STEAMFIELD DEVELOPMENT OPPORTUNITIES SUPPLYING PROCESS HEAT INDUSTRIES

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ABSTRACT

While large scalc geothermal dcvclopments are usually associated with electricity generation, it is widely accepted that the process heat market can be an alternative markct to be targeted by steamfield developers. This paper lakes a preliminary look at potential opportunities in the supply of heat to industry

1. INTRODUCTION

The development of hot geothermal fields on a large scale has typically been driven by electricity utilities and more recently by private power developers. An assumption behind this approach is that power generation is the only large scale developmcnt of sufficient size to achieve adequate returns for investors. This paper aims to show that such an assumption is incorrect. Existing steamfield developers and the new private investors should keep industry and process heat nceds in mind as well.

The price that a process steam user is prepared to pay for steam is considerably greater than the price an electrical power generator will pay. Fuel bills can be a significant cost in adding value to raw products by a process industry Profits can be increased if plant can he sited to take advantage of geothermal heat. Even if a process plant, located on a geothermal field, is using an alternative fuel, a retrofitted geothermal supply can still be cost effective, allowing the existing boilers to be mothballed.

The quality of process steam generated from a geothermal sourcc can be readily controlled. In some cases, geothermal steam may be used directly. In other cases, clean steam may be generated using heat exchangers. Geothermal wells can be developed to supply process steam for a full range of pressures, particularly if backed up by compressors.

Costs for developments will necessarily be site specific but principles established lor one situation will likely apply in a range of other situations. Some cost curves are derived in this paper and a New Zealand situation involving process heat supply to a New Zealand forestry industry plant is discussed.

It is recommended that steamfield developers and process heat users should investigate the possibility of using geothermal steam to supply process heat.

2. BRINGING PROCESS HEAT INDUSTRY AND STEAMFIELD DEVELOPER TOGETHER

Geothermally sourced process steam requires an agreement between a proccss steam user and a geothermal field developer.

Pre-requisites for agreement include:

a) Co-existence (or planned co-existence) nf process steam user and geothermal field.

b) Recognition by industry that geothermal heat is a clean and reliable cnergy sourcc that can meet quality and prcssure needs.

c) Preliminary field investigation so that production/ reinjection scenarios can be reasonably costed.

d) Recognition by field developers that a range of alternative fuels is available. and so significant advantage must be offered to industry to attract them to use the geothermal option.

e) Recognition by industry that there are manageable risks fur developers of geothermal resources so it is appropriate for benefits to be assigned in favour of the risk taker.

f) Open discussion on process heat requirements so the most appropriate design can be developed.

2.1 Location

Process plants are located based on consideration of the availability of raw materials, labour. cooling water and fucl sourccs. Transport costs and proximity to markets also help to determine location. Ultimately a plant's location is based on economic criteria with, at times, some political influencc.

Geothermal fields are located by natural forces. Steam and hot water are generally considered non-transportable i.e. they must be used on the field or within a few kilometres of it. Hence, the greatest hurdle fur supply of process plant with geothermal heat is for the two to coexist.

If industry is aware of the order of magnitude of costs associated with geothermally-sourced steam then this will help them to decide to locate in a geothermal area. There will almost certainly need to be a preexisting steamficld developer on site as the process industry is rarely interested in the uncertainties of field development and does not have that expertise.

2.2 Steam Quality and Reliability of Supply

The process heat user wants a reliable "boiler" that can generate the quantity and quality of steam the process requires. Geothermal systems can act as that "boiler".

The quality of steam required by industry varies from process to process. Geothermal steam itself contains a small portion of nun-condensable gas (mainly CO_2 with smaller quantities of H_2S) which may be acceptable in some cases. Where not appropriate, then a heat exchanger can be installed to generate clean steam. Geothermal wells are frequently discharged at pressures in the range 5 to 20 bara (equivalent temperatures of 150°C to 210°C), although could conceivably be discharged at higher pressures in some fields. Pressure requirements could readily be met through use of compressors if necessary. Hence steam quality and pressure requirements can be technically achieved.

It should be noted by the process heat industry that the geothermal puwer industry requires a high availability steam source. Geothermal fields have been reliably supplying steam to power stations (and process plants) for more than 30 years. Plant in Italy has an even longer history These stations generally require full load steam supply for 90% of the year or more. Availability exceeding 95% is realistic. Field maintenance is arranged to coincide with plant maintenance to maximise plant availability and load factor.

