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FEDERAL GEOTHERMAL ROYALTY INCOME DERIVED FROM
THE BENEFITS OF GOVERNMENT-SPONSORED R&D

By
Chris B. Amundsen
Thomas A. V. Cassel
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January 31, 1984

Work Performed Under Contract No. AC03-83SF11727

Technecon Analytic Research, Inc.
Philadelphia, Pennsylvania

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Prepared for:

THE U.S. DEPARTMENT OF ENERGY

Under Contract No. DE-AC03-83SF11727

ABSTRACT

This report affirmatively investigates the ability of Federally-sponsored geothermal R&D to, in effect, pay for itself through increased royalty payments resulting from enhanced resource development on Federal lands. The report concludes that achievement of current Federal R&D objectives is likely to result in significant royalty returns to both state and Federal governments. These returns are measured in terms of the increase in royalty payments attributable to the achievement of Federal R&D objectives, as opposed to those payments which would be expected from the on-going low level of private sector R&D absent any Federal support.

If a relatively modest set of expected Federal R&D objectives are met, and a "pessimistic" coal-based geothermal resource price is assumed, the present value of royalty income is forecast to increase by \$207 million because of R&D benefits. If the geothermal resource price is set at utility "avoided cost" rates, an increase in royalty income of \$600 million is forecast. One-half of this income would be retained by the Federal government, with the remainder distributed to the states in which production occurs. The retained Federal share of incremental royalty income would be adequate to support an R&D program at an annual funding level between \$30 and \$70 million over a 5 year period. Other substantial National R&D benefits, not included in the scope of this study, include: (1) the concomitant enhancement of geothermal resource development on non-Federal land; (2) diversification of the Nation's electric generating capacity; (3) reduced dependence on imported fuels; and (4) the environmental benefit associated with geothermal energy.

To perform this analysis, an integrated approach sequentially addresses (1) future wildcat drilling activity, (2) the number and quality of new resource discoveries, (3) the technological potential (megawatts) of the discovered resource base, and the likelihood that it will be developed, and (4) the royalty income which will be generated as a result of development of Federal land. This computer-based modeling approach has been developed by Technecon over the last 5 years under the sponsorship of both the Department of Energy and private industry. Portions of this model have been specially modified and updated during the course of this study.

PREFACE

During the past five years, Technecon has undertaken substantial research focused on the determinants of geothermal resource exploration and development. The purpose of this research has been to develop useful methodologies capable of predicting -- in a statistically accurate and cost efficient manner -- future geothermal power development. This report documents the results of these efforts, and utilizes the methodology to estimate royalty income benefits from Federally-sponsored geothermal research and development.

Earlier Technecon reports¹ have documented the techniques used to evaluate (1) wildcat drilling, (2) new resource discoveries, (3) the quality of new discoveries, and (4) future power development. This report carries our analysis one step further by providing a means to analytically estimate the royalty income benefits associated with geothermal R&D. This report is organized as follows:

Chapter One summarizes our methodology and results.

Chapter Two describes the integrated computer based approach used to forecast royalty benefits.

Chapter Three presents estimates of the royalty income benefits associated with achievement of current Federal R&D program objectives.

* * * * *

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¹See Cassel et al., 1982 and 1983. ii

our data concerning the characteristics of the known U.S. geothermal resource base. Last, though by no means least, the authors acknowledge Gloria Phelan for her patient and very capable assistance in the production of this report.

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CHAPTER ONE

INTRODUCTION AND EXECUTIVE SUMMARY

The purpose of this study is to assess the incremental royalty income that the Federal government may gain from enhanced geothermal development made possible by Federally-sponsored geothermal research and development. As technological advances gained through Federal R&D are transferred to and utilized by private industry, power development on Federal leaseholdings will accelerate and expand. The additional royalty income resulting from enhanced development can be considered as a return on the government's investment in geothermal research and may, over time, effectively repay the expenditures required to fund research activities. Research programs which can be shown to generate royalty income flows in excess of program costs will thus "pay for themselves" over a long-term planning horizon.

In the following analysis, future Federal royalty income is first estimated assuming only those near-term technological advances which are expected to result from current private sector research and development. This Base Case of "current technology" excludes any benefits which may be gained from Federally-supported R&D. Royalty incomes are then re-estimated assuming Federally-sponsored R&D achieves a supplemental set of modest, near-term technological advances in the areas of resource definition, heat cycle research, injection technology, and drilling and completion technology. These assumed technological advances are based on the goals and objectives of the current Federal research program. The differential royalty income gained by the government is then estimated. This "return" on the government's investment can then be equated with an "equivalent annual program funding level" to determine a level of annual research program outlays which could be supported on the basis of future royalty payments alone.

1.1 ROYALTY INCOME FORECASTING METHODOLOGY

Description of the methods used in this study is provided in Chapter Two. This methodological procedure has been developed by Technecon with DOE and industry assistance over the last several years. Detailed discussion of the procedures can be found in Cassel et al. (1982) and (1983). A brief summary is provided here.

To evaluate the expected effectiveness of alternative R&D program goals, a multi-step procedure is used. First, the characteristics of current and forecasted geothermal resource discoveries are estimated. This forecast reflects the likely future impacts of (1) resource depletion, (2) anticipated investment returns for geothermal and oil investments, (3) the number and quality of past resource discoveries, and (4) regional considerations. Known and forecasted resources are characterized in terms of multiple variables including temperature, well flow rate, well costs, year of discovery, salinity and producible acreage estimates. Portions of this modeling procedure have been specially updated for this study and are discussed in detail in Chapter 2.

Once a characterization of the applicable resource base has been obtained, parallel procedures are employed to estimate (a) the technological potential for development at each resource and (b) the numerical likelihood that such development will take place. A detailed cash flow and investment analysis is performed as part of this procedure. Statistically-sound techniques from the decision sciences (i.e., "multiattribute utility analysis" and "logit estimation of positive choice") are employed to evaluate the attractiveness of geothermal project investments relative to other investment opportunities.

