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Geothermal Wells – The Cost Benefit of Fracture Stimulation Estimated by the GEOCOM Code

Final Report

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GEOTHERMAL WELLS--THE COST BENEFIT OF FRACTURE STIMULATION ESTIMATED BY THE GEOCOM CODE

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ABSTRACT

GEOCOM, a computer code that provides life cycle cost/benefit analysis of completion technologies applied to geothermal wells, is used to study fracture stimulation techniques. It is estimated that stimulation must increase flow by roughly tons per $100,000 in order to be cost effective. Typically, hydraulic fracturing costs $100,000 to $500,000 per well, and the attempts at stimulation to date have generally not achieved the desired flow increases. The cost effectiveness of hydraulic fracturing is considered for several geothermal reservoirs.

FOREWORD

This report (BDM/A-83-466-TR-R1) has been prepared by The BDM Corporation, 1801 Randolph Road, S.E., Albuquerque, New Mexico 87106, for Sandia National Laboratories under contract 37-3096. The report describes the results of a geothermal well cost effectiveness study based on the GEOCOM computer code compiled in FORTRAN on Sandia National Laboratories' Cyber 176. The report was prepared by G. L. Brown of The BDM Corporation.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

CHAPTER I
EXECUTIVE SUMMARY

In the development of many geothermal reservoirs it has been common to encounter production wells in which either there is insufficient flow of geothermal fluids or flow cannot be started at all, even though the wellbore itself is free of problems that would impede flow. Attempts to increase flow from such wells are categorized as "well stimulation techniques" and commonly include:

(1) Redrilling the well (e.g., to deepen or underream it, or to drill a new leg)

(2) Pumping the well

(3) Treating the producing formation with chemicals (e.g., acid washing)

(4) Fracturing the producing formation.

A sometimes viable alternative is to abandon the existing well (perhaps calling it an injector) and to drill a new production well. In determining which technique to use, it is important to estimate both the cost and the effectiveness of each option. This report examines the costs and effectiveness of fracture stimulation.

The question of the cost effectiveness of fracture stimulation is perhaps best answered by use of a well model that allows the cost of stimulation and the increase of flow to be treated in a realistic manner. GEOCOM is such a model. GEOCOM is a computer code that provides life cycle cost/benefit analysis of technologies applied to geothermal wells. The code accepts cost data for drilling, completion, repair, operation and maintenance of the well. It also accepts data on the productivity of the well as a function of time and intended utilization. The code further accepts economic data (inflation rate, discount rate, etc.) and calculates the present value cost of producing useable energy over the life of the well. GEOCOM contains default well profiles for several resource areas. For this study, minor modifications were made in the well profiles for the Imperial Valley and the Valles Caldera, and stimulation cases were constructed around the modified profiles.

The costs of fracturing a geothermal well can be estimated fairly accurately. The major cost categories for fracture stimulation are 1) expendable materials, 2) equipment leasing, and 3) rig rates. Indirect costs (such as pulling the well liner) can sometimes exceed the direct costs of fracture stimulation. Assuming there are no major indirect costs, the cost of a hydralic fracturing job typically ranges between $100,000 and $500,000. The cost of an explosive fracturing job typically ranges between $40,000 and $100,000. The primary reason for cost exceeding the minimum is the length or volume of fracture to be produced.

Information on the effectiveness of fracture stimulation is much less well defined than information on cost. This uncertainty prohibits any definitive comparison of fracture stimulation to other stimulation options. However, it is possible to estimate the minimum effectiveness of fracture stimulation required to lower the cost of energy produced by the well.

The analysis of the results for fracture stimulation modeling yields the following general conclusions:

(1) The present cost of fracture stimulation is low enough to make it a viable option compared to drilling a new well.

(2) For a liquid-dominated resource, the fracture stimulation must increase flow by at least 5 tons per hour for each $100,000 invested. In some scenarios the minimum increase may exceed 20 tons per hour for each $100,000 invested.

(3) Fracture stimulation can be cost effective as a repair procedure on an old well.

(These conclusions are valid for wells supporting the production of electricity. They may or may not be valid for support of direct use projects.)

The results also yield the following special conclusions:

(1) As much as $800,000 ($300,000) could be spent on fracture stimulation of a dry well in the Valles Caldera (Imperial Valley) before drilling a new well would be a more attractive option.

(2) Fracture stimulation in the Valles Caldera (Imperial Valley) must increase flow by 5 (15) tons per hour for each $100,000 invested in order to be cost effective.

(3) Assuming it restored the well to its nominal flow prior to the onset of the problem, then a fracture stimulation repair costing $300,000 would still be cost effective on a Valles Caldera (Imperial Valley) well up to 10 (5) years into the productive lifetime of the well.

The Geothermal Reservoir Well Stimulation Program produced 6±3 tons per hour of additional flow for each $100,000 invested in stimulation. A comparison of the Program results and the results of the cost effectiveness analysis indicate that fracture stimulation is probably more cost effective than redrilling in some cases and not cost effective in other cases. Improvements in the technology are required to prove fracture stimulation a generally cost effective procedure.

CHAPTER II

FRACTURE STIMULATION - THE APPROACH TO COST EFFECTIVENESS

> "To some extent, the well flow rate can be increased through applying well simulation techniques such as hydrofracturing, acid leaching, pumping, well workovers and others. The costs associated with stimulation are usually included in the cost of the well, and it is the optimization of well flow versus cost which is paramount."
>
> Source Book on the Production of Electricity from Geothermal Energy, 1980, p. 705 (reference 1)

> "In fact, very little work has yet been done to acquire the data base needed to technically analyze stimulation feasibility and make the associated economic analysis."
>
> GRC Transactions, 1979 (reference 2)

A. INTRODUCTION

The DOE sponsored well stimulation program (reference 3) was designed to alleviate the data base problem identified above by Nicholson and his co-authors (reference 2). The program included six hydraulic fracture stimulation experiments at The Geysers, Raft River, East Mesa, and the Valles Caldera. These experiments were technically successful. However, the ultimate measure of success is the cost effectiveness of stimulation. This report addresses the cost effectiveness of fracturing as a means of geothermal well flow stimulation primarily through the use of a computer code called GEOCOM. GEOCOM is a life cycle cost/benefit model of geothermal wells specifically designed for this type of analysis (reference 4).

B. SCOPE OF THE REPORT

It is possible to create pressure within the well of sufficient magnitude to either widen existing formation fractures or create new ones. The idea is to increase the flow of geothermal fluid into the well by breaking through a zone of formation plugging near the well, or to connect the well (via pressure induced fractures) to nearby natural fluid bearing fractures.