It is not necessary to supply geothermal steam at a steady rate. Load-following is possible by combinations of backpressuring the supply system, venting surplus steam, and opening/closing well control valves. Such control systems are incorporated into existing field developments.

2.3 Field Investigation and Development

The process heat user, as a rule, knows little about geothermal energy or its investigation. As stated above, such industries want a reliable "boiler" with steam at a reasonable price. It is up to a steamfield developer to show that they can provide that need.

Preliminary field investigations, including the drilling of exploration wells will be necessary to give process plant developers and financiers confidence that an adequate resource is present at a reasonable price. The generally small steam requirement of these plants implies that they would have difficulty in bearing the cost of investigations. Hence, as a rule, process steam supply options should only be offered by field developers as a supplementary develupment to a larger project such as a power station. As incremental supplies, they will be particularly attractive. They will also provide a rapid mechanism for cash generation while testing the field.

2.4 Alternative Fuels

Alternative fuels for generating steam in process industries include gas, coal and waste products. These are listed in terms of increasing cost of fuel firing facilities and decreasing cost of fuel. These alternatives must be considered in setting an attractive price for the geothermal option.

For retrofitting situations, where a process industry already exists adjacent to a geothermal field, the geothermal development may have to compete with the cost of fuel only (i.e. the cost of existing steam generator plant will already be written off). Even in these situations a geothermal supply can be competitive.

2.5 Risk Allocation

Steamfield developers h o w the risks associated with geothermal developments, They must absorb costs associated with low output wells or the effects of decreasing well output with time. Similarly, they could expect to make a penalty payment for failure to deliver steam. The cost of such risks should be built into the price. The benefits of rapid development, generating revenue from long term production/reinjection trials should also be assessed. Rapid development is likely for retrofitting situations.

The process industry should reasonably expect to pay for the capital investment of the steamfield developer. As geothermal developments are capital intensive the contract for steam sales should be on a take-or-pay basis, or capacity plus energy charge basis, over a fixed period sufficient to allow recovery of costs and the achievement of minimum revenue goals.

1.6 Communications

Process heat user and steamfield developer need to communicate their needs to each other, so that appropriate options are reviewed and costed, and that key target dates are properly recognised.

2.7 Other Matters

Other matters need tu be considered in the development of agreements. Frequently, process industries have high electricity usage. Direct sales of electricity from geothermal generation can be considered, and incorporated into the agreement. The agreement itself can be very similar to existing steam sales agreements so may nut require a large legal input.

3. COSTS AND FINANCLAL ANALYSIS

Cnmparisons have been made of the steam production costs from conventional boilers fired by gas, coal and waste, and geothermal process heat development options to determine the conditions where a geothermal development would offer an advantage over the conventional boiler. In the tables that follow costs are given as a function of the flaw of process steam, F, in tonnes/hour. The geothermal development options cover the direct supply of geothermal steam, and generation of clean steam using either separated geothermal steam or a two-phase mixture in the heat exchanger.

All costs in this repon are given in New Zealand dollars. Note that at the time of writing (August 1994) NZ$1 ≈ US$0.60.

Also note that the capital costs given in tables 1 and 3 include all direct and indirect costs including escalation and financial charges.

3.1 Conventional Costs

The assumptions made are summarised in Table 1. Costs are taken from a company database. Fuel and O&M costs are indicative for a New Zealand situation. Note that while a zero fuel cost has been assigned to the waste fuel there may still be other processing and handling costs which have not been accounted for.

Table 1 - Cost Assumptions For Conventional Fuels

Fuel	Gas	Coal	Waste
Heating value	38.8 MJ/m^3 (HHV)	25 GJ/t	-
Fuel cost ($/GJ)	5.w	3.60	0
Fuel cost ($/t)*	16.25	11.7	0
O&M ($M/y):			
F = 0 → 7 t h	0.032	0.032	0.032
F = 7 → 30 t/h	0.282	0.282	0.282
F = 30 t/h →	0.482	0.482	0.482
Total Capital Cost ($M)	$0.44 + 0.10F^{0.7}$	$0.44 + 0.28F^{0.7}$	$0.44 + 0.54F^{0.7}$

* Fuel cost is $/t of process steam produced

3.2 Geothermal

Three geothermal development scenarios have been examined. These are:

- direct supply of geothermal steam.
- separation of the geothermal steam and water with clean steam generation using the separated geothermal steam.
- clean steam generation using a two-phase geothermal supply.