The output of this integrated forecasting model is a time-wise hydrothermal resource development profile over a 30-year planning horizon. An "expected" power development forecast is prepared for known resource discoveries and for projected future discoveries. This estimation procedure utilizes site-specific factors to insure that the fluid sales price ($\text{\$/kWh}$) is set at a level which would equate the levelized cost of hydrothermal power with the cost of alternative generation capacity (e.g., coal-fired capacity, oil-fired base load capacity, or at "avoided-cost" rates). Royalty income may then be estimated based upon the expected development profile, the resource selling price, the Federal royalty rate (generally 10% of gross revenues), and the fraction of development which occurs on Federal acreage.

1.2 SUMMARY OF RESULTS

As will be shown in Chapter Three, achievement of current Federal R&D objectives is likely to result in significant royalty returns to both state

and Federal governments. If the relatively modest Federal R&D objectives provided in Table 1-1 are met, and a "pessimistic" coal-based resource price is assumed, the net present value of royalty income is forecast to increase by \$207 million. This royalty differential (shown in Figure 1-1) is evenly distributed between the Federal government and the producing states. Table 1-2 shows the retained Federal share of differential royalty earnings under three alternative fluid pricing assumptions. As shown, future royalty "returns" may be adequate to support an R&D program at an annual level of funding between \$30 and \$70 million over a 5 year period.

Table 1-1
ASSUMED FEDERAL R&D PROGRAM ACHIEVEMENTS¹

Drilling and Completion Technology

- o Extend life of production wells by 24% in 1988.
- o Reduce production well cost by 5% in 1985, and by 10% after 1990.
- o Reduce surface piping capital cost by 8% after 1988.

Heat Cycle Research

- o Improve brine effectiveness by 7% after 1987, at the expense of a real increase in capital and operation and maintenance cost of 2% and 3% respectively.
- o Extend maximum operating temperature of downhole well pumps to 400°F (versus current temperature limit of 350°F) by 1987.
- o Increase plant availability by 2% after 1987.

Injection Technology Research

- o Extend injection well life by 24% in 1988.
- o Reduce injection well cost by 5% in 1985, and by 10% after 1990.

¹The technology advancements noted above are assumed to supplement those near-term technological advancements which are expected to result from current private sector R&D.

Figure 1-1. ESTIMATED ANNUAL FEDERAL ROYALTY INCOME DIFFERENTIAL
COAL-BASED RESOURCE PRICE

Table 1-2
FEDERAL DIFFERENTIAL ROYALTY INCOME
AND EQUIVALENT ANNUAL PROGRAM FUNDING LEVELS
(Million Dollars)

	Federal Share of NPV of Royalty Income ⁽¹⁾			Equivalent Annual Program Funding Level ⁽²⁾	
	<u>Current Technology</u>	<u>w/Federal R&D</u>	<u>Differential</u>	<u>5-Year Program</u>	<u>10-Year Program</u>
Coal-Based Pricing	\$301.1	\$404.4	\$102.3	\$28.7	\$14.7
Oil-Based Pricing	697.4	1,173.5	476.1	113.9	73.8
Avoided Cost Pricing	728.1	1,028.1	300.0	70.3	46.0

(1) Includes only the 50% share of royalty income retained by the Federal government.

(2) The net present value of disbursements to a program with the fixed annual budget and duration represented below, will equal the net present value of differential royalty income.

CHAPTER TWO

ROYALTY INCOME FORECASTING METHODOLOGY

The pace of future geothermal power development on Federal lease holdings will determine the future annual royalty income payments received by the Federal government. This rate of development will be dictated by numerous factors, including: (1) the quality and perceived profitability of developing known discovered resources, (2) the rate at which new, high quality resources are located and confirmed, and (3) the extent to which technological advancements may enhance the economic potential of resource development. Federally-sponsored R&D programs may impact each of these aspects by making available more efficient and less costly utilization technologies, or by reducing the perceived risks of resource development.

In this chapter, an integrated modeling approach is presented which incorporates these key determinants of future geothermal development. Using a dynamic simulation procedure shown in Figure 2-1, this model sequentially forecasts: (1) the number of new wildcat wells drilled, (2) the number and quality of confirmed resources located as a result of wildcat drilling, and (3) future expected power development at these forecasted discoveries, as well as development at currently discovered resources. Future royalty income streams are then estimated based on projected time-wise power plant development on Federal lands.

The geothermal forecasting model has been developed with both DOE and industry sponsorship over the past five years. This work benefits from the cooperation of 20 geothermal resource companies, 13 western electric utilities and a number of financial institutions and governmental agencies. Additional expertise has been provided by highly qualified geologists, reservoir engineers and power systems engineers. To this wealth of industry information, we added pertinent resource data from extensive USDOE and USGS computer files and then applied modern econometric and decision science techniques to develop a statistically-sound forecasting program. Detailed technical descriptions of this methodology can be found in Cassel et al., 1982 and 1983.

Figure 2-1. ROYALTY ESTIMATION FORECASTING MODEL

Of particular note are the revisions made during the course of this study to Technecon's wildcat drilling model, and the updated characterization of those resources discovered to date. The drilling model, first estimated and documented in 1982, is reestimated in light of the observed decline in field activity in recent years. The estimated quality of discovered resources is similarly updated, based on current understanding of geologic characteristics. These revisions will be discussed in the following sections of this chapter. Following is an overview of the structure and output of each key modeling component.

2.1 KNOWN RESOURCES

The presently known U.S. geothermal resource base was defined for this study by E.V. Ciancanelli of Cascadia Exploration Corporation, San Diego. A total of 20 discovered resources with temperatures greater than 300°F were identified, and further defined in terms of resource temperature, well flow rate, well cost, salinity, and producible acreage. Table 2-1 presents a listing of these currently discovered resources. These resource quality estimates have been specially updated for this study based upon literature review, recent field experience, and in-house proprietary data. Each of these resources are known today, but not all have been confirmed as producible resources. Therefore, a probability of confirmation is assigned to each resource. This probability reflects the estimated likelihood that the resource will be confirmed, based on current geologic data.

2.2 PROJECTED FUTURE RESOURCE DISCOVERIES

To estimate the quantity and quality of future resource discoveries, a forecasting model has been developed by Technecon which sequentially addresses the level of wildcat drilling in future years, the number of resource confirmations expected, and the quality of future resources. Similar modeling techniques have been extensively used in recent oil and gas industry evaluations, and are applied here to geothermal resources. The techniques have been shown to accurately replicate past trends in geothermal exploration, discovery and resource quality. Following is a brief summary of the methodology. A complete description and documentation of the exploration, discovery, and resource quality model can be found in Cassel, et al. (1982).