The primary techniques for creating a pressure pulse in the well involve either hydraulic or explosive force. The costs of performing such a stimulation were compared to the resulting increase in flow by constructing cases for the GEOCOM code that yield the life cycle cost/benefit.

The cost/benefit ratio of fracture stimulation is dependent upon many variables. For practical reasons, we have chosen to limit the study to typical wells in known reservoirs, specifically, wells in Valles Caldera and the Imperial Valley.

This study is limited to the economic effects of stimulation upon the cost of energy from a single well. "Project sized" economic issues associated with fracturing are not addressed.

C. STATEMENT OF THE PROBLEM

What makes a well a candidate for fracturing? There seem to be three basic instances. First, a newly completed well in a fracture dominated reservoir has a low rate of flow compared to neighboring wells, and it is believed that the well missed intersecting with nearby productive fractures. Second, it is believed that the production zone near the well has been plugged by fluids used in drilling, completing, maintaining, or repairing the well. Third, it is believed that the decline in flow from an initially good well is due largely to scale buildup in the formation near the well. In the first and second instances, the stimulation would occur as part of the completion or as a one-time repair. In the third instance, the stimulation might have to be repeated several times during the life of the well. One aspect of the problem is to investigate fracturing either as part of the completion, as a repair, or as a repeated workover.

The direct cost of a fracture stimulation job now ranges from fifty thousand to several hundred thousand dollars. However, indirect costs can often equal or exceed the direct costs. For example, if the well was completed with a slotted liner (as is often the case), the liner must be pulled. It might then be necessary to run and cement casing and then perforate in the zone to be stimulated. The wide variation in potential cost suggests that cost should be treated as a variable, and that some upper bound on economically acceptable cost be established.

How much additional total flow can be gained from fracturing? The available field data required to answer this question are quite sketchy. If the initial flows before and after stimulation are measured (under the same conditions), and reservoir decline rates for stimulated and unstimulated flow can be estimated, then the total flow can be estimated. (The existing data are compiled in appendix B.) Since total flows are not available to satisfy the benefit side of the cost/benefit ratio, the study attempts to provide insight into the question: how much initial flow increase is required to at least pay back the cost of stimulation?

D. METHODOLOGY

The GEOCOM computer model was used as the primary tool for evaluation of the cost effectiveness of fracturing. GEOCOM allows the user to build a life cycle cost and production time value of money model of a geothermal well (see reference 4 for details).

Since GEOCOM contains default models of typical geothermal wells in the Valles Caldera and Imperial Valley, these models were used as a point of departure for the study. The GEOCOM compatible descriptions of the wells used in the study are given in appendix C.

The primary figure of merit chosen for the study is dollars per million BTUs ($/MBTU). This number is the average cost to deliver useful energy for conversion to electricity. GEOCOM assumes the fluid is flashed and the steam used to run a turbine. As a point of reference, a commercially profitable geothermal well should deliver energy at a cost of under $2/MBTU. The commercial well must deliver BTUs at a low enough cost to pay for itself as well as help defray the cost of field development and operation.

The cost effectiveness of fracturing has been studied in two ways. First, families of constant $/MBTU curves were constructed that define the minimum increase in flow required for cost effective stimulation. Second, key parameters in the model of the well were varied to determine the resulting change in $/MBTU.

CHAPTER III
ANALYSIS OF COST DATA

A. TECHNICAL CONSIDERATIONS AFFECTING COST

There are a number of factors involved in the present technology for fracture stimulation that place lower bounds on certain costs. The technical factors involved in completing and operating the well also impact stimulation cost.

Fracture stimulation generally cannot be accomplished from inside a slotted liner because an explosive pulse would fracture the liner. A hydraulic pulse can be used only if the treatment interval spans the liner interval. However, since the maximum length of a treatment interval for hydraulic pulse is typically hundreds of feet while the liner completion is typically thousands of feet, the treatment interval usually will not span the liner interval.

The interval to be pulsed must be sealed off from the rest of the well. For an explosive pulse, a liquid or solid tamp is used. For a hydraulic pulse, packers are used above and below the interval to be stimulated, and tubing is typically stabbed through the packer. Sealing off the treatment interval is somewhat easier for explosive techniques than for hydraulic techniques because it is sometimes difficult to seal an open hole for hydraulic pulse.

If the completion is cemented casing, then the perforations must be of adequate density and distribution to couple the explosive pulse into the formation.

All techniques typically require the presence of at least a workover rig. It is usually necessary to clear debris from the well after explosive stimulation. Tubing must be run and packers set for hydraulic stimulation.

The time required to perform a pressure pulse stimulation is on the order of several days. Hydraulic stimulation requires time for site preparation and for setting up equipment and materials. Safety requirements for handling explosives require that a considerable amount of hardware assembly must be done at the site. The stimulation procedure may also require well logs before and after the treatment.

B. DIRECT COSTS OF FRACTURING

The cost of hydraulic fracturing can be dominated by the cost of materials (fluids and proppants) on a job requiring a large fracture. Costs of materials depend upon the contemplated fracture volume. A typical job might require 5000 barrels of fluid and 100,000 pounds of proppant at a cost of $100,000.

Pumping costs and related services are likely to be the second largest cost item for hydraulic fracturing. The high rates of pumping (perhaps 80 barrels per minute) and high wellhead pressures (perhaps 3000 psi) require special equipment. This item might typically cost $70,000.

Rig costs are related to the size of the rig and number of days of operation. A typical cost would be $40,000.

Other direct costs of hydraulic fracturing might add an additional $40,000. Hence the total direct cost of hydraulic fracturing would typically be about $250,000 (references 4 and 5). (See appendix A for cost breakdowns on actual hydraulic fracturing experiments.)

The direct costs of explosive fracturing are usually less than the costs of hydraulic fracturing. This is in part because the scale of explosive fracturing is on the order of small hydraulic fracturing jobs. However, costs are also less because the costly pumps and tanks used in hydraulic fracturing are unnecessary.

The cost of expendable hardware for explosive fracturing is likely to be in the neighborhood of $200 per linear foot of well to be stimulated (reference 4). An average sized job (200-foot treatment interval) would require $40,000 in expendable hardware including 1600 pounds of propellant, 30 sections of casing, and a detonator system.