Some fairly conservative assumptions have been used to avoid unnecessary distortion in favour of geothermal developments. These arc summarised in Table 2

Table 2 - Geothermal Assumptions

Wells:	Enthalpy = 1135 kJ/kg Production well depth = 1500 m Production well diameter = 8 5/8", 9 5/8" Average production/well = 150 t/h Maximum of 3 deviated wells per pad Injection well depth = 1100 m Injection well diameter = 8 5/8" Injection well capacity = 3 x production well output Nu monitor or exploration well costs.
separators:	Separation at each well pad (steam supply options only). Separation pressure = 7.9 bara
Pipes:	Steam line velocity = 35 m/s Separated water line velocity = 3 m/s Production and injection areas separated by 1 km
Injection:	Pumped
Miscellaneous:	Unlined dump pond with 2 days production Storage Allowance for venting, roads. land. steamfield electrical
Process steam:	(Clean steam options) - inlet temperature 120°C Outlet temperature = 150°C Make up is responsibility of process plant Process plant is only 200 m from production pad
Development Programme:	Two years with capital expenditure in last 6-12 months

Costs are summarised in Table 3 and Figures I and 2. It should he noted that capital costs for a geothermal development are dominated by well costs (about 75% of direct costs). Whilc pipe costs are not particularly high, a significant increase in length will increase well head pressure, decreasing well output, thus requiring more wells. Hence, pipe length increases could lead to well cost increases. The most significant savings will result from shallower production wells and increased enthalpy of discharge. Savings at the lowest end of the supply range would result if supply facilities were shared with parallel field developments.

Table 3 - Cost Assumptions for Geothermal Options

option 1 .Direct Supply (Geothermal 1)

Operations and Maintenance(including make up wells) ≈ 5.5% of capital

Total Capital Cost ($M):

$F = 0 \rightarrow 12.5$ t/h	$Cost = 7.8 + 0.029\,F$
$F = 12.5 \rightarrow 37.5$ t/h	$Cost = 6.2 + 0.16\,F$
$F = 37.5$ t/h $\rightarrow$	$Cost = 4.3 + 0.21\,F$

Option 2 - Clean Steam From Separated Steam (Geothermal 2)

Operations and Maintcnance (incl make up wells) = 5.5% of capital

Total Capital Cost ($M)

$F = 0 \rightarrow 11.25$ t/h	$Con = 7.8 + 0.032\,F + 0.068\,F^{0.7}$
$F = 11.25 \rightarrow 33.75$ t/h	$Cost = 6.2 + 0.18\,F + 0.068\,F^{0.7}$
$F = 33.75$ t/h $\rightarrow$	$Cost = 4.3 + 0.23\,F + 0.068\,F^{0.7}$

Option 3 - Clean Steam From Two-Phase Supply (Geothermal 3)

Operations and maintenance (including make up wells) = 5.5% of capital

ToW Capitd Cost ($M)

$F = 0 \rightarrow 12.5$ t/h	$Cost = 7.3 + 0.021\,F + 0.041\,F^{0.9}$
$F = 12.5 \rightarrow 37.5$ t/h	$Cost = 5.6 + 0.15\,F + 0.041\,F^{0.9}$
$F = 37.5$ t/h $\rightarrow$	$Cost = 4.2 + 0.19\,F + 0.041\,F^{0.9}$