Table 2-1
KNOWN U.S. GEOTHERMAL RESOURCES

No.	Resource	Temp ¹ (°F)	Unpumped Flow Rate ¹ (10 ³ lbs/hr)	Brine Contamination Index	Well Costs ¹ (\$m)	Producible Acreage		Probability of Confirmation	Federal Acreage Proportion
						90% Conf.	50% Conf.		
1	Mono-Long Valley	>450	700	1	.75	5000	10000	.25	.76
2	Salton Sea	>450	700	3	1.50	5000	10000	1.00	.21
3	Brady-Hazen	375	500	2	.40	1000	7000	.25	.53
4	Sulfur Bank	375	500	2	.75	5000	1000	.05	.23
5	Wilbur H.S.	>450	500	1	.75	2000	5000	.10	.6
6	Baca Loc #1	>450	150	2	1.50	2000	5000	1.00	.3
7	East Mesa	375	500	2	.75	3000	7000	1.00	.82
8	Heber	375	500	2	.75	3000	7000	1.00	0
9	Power Ranches	325	150	2	.75	650	300	.05	0
10	Soda Lake	425	500	2	.75	3000	7000	.25	.51
11	Brawley	>425	700	3	.75	1000	7000	1.00	0
12	Geowawe	425	300	1	.75	650	3000	.25	.52
13	Roosevelt H.S.	>450	700	2	.75	650	3000	1.00	.89
14	Westmoreland	425	500	2	1.50	650	3000	1.00	0
15	Goso	>450	700	2	.75	1000	7000	1.00	.93
16	Clear Lake	375	500	1	.75	5000	10000	.25	.40
17	Rye Patch	425	700	2	.75	650	3000	.25	1.00
18	Dixie Valley	>450	700	1	1.50	650	3000	.25	.98
19	Steamboat H.S.	425	700	2	.75	650	3000	.50	.17
20	S. Brawley	>450	700	2	.75	650	3000	.25	0

¹These values represent mid points of class ranges.

²Brine Contamination Index (TDS)

1 = < 2,000

2 = 2,000 - 100,000

3 = > 100,000

2.2.1 Wildcat Well Drilling Model

The Wildcat Well Drilling Model provides forecasts of the number of wildcat wells completed yearly, based on the perceived profitability of geothermal ventures relative to alternative oil and gas investment opportunities. The model is estimated using a time series of wildcat well drilling activity, coupled with historical estimates of the risk-adjusted rate of return in both the geothermal and oil and gas industries. The current drilling model updates and modifies the drilling model estimated in previous work.

To update this model, an in-depth review was conducted of available time-series data sets to document historical wildcat drilling activity and oil and gas industry profitability levels. The data sets used in the previous model estimation procedure were found to be inadequate for purposes of this study, as both lacked information for the 1980-1982 period. Alternative data sources were selected which offered both current data and improved documentation for the entire 1960-1982 period. The sources of this data and the data collection procedure are summarized below.

Wildcat Well Drilling Database. The wildcat drilling data base is a comprehensive historical time series of drilling activity between 1958 and 1982. The database was created by screening the complete set of Petroleum Information's Corp.'s geothermal well completion cards (1429 cards total). The following well types were removed during the screening process: (1) wells within the Geysers KGRA, (2) temperature gradient and observation wells, (3) production wells (defined as wells drilled after completion of first "producing" well), and (4) wells drilled by governmental (or quasi-governmental) agencies. The final dataset comprised 103 observations with the following data: well depth, location (by state) and date spudded. Table 2-2 presents a summary of wildcat well drilling activity from 1958 to 1982.

Rate of Return on Geothermal Investments. A major determinant of geothermal wildcat well drilling activity is the anticipated return offered on geothermal investment opportunities. Exploration effort will not be undertaken unless the economics of geothermal resource development are expected to satisfy minimal corporate profitability criteria. To derive a

Table 2-2
WILDCAT WELL DRILLING HISTORY

<u>Year</u>	<u>Yearly Summary</u>		<u>Cumulative Total to Date</u>		
	<u>Wildcat Wells</u>	<u>Discoveries</u>	<u>Wildcat Wells</u>	<u>Discoveries</u>	<u>Drilling Success Ratio</u>
1957	1	0	1	0	0
1958	0	0	1	0	0
1959	1	1	2	1	50.0
1960	1	0	3	1	33.3
1961	1	1	4	2	50.0
1962	2	0	6	2	33.3
1963	2	0	8	2	25.0
1964	8	2	16	4	25.0
1965	2	0	18	4	22.2
1966	0	0	18	4	22.2
1967	0	0	18	4	22.2
1968	1	1	19	5	26.3
1969	1	0	20	5	25.0
1970	1	1	21	6	28.6
1971	0	0	21	6	28.6
1972	5	2	26	8	30.8
1973	7	1	33	9	27.3
1974	8	0	41	9	22.0
1975	5	2	46	11	23.9
1976	11	1	57	12	21.1
1977	9	3	66	15	22.7
1978	7	0	73	15	20.5
1979	16	5	89	20	22.5
1980	7	0	96	20	20.8
1981	5	1	101	21	20.8
1982	2	0	103	21	20.4

historical series of geothermal investment profitability, the expected internal rate of return was estimated for typical geothermal investment opportunities over the past 20 years. A detailed cash flow analysis program was used to generate a twenty-year time series of the internal rate of return offered by hydrothermal investment opportunities. Included in the analysis were all capital costs and expenses related to 1) Pre-Confirmation Cashflow, 2) Reservoir Confirmation and Field Development Cashflow, and 3) Production Cashflow. The cash flow program was simulated on a yearly basis, beginning in 1958. An "average" quality resource was assumed in this simulation. Fully documented descriptions of the cash flow program can be found in Cassel et al., 1983.

The results of this analysis are provided in Figure 2-2. As shown, the profitability of hydrothermal investment opportunities declined during the 1964-1969 period. This was due largely to the actual decline in the cost of alternative baseload generating capacity, coupled with significant yearly increases in well drilling costs. Post-1970 investments show rapidly rising rates of return, triggered by large increases in both the fuel and capital cost of alternative generating capacity. Well drilling costs rose, but with a lag, yielding significantly higher returns for geothermal projects.