The cost of basic services would include assembly of the package on site, running the package in the hole, setting tamps, and cleaning debris out of the hole after the shot. The workover rig could be required for

48 hours and cost $5,000. Moving and rigging the rig could cost $6,000. An average of four men required for 4 days would cost $1,000. Supplemental equipment, contingencies, fuel, and travel might add another $5,000 to the total. Hence, basic services for explosive fracturing could easily cost $17,000. This would bring the total cost of the explosive fracturing to about $60,000.

In summary, a typical hydraulic fracture has direct costs of $250,000 and a typical explosive fracturing job costs $60,000. Since explosive fracturing is usually cheaper, why consider the option of hydraulic fracturing? The answers are that indirect costs may alter the cost picture, and that the estimated effectiveness of hydraulic fracturing may be much higher in some situations.

C. INDIRECT COSTS OF FRACTURING

The indirect costs of fracturing can often exceed the direct costs. The major contributor to indirect cost is the requirement for a compatible well completion. A liner completion is incompatible and can be removed and replaced at a typical cost of $100,000 (reference 4). Explosive stimulation may require a higher density of perforations in a cemented casing than might otherwise be required. A remedial perforation of a 200-foot interval would typically cost $50,000 (reference 4).

If the original completion design of the well was chosen in part for compatibility with fracturing requirements, then some fraction of the additional cost (or savings) of the completion becomes an indirect cost of fracturing. A likely scenario would be to complete a well with a perforated, cemented casing rather than a liner. The additional cost of such a completion is usually substantial and might typically add $100,000 to the indirect cost of fracturing.

Other indirect costs can include restarting the flow (reference 4 states $1,000 for this item), flow testing and analysis, and prefracturing testing and analysis.

In summary, indirect costs are scenario dependent, but can be over 50 percent of the total cost of fracturing. In some cases, indirect costs can be more than three times as great as the direct costs.

CHAPTER IV

COST/BENEFIT OF FRACTURE STIMULATION BASED ON GEOCOM MODELS

A. FRACTURING AS PART OF THE WELL COMPLETION PHASE

Suppose the flow from a new well is below the minimum level of acceptability. Should the well be abandoned immediately or fractured in an attempt to obtain commercial flow? Assume that the cost of a new well is C and the probability of it being commercial is P. Then the weighted cost of the commercial well is C/P, which includes the cost of the non-commercial ancestors of the commercial well. Now suppose the cost of fracturing (expressed as a fraction, aC, of the well cost, C) is added to give C + aC, and the probability of a commercial well increased to P + bP (where bP is a fractional increase in P). Then the new weighted cost of a commercial well is (C + aC)/(P + bP). The needed condition for cost effective fracturing is that

$$(C + aC)/(P + bP) \leq C/P$$

which reduces to

$$a \leq b.$$

This simply says that the marginal increase in probability of success must exceed the marginal increase in cost. Assume that C is $1,000,000 and that P is 0.5. (This would roughly correspond to expected values in the Valles Caldera.) Figure 1 indicates the probability of a successful well needed to justify the given cost of stimulation. Now assume that C is $500,000 and that P is 0.9. (This would roughly correspond to expected values in the Imperial Valley.) Figure 2 indicates the probability of a successful well needed to justify the cost of stimulation.

The linear boundaries in figures 1 and 2 indicate that success rates of less than 0.1 can be cost effective.

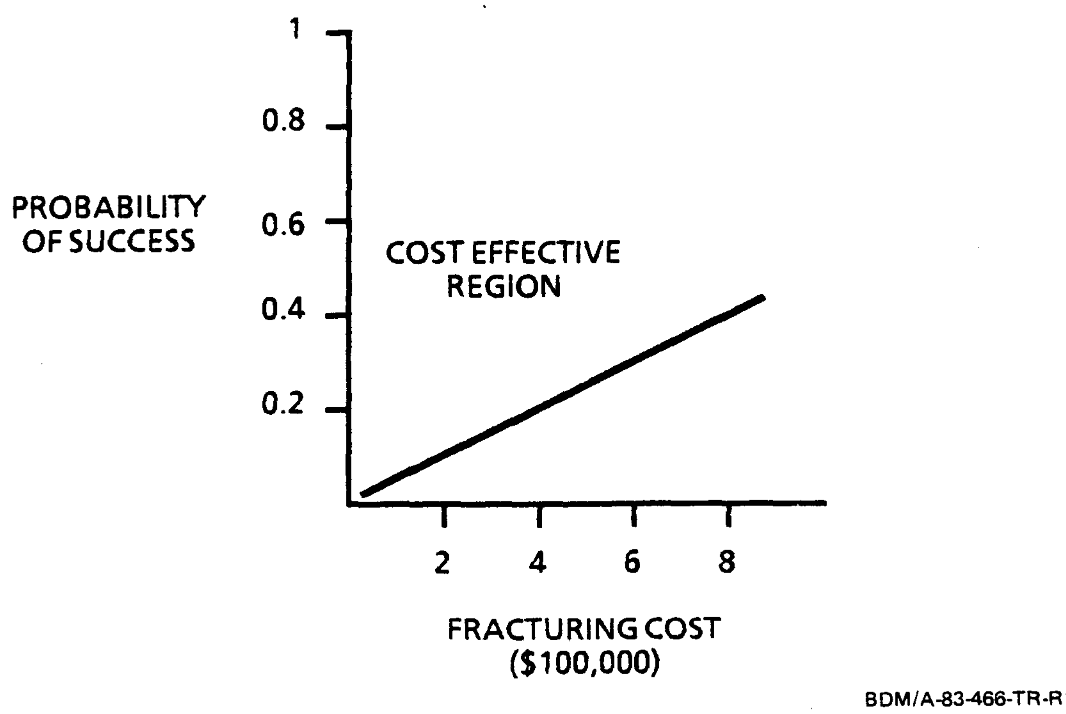

Figure 1. The Cost Effectiveness of Fracturing a Non-Commercial Valles Caldera Class Well