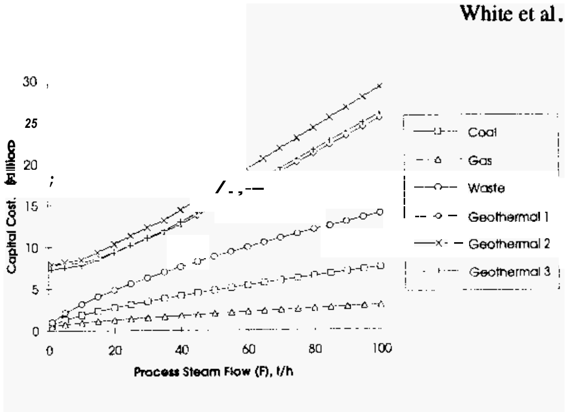

Figure 1 - Capital Cost Comparison

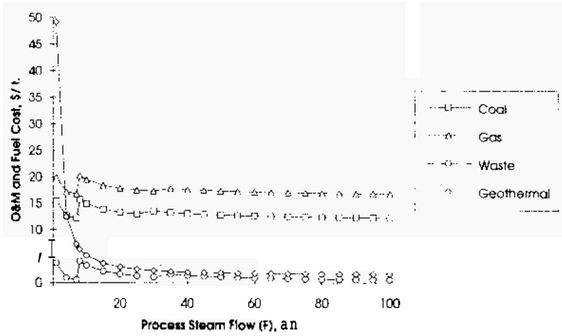

Figure 2 - O&M and Fuel Cmts Comparison
(100% Net Capacity Factor)

3.3 Financial Analysis

Comparisons have ken made of the steam production costs hy the various methods outlined above. The analyses were carried out using the following common financial paramcters:

Dcht to equity ratio:	70:30
Loan interest rate:	10%
Loan repayment period	10 years
Project lifetime:	15 years
Tax rate:	33%
Depreciation:	15 ycar, straight line
Construction period	1 ycar
Inflation rate:	3% per year
Rate of return on equity:	20%

Results are summarised in Figures 3 and 4 allowing for comparison of all options on a $/t hasis. It is assumed that all options will he available. In practice, some options may not be available and waste firing (an extremely competitive option if available) may not yield sufficient heat for process needs.

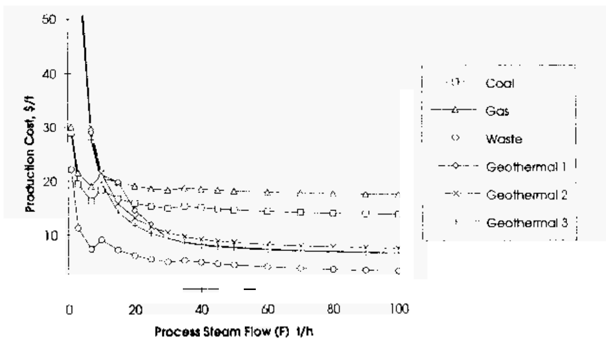

Figure 3 - Production Costs - 100% Net Capacity Factor

From Figure 3, waste firing is universally, the least expensive option for process steam supply. Geothermal options become competitive for process steam supplies greater than 10 to 15 t/h. It should be noted that at these low flows the estimates for geothermal options used in this paper have been inflated through the use of dedicated production and reinjection wells. If facilities were shared with parallel developments on the field the crossover point far geothermal developments could be shifted to a lower flow. Also note that for the most part, the Geothermal 1 and 3 options are indistinguishable while Geothermal 2 is little different.

production costs for the coal-fired and gas-fired plant become relatively constant above 10 t/h at approximately $14.00/tonne for coal-fired plant and $17.50/tonne for gas-fired plant due to fuel costs dominating the steam production cost. Geothermal steam production costs continue to reduce with output, tu the range of *50* tu 60 t/h where production costs are about $7.00/tonne.

The variation of production costs with Net Capacity Factor (NCF) was investigated for a system operating at a production level of *25* t/h. This variation is shown in Figure 4.

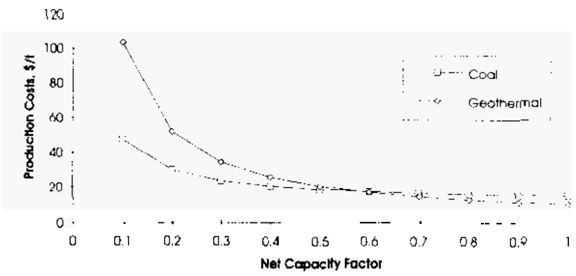

Figure 4 - Production Costs for Varying Net Capacity Factor

The figure shows that the geothermal system must operate at a net capacity factor higher than 60% tu be more economic than a coal-fired boiler at this low steam demand.

In summary, the financial analysis indicates that the economic advantage of geothermal process heat depends on a relatively high steam use (over **20 t/h**) at a reasonable net capacity factor. These results are consistent with previous studies of direct geothermal heat use (NZERDC 1985).

3.4 Vapour Compression Systems

The available steam pressure and flows from a geothermal well depend on the characteristics of the specific field. If the geothermal well or heat exchanger cannot produce a flow or pressure high enough for process heat use, it is possible to consider vapour Compression systems to increase pressures. Since the unit cost of the geothcmal resources can he quite low under high flow situations, it may be economically justifiable to provide for compression of the steam prior to use in the process.