Rate of Return on Alternative Oil Investments. Because many of the major geothermal exploration firms are also active in the petroleum industry, investments in geothermal ventures may compete for funds with oil-related projects. It may be argued that in years in which potential oil profits are unusually high, firms will be unwilling to allocate scarce capital to potentially less lucrative geothermal ventures. Alternatively, it is argued by some that geothermal exploration programs are funded out of "discretionary" capital sources. To test both hypotheses, yearly changes in the rate of hydrothermal exploration were compared to changes in the profitability of oil and gas ventures. Standard and Poor's Composite Industry Data on Integrated Domestic Oil Companies was used as the source of return on book value, a measure of overall industry profitability.

As shown in Figure 2-3, the rate of return for oil companies generally declined over the 1967-1973 period due to relatively stable selling prices (rising only 3.0 percent per year) and escalating exploration costs. The impact of the OPEC oil embargo is observed in 1974-1977, as returns increased

Figure 2-2. HYDROTHERMAL INVESTMENT PROFITABILITY

Figure 2-3. OIL AND GAS INVESTMENT PROFITABILITY

dramatically over the previous year. Returns then dropped to lower levels in 1978 due in part to federal price control and price rollback policies. The stimulus brought about by the government's 1979 decontrol initiative led to increases in profitability in 1979 and 1980.

Model Estimation. Regression analysis was used to estimate the well drilling relationship as a function of the rate of return on geothermal investment and oil and gas returns. The return variables were reduced by the return on six-month Treasury Bills to produce real, risk-adjusted profitability measures for both time series. In estimating the drilling function, the explanatory power of both variables was enhanced when entered into the equation with a one year lag.

The form of the estimated relationship is:

$$\ln (WCAT + 1) = 0.06 (RORG_{-1}) + .02 (RORO_{-1})^2 \quad (1)$$

(4.1) (2.4)

$$R^2 = .89 \quad F\text{-Stat} = 87.0 \quad \text{Period} = 1958\text{-}1982$$

or equivalently:

$$WCAT = -1 + \exp [.067 (RORG_{-1}) + .012 (RORO_{-1}^2)] \quad (2)$$

Where:

WCAT = annual number of geothermal wildcat wells

RORG₋₁ = expected real, risk-adjusted rate of return on geothermal projects, lagged one year

RORO₋₁ = risk-adjusted return on book value for integrated domestic oil companies, lagged one year.

Equation (1) was estimated using ordinary least squares on annual data for the period 1958 to 1982. Statistical measures of the goodness of fit are shown below the equation; figures in parentheses are t-statistics. The equation was estimated without a constant term. The squared oil industry return variable led to better model fit than the same variable unsquared.

As indicated by the goodness of fit statistics, equation (1) explains the observed number of geothermal wildcat wells extremely well. Drilling for new geothermal resources is highly dependent on the risk-adjusted return on geothermal projects. For each one percentage point increase in the real, risk-adjusted rate of return, approximately one additional wildcat well will

be drilled. The return on book value for oil companies is equally important, indicating the importance of oil-related cash flow in supporting geothermal activities. Figure 2-4 compares observed wildcat drilling versus drilling activity estimated by the model. As can be seen, the model tracks actual drilling well, except in 1964 and 1979. In these periods, site-specific activity in California and Nevada, respectively, led to these unusual peaks of drilling activity.

Forecasting Wildcat Drilling Activity. Equation (2) is utilized to forecast future wildcat drilling activity. Beginning in 1984 (the first year of the simulation period) a cash flow analysis is conducted to estimate the internal rate of return for development of each of the 30 different resource types in the undiscovered resource base (see Section 2.2.3). The 30 estimated internal rates of return, when multiplied by the probability that each resource will be the next discovered, yields the "expected" rate of return on geothermal investments. The second independent variable in Equation (2), return on book value for integrated domestic oil companies, is projected based upon the long-term historical average for the data series. Equation (2) may then be used to forecast wildcat drilling in 1984. This activity is then disaggregated on a regional basis (Southern California, Nevada, and all other regions), based upon the relative likelihood that a high temperature ($>400^{\circ}\text{F}$) resource will be discovered. As the simulation proceeds to future years, and new regional high temperature resource discoveries are forecast, wildcat drilling is assumed to be redirected to those areas less affected by resource depletion.

2.2.2 Geothermal Discovery Model.

In the next step of the forecasting procedure, the number of new resource discoveries resulting from wildcat drilling is estimated. As shown in Table 2-2, the cumulative success ratio for wildcat wells is approximately 20 percent over the last 20 years. This historic drilling success ratio was derived from the Petroleum Information Council geothermal completion database, and corroborates the success ratio previously documented by Technecon.

To forecast new resource discoveries, it is assumed that the average national drilling success rate will remain at 20 percent over the forecast period. Depletion effects may be observed on a regional basis, as

Figure 2-4. ACTUAL VERSUS PREDICTED WILDCAT DRILLING

discoveries begin to exhaust the total regional resource base. As noted in the previous section, however, the wildcat drilling model assumes that drilling activity will be redirected towards other locations which have higher success probabilities. Consulting geologists have estimated that the nation's undiscovered resource base comprises over 120 reservoirs with temperatures greater than 300°F. It is unlikely that significant declines in the national drilling success will be observed due to resource "scarcity" in the foreseeable future, even with accelerated wildcat drilling activity.

2.2.3 Geothermal Resource Quality Model.

Future geothermal resource discoveries will be drawn from an underlying resource base. Consulting geologists have estimated that this resource base is composed of 30 different resource types, each of which has a unique "generic code" describing that resource in terms of temperature, flow rate, salinity, well cost, and producible acreage. Table 2-3 presents a listing of the 30 different resource types which are thought to exist in the undiscovered resource base. The relative frequency of occurrence of each resource type in this resource base is not uniform. For example, consulting geologists have estimated that 75 percent of the resources have a temperature between 300 and 400°F, 15 percent between 400 and 450°F, and 10 percent over 450°F. Regional differences in the underlying resource base are also thought to exist, and have been estimated and documented in previous reports.