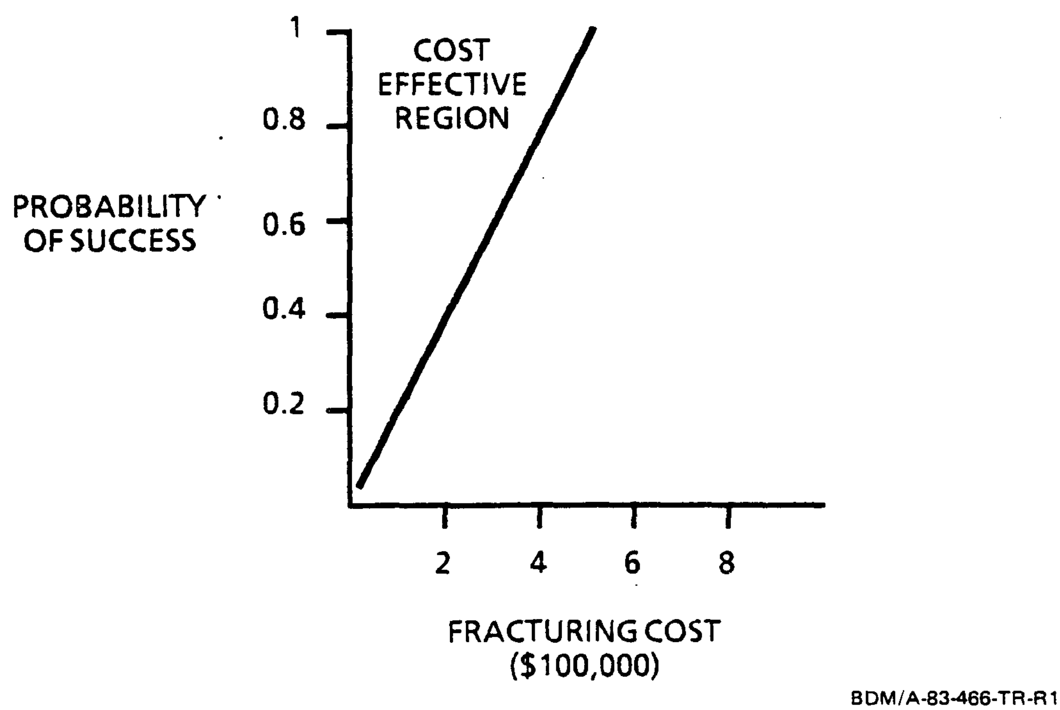

Figure 2. The Cost Effectiveness of Fracturing a Non-Commercial Imperial Valley Class Well

A procedure that was successful less than 30 percent of the time would probably never achieve credibility regardless of its cost effectiveness. Certainly a procedure that averaged 10 percent success or less would not even make a relevant contribution to field development. A more expensive (but more successful) stimulation procedure will tend to win out over a less expensive (but less successful) procedure even when the latter is somewhat more cost effective than the former. If $P \geq 0.5$ for stimulation is considered a lower practical bound of acceptability, then any fracturing technique costing under $1,000,000 would be cost effective on a Valles Caldera class well. Any technique costing under $300,000 would be cost effective on an Imperial Valley class well.

If the well has sufficient initial flow so that the cost of finishing, connecting, and maintaining it will result in a cost of energy lower than the marginal cost, then the well is not necessarily "noncommercial," but neither is it necessarily a good producer. Should fracture stimulation be used to turn a marginal well into a good producer? The GEOCOM computer code was used to construct the data given in figures 3 and 4. Figure 3 shows how much additional initial flow must be achieved to justify a fracturing in a Valles Caldera class well given a known initial flow. Figure 4 gives the same kind of information for an Imperial Valley class well. The interpretation of figures 3 and 4 is as follows: given an initial flow as a point on the horizontal axis (for example the point marked A in figure 1), the life cycle cost of producing energy from the well can be interpolated from the family of curves (about $3.50/MBTU in the example). If a stimulation at a given cost produces an additional flow (for example the point marked A' in figure 1), then the new life cycle cost of producing can be interpolated from the family of curves. The new life cycle cost in the example is about $2.50/MBTU, so the example is a cost effective stimulation.

The average slope of the family of curves in figure 1 indicates that the break-even point for stimulation of a marginal well in the Valles Caldera is about 5 tons per hour of initial flow for every $100,000 invested in stimulation. Likewise, figure 2 indicates a break-even point