The additional cost of cumpression depends on the flow, the pressure ratio required and the cost of electrical energy for the compressors. For flows of 15 t/h or greater through a single compressor, the maximum pressure ratios are about 2. For flows less than 10 t/h, pressure ratios of up to 7 can be cunsidcred but electricity costs increase rapidly with increasing pressure ratio.

As an example, the cost of increasing the pressure of a *20* to 100 t/h flow by a factor of two is estimated at $3.60/t with a 5 c/kWh electricity, increasing to approximately $5.20/t at 8 c/kWh.

With a production cost of between $14.50/t at *20* t/h and $6.50/t at 100 t/h from geothermal sources, the use of vapour Compression to produce higher pressure process steam could be economic at higher steam flow. The differential cost of production between geothermal and coal-fired plant ranges from about $3.40/t at 35 t/h to about $7.20 at 100 t/h. Vapour compression by a factor of 2 would be marginally economic at about 30 t/h, but the use of two stages of compression could only be considered for steam flows of about 100 t/h with low electricity price.

4. A NEW ZEALAND EXAMPLE - TASMAN PULP AND PAPER MILL

4.1 Overview

Tasman Pulp and Paper Company Ltd's Kawerau Mill is one of the largest in the world. It was one of the first industrial users of geothermal heat and provides an example of a process steam application. The mill has heen successfully using geothermal heat since it was commissioned in the 1950's. Indeed one of the reasons for siting the mill at Kawerau was the possibility of using the adjacent geothermal field as a source of process heat.

Other reasons for plant location at Kawerau included proximity of large exotic forests planted throughout the Taupo Volcanic Zone, good water supplies and presence of a railway line connecting the mill to a major port for export.

The Kawerau geothermal field spans 19-35 km², with subsurface temperatures in excess of 315°C (Allis et al. 1993) and an average field enthalpy of around 1200 kJ/kg (Wigley & Stevens 1993). Field development began in the early 1950's with the first well on line in 1957. Around 14 wells have supplied steam to the mill over nearly 40 years of production.

Tasman Pulp & Paper Company's Mill at present produces some 200,000 tonnes per annum of market kraft pulp and 400,000 tonnes per annum of newsprint. Not surprisingly the mill requires a considerable amount of heat and power (roughly 4,000,000 tonnes of steam and 800,000 MWh of electricity per annum). Geothermal heat is used for 5% of clecuicity and 30% of prncess steam requirements. Remaining process steam is supplied by two wood waste fired boilers and two chemical recovery boilers firing black liquor, a byproduct of the pulping process. Fuel ail supplies are rarely used.

4.2 Geothermal Steam Supply

Geothermal brine discharged from the wells is first separated into steam and water by Webre type separators located at flashplants either side of the Tarawera River. Some of the separated water is now used for electricity production in binary power plants. The remaining separated water is passed through a cooling channel before being discharged to the Tarawera River. Steam is supplied to the mill via two main pipelines traditionally referred to as the HP and LP lines. The HP line supplies 40 t/h of steam at 9.1 bara while the LP line supplies 223 t/h of steam at 7.8 bara.

A surplus of steam is needed to account for rundown between well cleanouts. and for overall well rundown with time. Cleanout of calcite from well bores is required every one or two years. Makeup drilling has been less frequent.

Field investigation has been funded largely by government. However some early production drilling and the original steam gathering facilities were developed by Tasman using Bechtel as consultants. The steam gathering facilities were later sold by Tasman to the government who have continued to expand the facilities to meet Tasman's growing demand. Steam supply to Tasman has increased by more than 50% since government purchase. It is possible that sale of these facilities back to private ownership is imminent.

4.3 Use of Geothermal Steam

Geothermal steam utilisation has been a process of refinement and uptimisation to improve both energy efficiency and plant operability (see Figure 5). Due to the non-condensable gas present within geothermal steam it cannot be used directly in the pulp and paper process. As a result geothermal steam is used in the following ways (Carter & Hotson, 1992):

- In five shell and tube heat exchangers to supply process steam at 3.45 barg. Geothermal steam is on the tube side while clean steam is produced on the shell side. Around 90% of the geothermal steam is condensed before exiling the heat exchanger. Boiler-generated superheated steam is added to the clean steam before entering the process.
- To preheat combustion air for the chemical recovery boilers.
- In boiler feed water heaters for bath the chemical recovery and waste wood-fired boilers
- The geothermal seam is also used to produce electricity in an 8 MW back pressure turbine. Heat from the turbine exhaust is used in heat exchangers to provide process hot water and evaporate water from black liquor.