Exploration for geothermal resources is directed toward the discovery of high temperature, high quality resources. Therefore, resources discovered to date have, on average, been significantly higher in temperature than the estimated mean temperature of the underlying resource base. This observed high temperature bias suggests that the expected temperature of sequential discoveries is not a random "draw" from the population of undiscovered resources. Rather, it can be more accurately described as a sampling experiment in which high temperature resources are withdrawn from the population at frequencies higher than a random selection process would dictate. It must also be recognized that as more resource discoveries are made, the "quality" (in terms of temperature) of the undiscovered resource base will degrade. Such depletion effects will result in a declining temperature profile for sequential new discoveries.

Table 2-3
GENERIC HYDROTHERMAL RESOURCES >300°F

Resource No.	Temperature (°F)	Unpumped Well Flow (1000 lbs/hr)	Salinity Index ⁽¹⁾	Well Cost (\$1,000)	Producible Acreage	
					90% Confidence	50% Confidence
1.	325	650	2	1,500	3,000	7,000
2.	325	650	2	1,000	650	1,500
3.	325	75	1	600	650	1,500
4.	325	150	2	1,000	650	3,000
5.	325	150	1	600	650	1,500
6.	325	300	1	1,000	650	1,500
7.	325	300	2	1,500	650	1,500
8.	325	300	2	1,000	3,000	7,000
9.	325	300	2	600	650	1,500
10.	375	75	2	1,000	650	3,000
11.	375	150	2	1,500	3,000	7,000
12.	375	150	2	1,000	1,000	7,000
13.	375	300	2	1,500	1,000	7,000
14.	375	300	2	1,000	3,000	7,000
15.	375	300	2	1,000	1,000	7,000
16.	375	500	2	1,500	1,000	7,000
17.	425	75	2	1,500	650	3,000
18.	425	150	2	1,500	650	3,000
19.	425	300	2	1,500	650	3,000
20.	425	500	1	1,000	650	5,000
21.	425	500	2	1,500	650	5,000
22.	425	500	2	1,000	650	5,000
23.	425	700	2	1,500	1,000	7,000
24.	475	150	2	1,500	2,000	5,000
25.	475	300	2	1,500	650	3,000
26.	475	300	2	1,500	3,000	7,000
27.	475	500	2	1,750	3,000	7,000
28.	475	500	3	1,500	3,000	7,000
29.	475	700	2	1,500	650	3,000
30.	475	700	2	1,000	650	3,000

(1) Brine Contamination Index

0 = < 2,000 ppm TDS

1 = 2,000 - 100,000 ppm TDS

3 = > 100,000 ppm TDS

The resource quality model incorporates the factors described above. New discoveries are forecast to have elevated temperature profiles, declining as depletion effects begin to take effect. Figure 2-5 illustrates the expected temperature of future discoveries in Southern California, Nevada, and other regions. To fully characterize the quality of future discoveries, discoveries within each temperature class were further defined in terms of well flow, salinity, well cost, and producible acreage. This disaggregation procedure is based upon the predicted frequency of occurrence of specific resource types, as determined by consulting geologists.

2.3 POWER DEVELOPMENT AND ROYALTY REVENUE FORECASTING MODEL

Having derived estimates of the quality and number of current and future resource discoveries, the next step in the modeling procedure is to forecast expected future resource development. As shown in Figure 2-6, two parallel procedures are used to forecast (1) the technological potential for development at each resource (unconstrained by economic and financial concerns) and (2) the numerical likelihood that this development will take place (constrained by economic and financial concerns). Results from this methodology are expressed in terms of "expected power" which is the product of these two estimated values. A brief description of the methodologies used in performing each procedure is summarized below. More detailed discussions can be found in Cassel, et al. (1982).

2.3.1 Potential for Resource Development.

The technological potential, in megawatts, for resource development without concern for economic constraints is estimated as a function of five variables, namely: estimates of producible acreage at the resource; well spacing requirements (acres/well); well flow rate estimates (lbs/hr); brine effectiveness of the power plant (watts per lb/hr); and requirements for spare production wells. Values for the first 3 of these variables are provided on a resource-specific basis by consulting geologists, reservoir engineers and resource developers. Once the megawatt potential of a resource has been estimated, the potential rate of development is addressed. If there is no existing development or planned commitments, the resource's megawatt potential is assumed to be reached by following a development profile that begins with an initial 20 MWe unit 5 years after resource confirmation and

Figure 2-5. HISTORIC AND PROJECTED REGIONAL EXPECTED TEMPERATURES OF DISCOVERY

Figure 2-6. POWER DEVELOPMENT FORECASTING MODEL

progressively accelerates until 200 MWe are being installed per year (The Geyser's growth rate) 7 years later.

2.3.2 Likelihood of Resource Development.

The likelihood that the power potential of a resource will be developed depends on the risks and returns associated with the investment opportunity. Development is likely to occur only if geothermal project returns are expected to be competitive with the returns of alternative investment opportunities. Interviews with management representative of the twenty firms participating in Technecon's earlier analyses indicate that four objectives are of primary concern to investment decision-makers in the energy resource industry. These investment objectives are to:

- o maximize the efficiency of invested capital (as assessed in terms of the anticipated net after-tax rate of return).
- o minimize the length of time during which invested capital is at risk (as assessed in terms of the anticipated investment payback time).
- o undertake projects which are compatible with the firm's scale of operations (as assessed in terms of the anticipated net present value of the profit stream).
- o avoid financial ruin (as assessed in terms of the amount of invested capital at risk and the probability of incurring this loss).

Decision-makers weigh the risks and returns that are described by these five attributes for particular geothermal opportunity. Positive investment decisions follow if the geothermal opportunity appears attractive relative to alternative investment opportunities that may be available to the firm.

The likelihood of resource development is thus estimated as a two step process. First a detailed, discounted cash flow analysis is performed for resource development and ultimate resource production. Measures of financial performance are computed which provide quantitative measures for the four investment objectives cited above. Finally, these financial performance measures are used to forecast development likelihood. These procedures are briefly summarized below.

Attributes of Cash Flow Projections for Resource Development. Based upon the resource quality, detailed cash flow estimates are computed for geothermal projects at each known and projected resource. Capital costs,

operating expenses, taxes and revenues are estimated for both well field and power plant development. Revenues are based upon marginal competition with alternative generation (either coal-fired, oil-fired, or "avoided cost" rates as discussed later in Section 3.2). Key cash flow attributes from the resource developers point of view include rate of return, duration of investment exposure, project size, amount of capital at risk, and the probability of project failure.