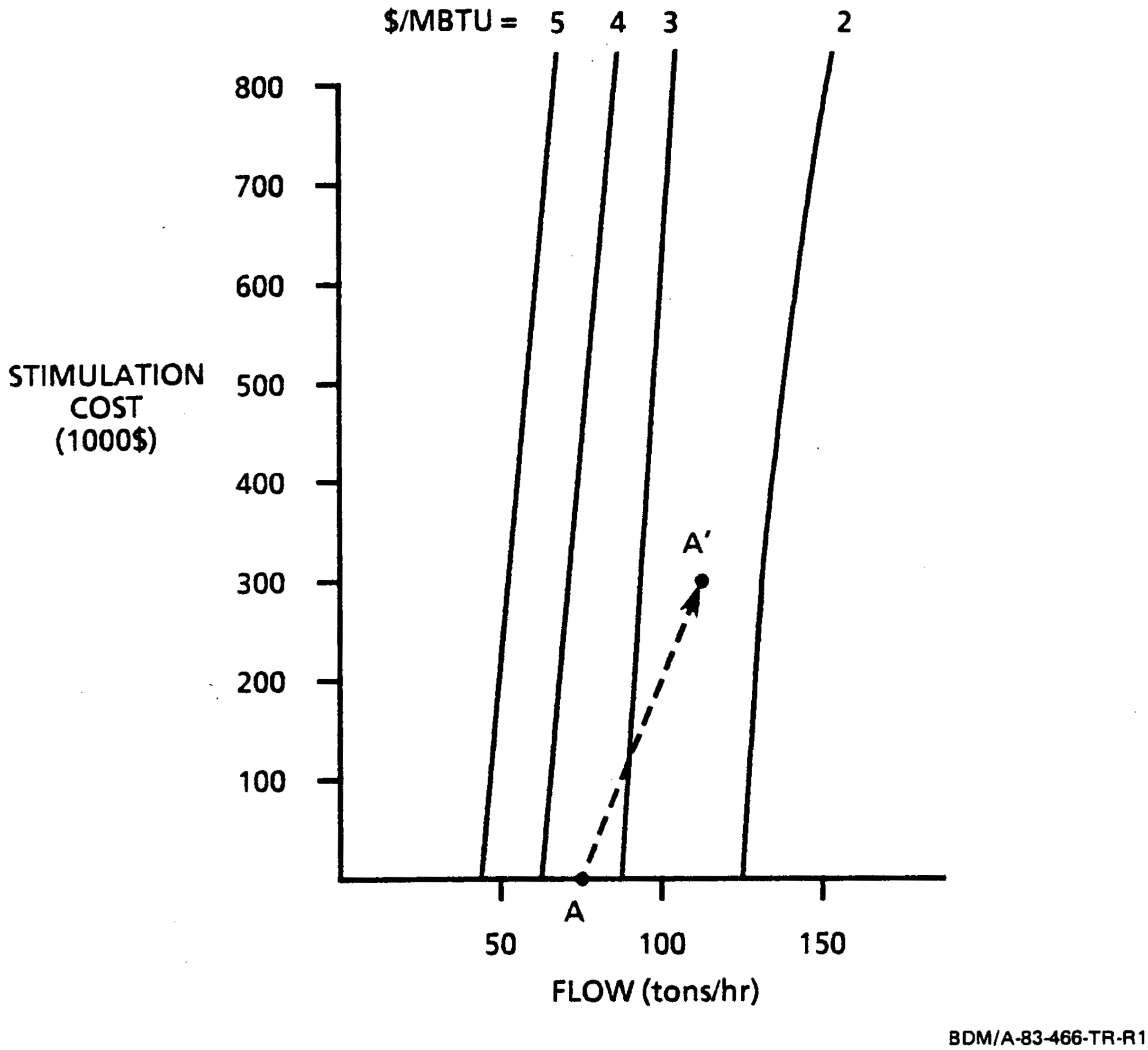

Figure 3. Cost/Benefit of Fracture Stimulation at Well Completion for Valles Caldera Class Wells

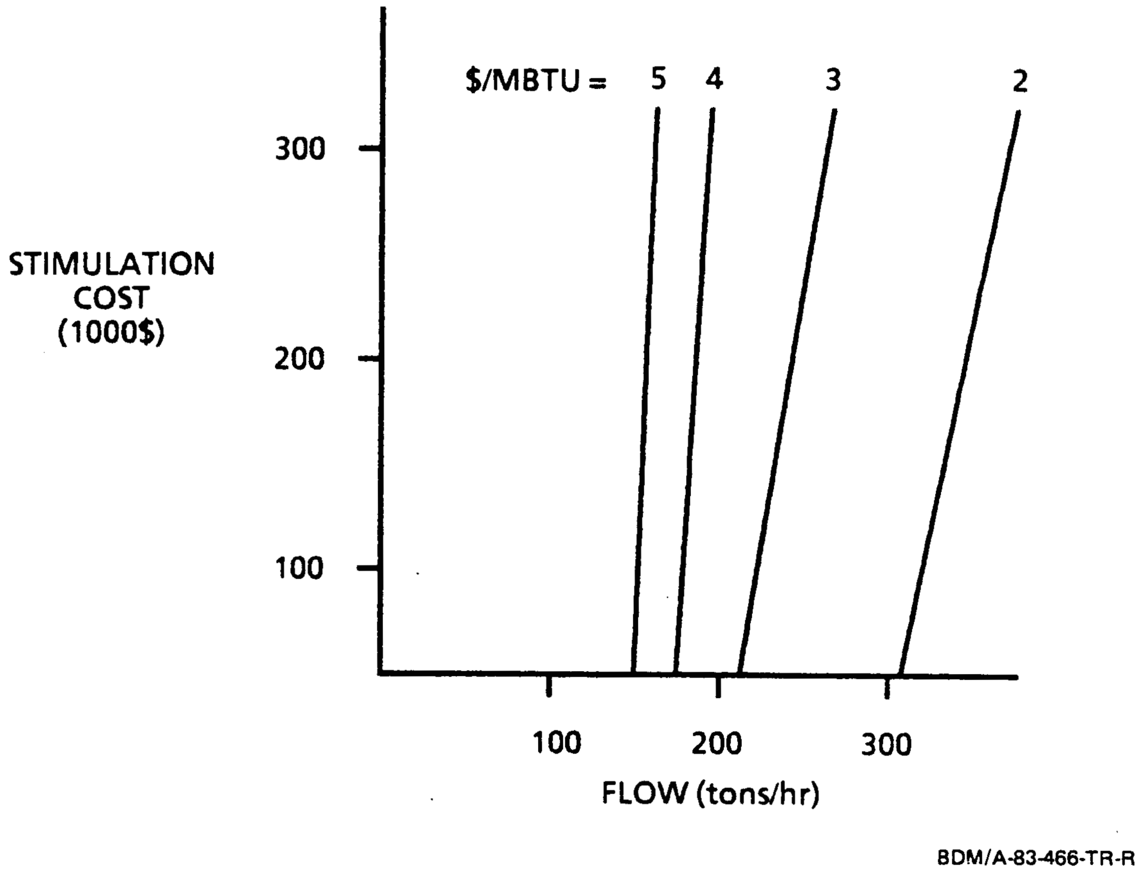

Figure 4. Cost/Benefit of Fracture Stimulation at Well Completion for Imperial Valley Class Wells

of 15 tons per hour of initial flow for every $100,000 invested in the Imperial Valley.

Although other factors can also affect the actual cost/benefit of stimulating a marginal well, the initial flow rate achieved is the factor to which cost/benefit is most sensitive. Figures 5 and 6 present the impact on cost/benefit of several factors that might also be related to the cost effectiveness of stimulation. These figures were constructed from a series of GEOCOM runs in which a single parameter was altered in value while all others were held constant. Qualitatively, there is no difference between Valles Caldera and Imperial Valley wells for the variables studied. In each case the order of significance is (1) initial well flow, (2) economic inflation rate and reservoir driven flow decline rate, (3) cost of stimulation, and (4) well lifetime and initial delay in bringing the well into production. Over a wide range, the cost of fracture stimulation has up to a 25 percent impact on the cost of energy from a single well in Valles Caldera and up to a 15 percent impact on the cost of energy from a single well in the Imperial Valley. Appendix C presents the baseline values used to define the 100 percent point on figures 3 and 4.

B. FRACTURING AS A REPAIR OR WORKOVER

The previous section of this report concluded that a typical fracturing job costs $300,000 and would be cost effective under Valles Caldera or Imperial Valley conditions (given any reasonably high probability of success). However, the conclusion was reached on the assumption that the stimulation was part of well completion. To what extent is fracturing cost effective as a repair or a workover?