Geothermal condensate from the turbine and various heat exchangers is collected and passed through a condensate recovery plant. This conditions the condensate to provide feed water comparable in quality to demineralised water fur steam generation. The condensate recovery plant consists of a flash vessel and stripping vessel. The flash vessel separates any uncondensed steam and a large proportion of non-condensable gases. Any remaining "on-condensable gases are removed in the stripping vessel.

4.4 Technical Difficulties

The use of geothermal *stem* has nut been trouble free, largely as a result of non-condensable gas present in the steam. For example on a few occasions geothermal steam has leaked into the clean steam side of the shell and tube heat exchangers. This has then caused gas accumulation with corresponding reduction in heat transfer rates in the drying cylinders.

A second gas-related difficulty is general corrosion of exposed structures. As the nun-condensable gas contains both H_2S and CO_2, fallout is corrosive.

Tasman's mill was originally sited to be adjacent to the Kawerau geothermal field. Subsequent resistivity surveys as geoscience has developed, have indicated field boundaries considerably greater than first thought and encompassing the mill site. As a result field subsidence, which could effect mill machinery, may limit steam production from the field. Reinjection trials, presently under investigation, will however go some way to addressing this potential problem.

Despite these technical difficulties both the plant and steam gathering facilities operate with high availabilities and capacity factors. Problems experienced at Kawerau need not be repeated elsewhere.

5. CONCLUSIONS

This paper has reviewed the cost of process steam generation using geothermal heat and alternative fuels for a New Zealand situation. Despite the use of some conservative assumptions, geothermal heat has been shown to be competitive, allowing reasonable returns to steamfield developers and industry.

A New Zealand example has been discussed (Tasman Pulp and Paper Mill). A long successful history of geothermal supply is reflected in increased usage by the mill. Geothermal heat is a reliable heat source for process industries.

Contributing factors towards an agreement between process industry and steamfield developers have been discussed, the most important requirement is proximity of industry to the steamfield. Given proximity, and understanding of the process steam needs then agreement should be readily achieved.

Steamfield developers should pursue process heat supply contracts, coupled with parallel power sales contracts where opportunities exist.

Despite the relatively small sire of most process industry steam demands, there is still considerable room for profit, both for the heat supplier and for the industry.

6. ACKNOWLEDGEMENTS

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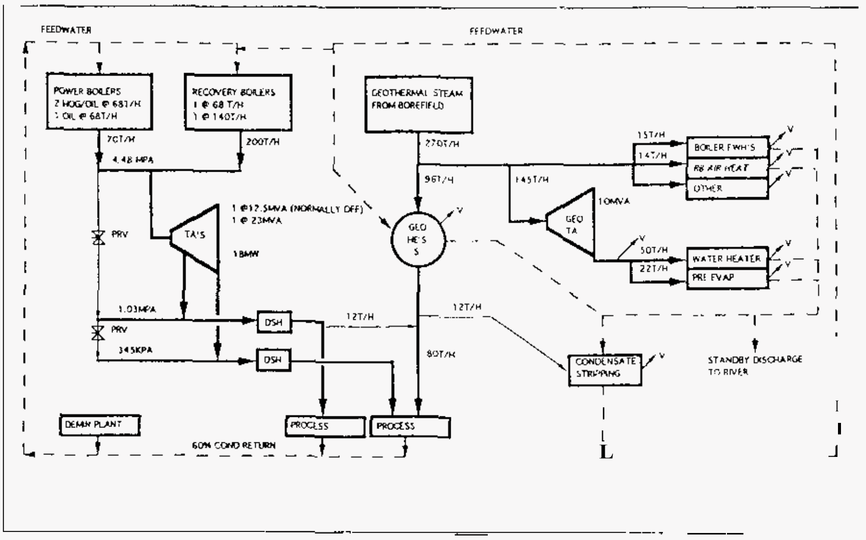

Figure 5 - Tasman Mill Energy System (after Carter et al, 1992)

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