Likelihood of Resource Development. The final forecasting step focuses on the investment behavior of resource developers and electric utilities. The probability of investment at each known and new resource is evaluated using a methodology which incorporates two modern techniques from the decision sciences, namely "multiattribute utility analysis" and "logit choice estimation". These methods key on the abovementioned cash flow attributes and compare the geothermal investment opportunity to alternative investment opportunities that are likely to be available. A computerized multiobjective analysis then provides estimates, over time, of the joint likelihood of investments to develop well fields and to construct on-site power plants and transmission facilities. These models are statistically-strong in their ability to reproduce investment preferences as expressed in extensive interviews and demonstrated field practice.

2.3.3 "Expected Power" Estimates

As discussed previously, part of our analysis is concerned with the potential quantity of power (in megawatts) that may be developed at a specified resource area over time. The potential amount of development is based upon a function of producible acreage, well spacing, well flow rate and power plant efficiency. The rate of development is based upon historical lead times and plant intervals as experienced in geothermal resource development.

From the decision analysis discussed above, we derive two parameters by which to evaluate geothermal resource development. The first is the estimated probability that a resource company will decide to invest in a specified geothermal project. The second is the estimated amount of electric power that will be brought on-line over time if such a positive investment decision is made. The product of these two parameters, known as "expected

power", reflects both the probability and the amount of geothermal power at a given area within time (t), i.e....

"Expected" $MW(t) = [Potential\ MW(t)] \times [Probability\ of\ Investment]$.

In this study, expected power estimates are provided for each known and forecasted geothermal resource in the U.S. between 1985 and 2015. National estimates of expected geothermal power are provided by summing over the U.S. resource base.

2.4 ANALYZING R&D INITIATIVES

The desired effect of Federally-sponsored R&D programs is to enhance the decision-maker's perception of geothermal projects by reducing investment risks and/or improving investment returns. For example, an R&D goal of improving power plant efficiency will reduce geothermal fluid requirements and thereby reduce well field capital expenditures. If this gain in plant efficiency can be achieved without an excessive increase in plant capital cost, then the economies realized by decreased well field costs will serve to enhance the geothermal opportunity. As described in the preceding discussion, this enhancement will have two major impacts; (1) accelerate resource exploration and confirmation activity as the expected geothermal rate of return is increased, and (2) increase the likelihood of resource development and potentially expand the technological potential for resource development.

2.5 ROYALTY INCOME ESTIMATION

Holders of producible federal leases must pay a royalty on the "amount or value of steam, or any other form of heat or energy derived from production under the lease".¹ This royalty can vary from 10 to 15 percent initially, to 22 percent after 20 years. Total royalty incomes are distributed evenly between the Federal Government and the states in which the production site is located.² Federal statutes dictate that royalties be assessed on the gross revenues of the power plant and are treated as an expense for Federal tax purposes.

¹Geothermal Steam Act of 1970, PL 91-581, Sec. 5(a).

²Federal Land Management Policy Act of 1976, PL 94-579, Sec. 317(a).

Estimates of the proportion of federal lands in the discovered and prospective geothermal resource areas are required for federal royalty income calculation. Federal acreage estimates for KGRAs in six Western states (Arizona, California, Idaho, Nevada, Oregon and Washington) were obtained from USGS (1980).³ The resource areas included in this USGS report are generally the most likely to be developed. The federal acreage estimates for the remaining KGRAs in New Mexico and Utah and for non-KGRA resource areas were derived from Bureau of Land Management Wilderness Status Maps. These 1:1,000,000 scale maps identify federal lands (i.e., National Parks, National Forests, Wilderness Areas, and BLM land in the Western States). Examination of ownership within the relevant KGRAs and within 5 miles of prospective resources provided estimates of Federal acreage.

Total federal royalty income is calculated by applying these federal acreage estimates against the electric power development projections output from the Power Forecasting Model. Individual federal acreage estimates are used for the 20 discovered resources. These estimates can be found in Table 2-1. For the remaining undiscovered resources an average federal lands proportion estimate of 63 percent is used.⁴

³USGS efforts to collect comprehensive Federal acreage and lease information for the remaining Western states was not continued after the reorganization of DOI in 1981. Data collection on an adhoc basis has been shifted to individual state BLM offices.

⁴Derived by taking the arithmetic average of the federal lands estimates for the remaining prospective resource areas.

CHAPTER THREE

ESTIMATION OF FUTURE ROYALTY INCOME BENEFITS

The purpose of this chapter is to assess the extent to which Federally-sponsored research and development may stimulate geothermal development, and to estimate the royalty income generated as a result of this stimulus. As more efficient and less costly geothermal technologies are made available as a result of Federal research, the pace of development will increase as (1) field exploration and discovery rates climb due to the enhanced prospective investment returns, (2) technology advancements enable an expanded resource base to be economically developed, and (3) increased utilization efficiencies permit higher development levels to be reached at individual resources. In this chapter, the time-wise increase in power development attributable to Federally-sponsored R&D is first estimated. The increase in Federal royalty income generated as a result of accelerated development is then forecast.

The additional royalty income gained by the Government as a result of Federally-supported R&D can be viewed as a return on the Government's investment in geothermal research. Estimation of the royalty "returns" associated with specific R&D activities can serve as an indication of the extent to which such programs may "pay for themselves" in future years. It must be noted, however, that royalty returns are an incomplete measure of the benefits to the nation of R&D programs. Other benefits will accrue from (1) less costly and more efficient development of resources on non-Federal land (thus generating no Federal royalty income), (2) diversification of the Nation's electric capacity, (3) reduced dependence on imported fuels, and (4) environmental benefits associated with geothermal energy. Estimation of these important benefits is beyond the scope of this research.

In the following sections, projected royalty returns from current Federal R&D activity is estimated. Assumed near-term Federal program accomplishments are established based upon the status of on-going research and discussions with industry representatives and DOE program managers. Returns associated with this investment in R&D are then estimated, and a program funding level is established such that the program would pay for itself over the long term planning horizon.

3.1 FORECASTING METHODOLOGY

To forecast differential royalty income, the integrated development forecasting model described in Chapter 2 is used to estimate a time-wise development profile with (1) only those near-term technological advances which are expected to result from current private sector R&D (the Base Case of current technology) and (2) the additional achievement of current federal R&D objectives. For each case, new resource discoveries are first forecast, followed by projected total power development power over the 1984-2015 period. Yearly Federal royalty income payments are then estimated, based upon the share of development expected to take place on Federal leases. The differential net present value of royalty income streams (i.e., income with achievement of current Federal R&D objectives versus income with current technology) may then be estimated.