For any geothermal well, the steady decline of the reservoir means the well has a finite useful economic life which may be further shortened by mechanical failure. The lifetime of wells in the Imperial Valley has been estimated to be 10 years, and in the Valles Caldera has been estimated to be 30 years (reference 4). In fact, these estimated lifetimes

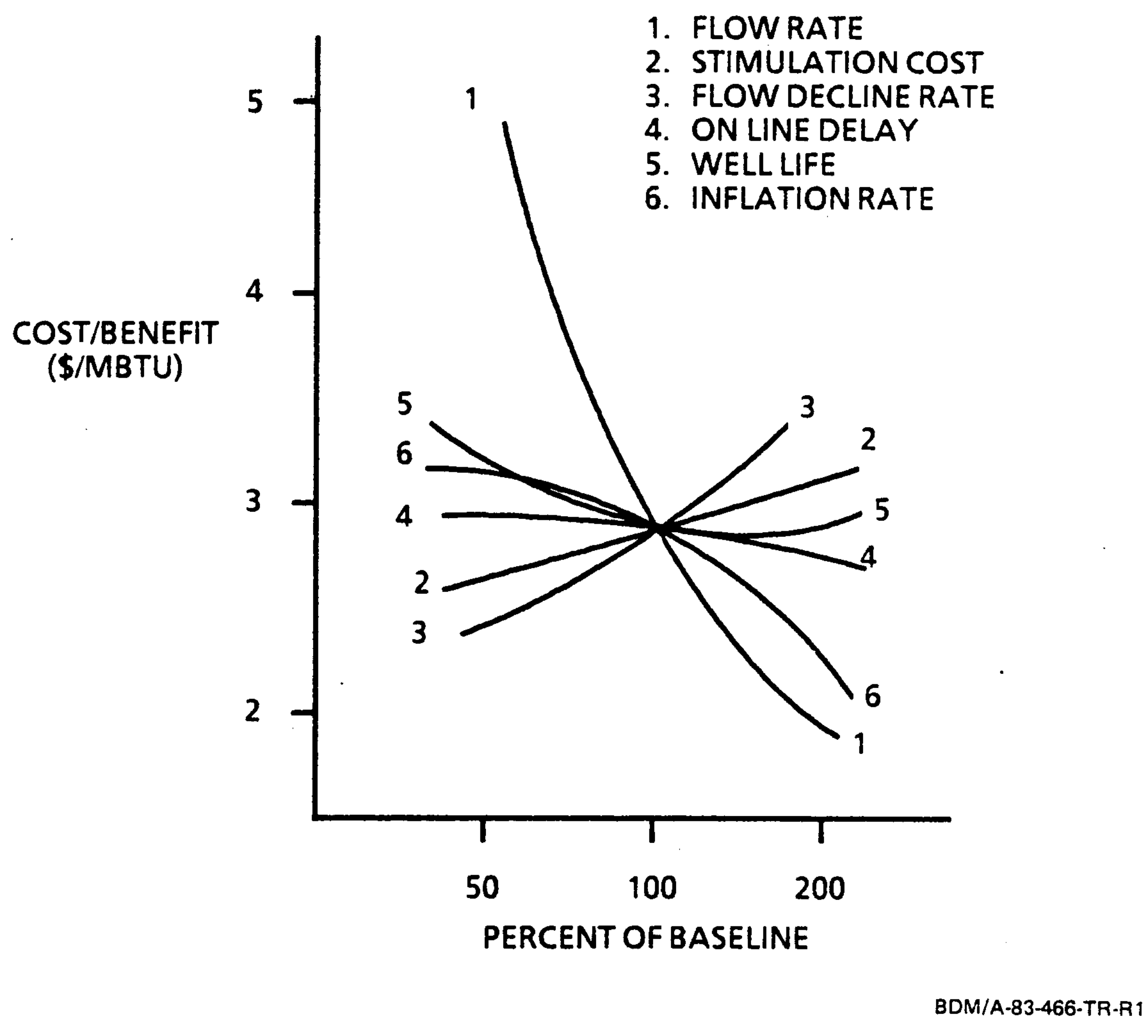

Figure 5. Comparison of the Sensitivity of the Cost/Benefit Ratio to Changes in Magnitude of Some Key Variables (Valles Caldera Class Well)

