewing the experience base of research into multi-phase flow phenomena in pipes.

6 Other uses

Low-temperature direct usage

Heat pump applications

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[21] 'Deep' usually means >3km depth.