An important factor determining the pace of development will be the type of generation capacity with which geothermal power must be economically competitive if public utility acceptance of geothermal power is to be gained. The relatively expensive cost of oil- or gas-fired generation which, in the case of many California utilities, is their "avoided cost" of generation, is presently allowed as an upper limit to a utility's cost of geothermal power from either: (a) initial utility-owned plants at an undeveloped resource, or (b) qualified non-utility-owned plants under the power purchase provisions of the Public Utility Regulatory Policies Act (PURPA). The text of recent PUC rulings implies, and discussions with utility and commission staffs substantiate, that the less expensive cost of coal-fired generation is likely to dictate an allowable upper limit for geothermal power costs in the future for utility-owned plants which follow the initial demonstration plants at a new resource.

For this reason, differential royalty incomes will be estimated for three fluid pricing scenarios: (1) utility-owned geothermal plants being competitive with new coal-fired capacity, (2) utility-owned geothermal plants being competitive with new oil-fired base load capacity, and (3) non-utility owned geothermal plants being competitive at projected "avoided cost" rates. As noted in Figure 3-1, the assumed pricing scenario has a substantial impact on fluid purchase price, and hence revenue and royalty streams.

Figure 3-1. COMPETITIVE GEOTHERMAL FLUID PRICES

Table 3-1. ECONOMIC AND FINANCIAL ASSUMPTIONS FOR GEOTHERMAL FLUID PRICING (FIGURE 2-8)

GENERATION TYPE:	COAL	OIL	GEOTHERMAL	
Power Plant Ownership:	Utility	Utility	Utility	Non-Utility
Fuel Cost (1983 Mills/kWh)	18.8	51.8	(Fig.3)	(Fig.3)
Fuel Escalation Rate	7.0%	7.0%	7.0%	7.0%
Plant Capital Cost (1983 \$/kW)	1200	785	(Fig.3)	(Fig.3)
O&M Expense*	6.2%	2.0%	4.0%	4.0%
Common Stock Fraction	0.35	0.35	0.35	0.25
Preferred Stock Fraction	0.15	0.15	0.15	0
Long-Term Debt Fraction	0.50	0.50	0.50	0.75
Cost of Common Stock	0.16	0.16	0.16	0.25
Cost of Preferred Stock	0.11	0.11	0.11	0
Cost of Long-Term Debt	0.11	0.11	0.11	0.12
Federal Income Tax Rate	0.46	0.46	0.46	0.46
State Income Tax Rate	0.09	0.09	0.09	0.09
Investment Tax Credit	0.10	0.10	0.10	0.25
Tax Life (Years)	15	15	15	5
Book Life (Years)	30	30	30	30

*Includes annual operation, maintenance, insurance, local taxes administrative and general expense expressed as a percentage of initial plant capital cost.

3.2 EXPECTED FEDERAL R&D PROGRAM ACCOMPLISHMENTS

Federally-funded R&D in geothermal technologies is expected to produce improvements in a number of areas of cost and performance on geothermal projects. These advancements will supplement technology progress made as a result of private sector research and development activities. Previous review of DOE R&D programs by Technecon (1983) indicated that modest government support of research in injection technology, reservoir definition, heat cycle research, and hard-rock penetration can achieve the following program objectives:

- o Increase geothermal power plant efficiency, i.e. "brine effectiveness", by 7% after 1987 (with 2% real increase in capital cost and 3% real increase in annual O&M expenses).
- o Extend well life 24% after 1987 by improving materials and reworking and stimulation methods.
- o Improve pumps, well drilling and completion methods to reduce effective well costs by 5% after 1985 and by 10% after 1990.
- o Reduce surface piping costs by 8% after 1987 by materials and design research.
- o Increase on-line availability of geothermal power plants by 2% after 1987 by improving reliability through materials and design research.

This set of objectives was compiled through detailed review of DOE program documents, interviews with DOE program personnel, and discussions with industry representatives. Industry and government sources indicated that these objectives were realizable and could be substantially surpassed with additional increase in Federal support. For this report, only the set of objectives listed above is used.

3.3 DATA INPUTS AND MODELING ASSUMPTIONS

Input parameters required for projecting future royalty income streams include both resource quality dependent and non-resource quality dependent variables. The values assigned to each parameter are based on the combined judgment of Department of Energy staff, personal interviews with industry representatives, and extensive reviews of the published literature. More extensive documentation of selected input parameters can be found in Cassel et al. (1983).

Table 3-2 provides "global" (i.e. non-resource dependent) variables relating to basic economic, financial, tax, well field, and other miscellaneous modeling assumptions. Values for these parameters are unaffected by the type of resource being analyzed, and are not impacted by Federal R&D activities. Table 3-3 illustrates the base case values for resource-dependent variables, including: (1) hydrothermal power plant capital cost, (2) net brine effectiveness, (3) well life, (4) surface piping cost, (5) downhole well pump capital cost, and (6) well field operation and maintenance cost.

To assess the effect of R&D advances identified in Section 3.2 on geothermal power development, several variables relating to technological costs and performance were adjusted in the forecasting model. These adjustments are provided in Table 3-4.

3.3.1 Differential Royalty Income Estimate: Coal-Based Resource Price.

Table 3-5 illustrates projected future wildcat drilling and new resource discoveries assuming the levelized cost of geothermal power is constrained to be cost-competitive with new base load coal-fired capacity. As shown, with current technology 110 new wells are expected to be spudded, resulting in the discovery of 16 new resources over the next 30 years. Power development is expected to reach 4550 MWe by 2000, and increase to slightly over 7000 MW by 2010. With fluid sale price set at a level competitive with coal-fired capacity, the net present value of royalty income returned to the government is estimated to total \$602 million. Figure 3-2 illustrates the forecast stream of royalty inflows (in 1984 constant dollars).