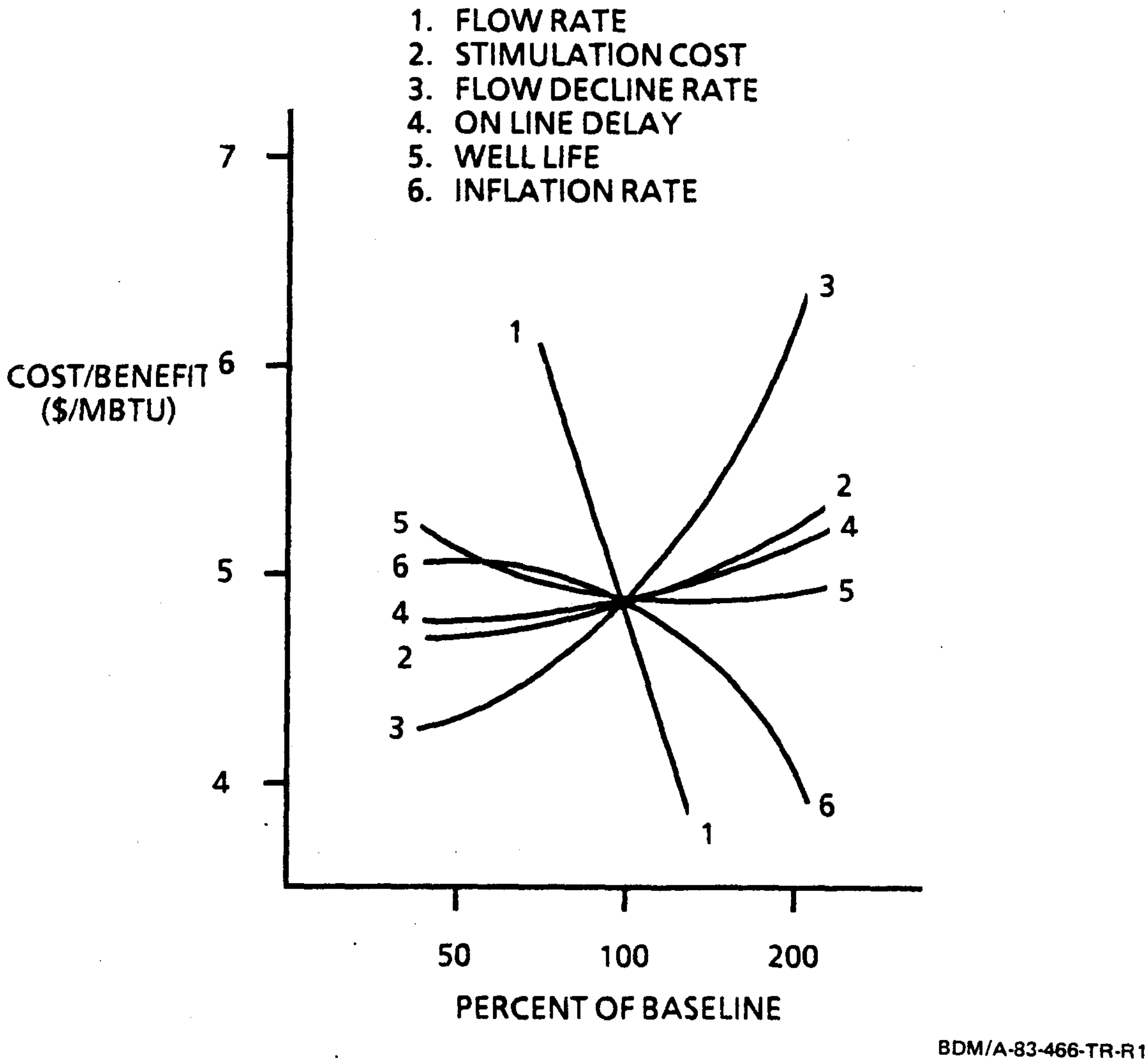

Figure 6. Comparison of the Sensitivity of the Cost Benefit Ratio to Changes in Magnitude of Some Key Variables (Imperial Valley Class Well)

formed part of the baseline well models used in the previous section of the report. Using those same baseline models, let us now assume that a well has become non-commercial due to a mechanical problem that can be remedied by fracturing. How far into the well lifetime would a fracture stimulation costing $300,000 still be cost effective? (It is assumed that the stimulation restores the flow rate observed before failure, and the stimulation has a 100 percent chance of success.) Figure 7 indicates that stimulation can be cost effectively employed for a significant fraction of the expected useful life of the well. Figure 7 was derived from a series of GEOCOM computer code runs in which all parameters were held constant except the age of the well when failure and repair were simulated.

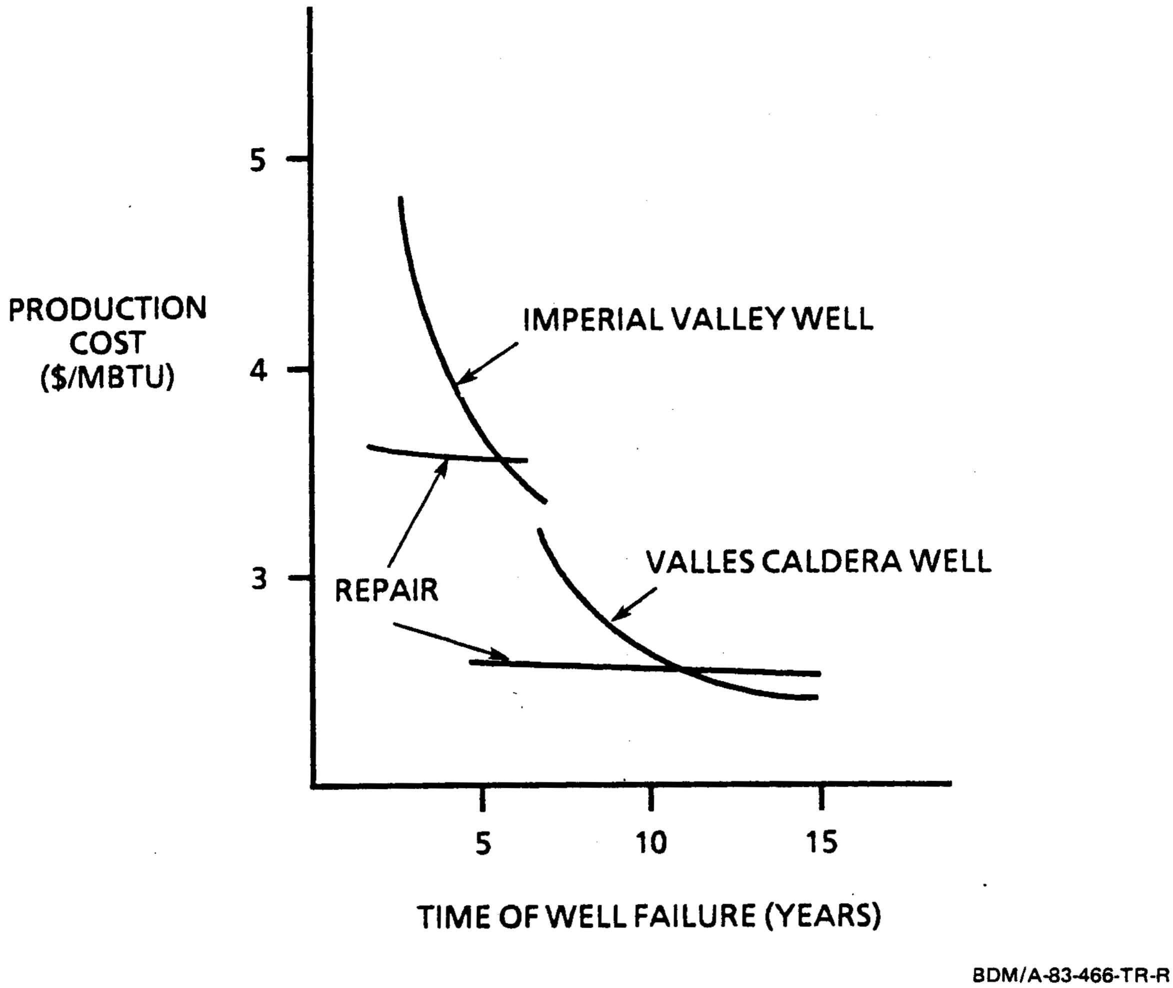

Figure 7. If a Mechanical Well Failure Occurs Before 5 Years. (Imperial Valley) or 10 Years (Valles Caldera), Then a $300,000 Stimulation Repair Would be Cost Effective as Indicated by the Crossover Points

CHAPTER V
POTENTIAL AREAS FOR FURTHER INVESTIGATION

Fracturing as a means of stimulating geothermal wells has been shown in this report to be cost effective under certain circumstances. From a practical standpoint, however, considerable uncertainty still remains concerning the actual cost effectiveness in a particular application. The primary reason for this uncertainty centers upon the expected success rate from fracture stimulation. Some preliminary work by the authors (as yet unreported) suggests that the success rate could be limited to less than 20 percent in some reservoir situations. For the Valles Caldera, this success rate would restrict the average cost of a fracture stimulation to $400,000 in order to maintain cost effectiveness. However, a 20 percent success rate is so low that one must question whether a costly procedure with such a low success rate could ever gain credibility.

It must be remembered that, even if cost effective, the option of fracturing should be compared (on a cost divided by success rate basis) to other options for well stimulation. Other stimulation options include redrilling the completion zone and pumping. Comparisons of cost effectiveness between pumping and fracture stimulation have not been addressed. However, the GEOCOM code does contain modules to allow the evaluation of the cost/benefit of pumping. Pumping is an option for increasing the flow from a marginally commercial or noncommercial well. There are instances where pumping is not a competitive option to fracturing, e.g., when the completed well is noncommercial because it did not intersect the reservoir fracture system.

The cost of redrilling is usually comparable to the cost of a typical fracture stimulation. Therefore, the expected increase in flow rate is the major determining factor in a choice between fracturing and redrilling. Some preliminary investigation by the authors has been done to compare the cost effectiveness of redrilling to fracturing. In the Valles Caldera, it was estimated that a redrilling job would typically cost about $300,000 (the same cost as a typical fracture stimulation).

However, the estimated success rate for the redrilling was higher (0.3) for redrilling than the estimated success rate for fracture stimulation (0.2). These estimates were based upon very simplistic models and assumptions and should not be considered to be the last word on the subject.

An increase in temperature is economically more important than an equivalent increase in flow. Therefore, any method that effects an increase in wellhead temperature deserves consideration before one that increases flow. There is evidence to suggest that fracturing could be employed to increase the wellhead temperature of the fluid as well as the flow (reference 6). In general, this could be achieved by selectively fracturing in the hotter portions of the well. The cost effectiveness of increased flow coupled with a rise of temperature has not yet been investigated.

APPENDIX A

EXPERIMENTAL FRACTURE STIMULATION COST

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EXPERIMENTAL FRACTURE STIMULATION COST

Table A-1 summarizes the costs of the hydraulic fracturing experiments conducted by the Geothermal Reservoir Well Stimulation Program (references 5, 6, 7, and 8). These costs are somewhat higher than would be achievable in commercial jobs due to the experimental nature of the program. The high indirect costs at Raft River were incurred because of the need for a compatible well completion. The data suggest a minimum fracture stimulation cost of about $100,000 and a typical cost of about $300,000.

The experiment at The Geysers is classed as "acidation" stimulation by some. However, the intent of the experiment was to use pumps to create hydraulic pressure in the well. Thus, the cost factors were similar to the cost factors on the other experiments. The Geysers experiment was different only in the sense that the expendable pumped fluid was not a gel/proppant mixture.

TABLE A-1. COSTS OF HYDRAULIC FRACTURING

Location	Cost ($1000's) Direct	Indirect
Valles Caldera	360	40
Raft River	64	240
Raft River	129	281
East Mesa } East Mesa	420	34
The Geysers	300	34

APPENDIX B

EXPERIMENTAL FRACTURE STIMULATION COST EFFECTIVENESS

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The required measure of effectiveness for fracture stimulation is "amount of additional fluid produced over the lifetime of the well." This measure can be estimated from the additional initial flow and an estimate of the flow decline rate. If the flow decline rate for stimulation flow is different from the rate for "natural flow," then effectiveness measurement becomes complicated. Indeed, the fracture stimulation experiments at Valles Caldera both experienced very rapid initial declines (references 5 and 9).

The analysis in this report suggests that additional initial flow amounts of from 2 to 20 tons per hour for each $100,000 invested could be cost effective. How cost effective have fracture stimulation experiments been to date? Six fracture stimulation experiments were made on the Geothermal Well Stimulation Program (reference 3). The data from the program are not reported in terms of additional initial flow, so that the estimates made here are somewhat suspect (see table B-1). For example, the East Mesa well had a reported before stimulation flow of 93,000 lb/hr at 50 psig and an after stimulation flow of 175,000 lb/hr at 27 psig. But the experimenters at East Mesa also found it necessary to seal off part of the original production zone.

A comparison of values between tables A-1 and B-1 yields a global average of 5-10 tons of initial flow for each $100,000 of fracture stimulation direct cost. The estimate varies depending upon the guess for increased flow at East Mesa. If indirect costs are included, the achieved flow is somewhat less per $100,000.

Although one must be extremely cautious in making commercial inferences from experiments, the experimental results seem favorable to the contention that cost effectiveness can be achieved.

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A comparison of values between tables A-1 and B-1 yields a global average of 5-10 tons of initial flow for each $100,000 of fracture stimulation direct cost. The estimate varies depending upon the guess for increased flow at East Mesa. If indirect costs are included, the achieved flow is somewhat less per $100,000.

Although one must be extremely cautious in making commercial inferences from experiments, the experimental results seem favorable to the contention that cost effectiveness can be achieved.

TABLE B-1. FRACTURE STIMULATION EFFECTIVENESS ESTIMATES

Location	Additional Initial Flow (ton/hr)	Pressure (psig)
The Geysers	0	--
Raft River	0	--
Raft River	12	14?
Valles Caldera	10	24
Valles Caldera	35	37
East Mesa	?	50

APPENDIX C

WELL MODELS

APPENDIX C
WELL MODELS

Table C-1 contains the parameter values used to define the basic well models used in this report. These models were used to produce the graphs in the main body of the report.

The cost of energy is driven upwards by several non-optimistic features of the well models. First, the model assumes a flow loss due to scaling in the wellbore. The rate of scaling is such as to require a well descaling costing $25,000 every 8 months. Second, the reservoir decline rates estimated by the model may be higher than others have estimated. Third, the initial flow and temperature selections may be lower than others have estimated for a typical well. The values of 3 to 5 $/MBTU obtained by these well models could easily be driven below $2/MBTU by various relaxations of these basic assumptions.

TABLE C-1. GEOCOM PARAMETER VALUES USED AS BASELINES FOR FIGURES 1-4

Parameter*	Units	Valles Caldera	Imperial Valley
Energy Conversion	BTU	Flashed	Binary
Stimulation Cost	$	300,000	150,000
Initial Flow	lb./hr.	200,000	400,000
Well Cost	$	1,075,000	724,000
Flow Decline (Reservoir)	frac./mo.	.003083	.005
Flow Decline (Scaling)	frac./mo.	.0625	.0625
Scale Removal	$/8 mo.	$25,000	$25,000
Inflation Rate	frac/mo.	0.006	0.006
Well Life	years	20	10
Production Delay	months	12.	12.
Temperature	^oF	358	340

* There are many other parameters in GEOCOM that were simply left at the Baca (Valles Caldera), and East Mesa (Imperial Valley) default values.

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