If the target objectives of Federal R&D are met, geothermal development would be significantly increased. As shown in Table 3-5, the higher prospective investment returns would increase the pace of exploration by 30 percent, with 145 new wildcat wells drilled, and 28 new resources discovered by 2010. An estimated 6050 MWe of hydrothermal capacity is forecast by 2000, rising to 10,230 MWe by 2010. The net present value of royalty income earned by the government total \$809 million, representing a net increase of \$207 million over current technology (see Figure 3-2).

Table 3-2. GLOBAL INPUT VARIABLES
AND MODELING ASSUMPTIONS

ECONOMIC PARAMETERS	CODE	VALUE	FINANCIAL AND TAX PARAMETERS	CODE	VALUE
Capital cost of competing coal-fired power plant	CALT	\$1200/kWe	Depletion allowance	PDPL	.15
Capital cost of competing oil-fired power plant	CALT	\$785/kWe	Ad Valorem tax rate	ADV1	.04
Annual O&M cost of coal-fired power plant	BETAA	.062	Ad Valorem tax assessment rate	ADV2	.25
Annual O&M cost pf oil-fired power plant	BETAA	.020	Investment tax credit: baseload alternative	ITCA	.10
Capacity factor of competing power plant	CAPA	.75	Well tax life	PTLF	3
General inflation rate	G	.075	Federal tax rate: power plant owner	TFH	.46
Capital cost escalation rate	GC	.08	Federal tax rate: resource producer	TF2	.46
Fuel cost escalation rate	GF	.09	Tax life: power plant	TLFH	15
Cost of fuel: competing coal-fired power plant	PALT	18.8 mills/kWh	State tax rate: power plant owner	TSH	.09
Cost of fuel: competing oil-fired power plant	PALT	78.8 mills/kWh	State tax rate: resource producer	TS2	.09
Plant life: competing baseload power plant	PLFA	30	Fraction of common stock: power plant	FCH	.35
Plant life: hydrothermal power plant	PLFH	30	Fraction of debt equity: power plant	FDH	.50
Royalty fraction	RLF	.10	Fraction of preferred stock: power plant	FPH	.15
Base price year	YP	1984	Cost of common stock: power plant	KCH	.16
Discount rate	DTL	.12	Cost of debt equity: power plant	KDH	.11
			Cost of preferred stock: power plant	KPH	.11
WELL FIELD PARAMETERS	CODE	VALUE	MISCELLANEOUS MODEL PARAMETERS	CODE	VALUE
Ratio of producer to injector wells	PIR	2	Sequential plant capacities in MW (1st, 2nd, 3rd, 4th, all others)	MWVS	20 50 50 100 200
Dry well cost as fraction of successful well cost	DVC	.90	Representative geothermal plant capacity (MW)	MWN	50
Intangible fraction of producer well cost	IF	.75	First year of simulation	TFIRST	1984
Fraction of new wells requiring redrilling	IRD	.30	Last year of simulation	TLAST	2010
Redrilling cost as fraction of initial cost	RDC	.35	Years between decision and plant on-line (plants 1-5)	DELDP5	5 3 3 3 3
Rework cost as fraction of initial cost	RWC	.35	Interval between successive plants in years (plants 2-5)	PIVS	0 3 2 1 1
Spare well fraction	SXF	.20	Years from first plant-related cost until plant on-line	DUT	3
Well spacing (acres per production well)	WSPACE	40			

1 fraction of capital cost (includes operation, maintenance, administration, ad valorem taxes).

Table 3-3
BASE CASE RESOURCE-DEPENDENT INPUT VARIABLES

	<u>Low Salinity Resource⁽¹⁾</u>				<u>High Salinity Resource⁽²⁾</u>			
	<u>Resource Temperature (°F)</u>				<u>Resource Temperature (°F)</u>			
	<u>325</u>	<u>375</u>	<u>425</u>	<u>475</u>	<u>325</u>	<u>375</u>	<u>425</u>	<u>475</u>
Hydrothermal Power Plant Capital Cost (\$/kw)	1,260	1,110	980	866	1,450	1,280	1,130	1,000
Net Brine Effectiveness (w-hr/lb of Fluid)	5.43	8.51	11.58	14.65	4.36	7.43	10.51	13.58
Well Life (Years)	15	15	15	15	5	5	5	5
Surface Piping Capital Cost (\$/kWe net) ⁽³⁾								
With Unpumped Wells	300	220	160	120	350	260	190	140
With Pumped Wells	230	130	80	40	260	150	90	50
Downhole Well Pump Capital Cost (\$1000) ⁽³⁾	230	230	230	230	230	230	230	230
Well Field Operation and Maintenance Cost (\$1000) ⁽³⁾								
With Unpumped Wells	4,500	2,700	2,000	1,600	13,400	8,300	6,000	4,800
With Pumped Wells	8,400	5,000	3,500	2,800	18,100	10,800	7,700	6,100

⁽¹⁾ Brine Contamination Index = 0

⁽²⁾ Brine Contamination Index = 2

⁽³⁾ Assumes 500,000 lb/hr flow rate

Table 3-4
ASSUMED FEDERAL R&D PROGRAM ACHIEVEMENTS¹

Drilling and Completion Technology

- o Extend life of production wells by 24% in 1988.
- o Reduce production well cost by 5% in 1985, and by 10% after 1990.
- o Reduce surface piping capital cost by 8% after 1988.

Heat Cycle Research

- o Improve brine effectiveness by 7% after 1987, at the expense of a real increase in capital and operation and maintenance cost of 2% and 3% respectively.
- o Extend maximum operating temperature of downhole well pumps to 400°F (versus current temperature limit of 350°F) by 1987.
- o Increase plant availability by 2% after 1987.

Injection Technology Research

- o Extend injection well life by 24% in 1988.
- o Reduce injection well cost by 5% in 1985, and by 10% after 1990.

¹The technology advancements noted above are assumed to supplement those near-term technological advancements which are expected to result from current private sector R&D.

Table 3-5. PROJECTED WILDCAT DRILLING, RESOURCE
DISCOVERY AND EXPECTED POWER DEVELOPMENT FORECASTS

	Forecasted During:					Cumulative Forecast: 1984 -				
	1984- 1989	1990- 1994	1995- 1999	2000- 2004	2005 2009	1989	1994	1999	2004	2009
Resource Pricing Assumption I: Fluid Priced Competitive w/Coal-Fired Generation										
<u>Wildcat Wells Drilled</u>										
o Base Case (current technology)	24	20	21	22	23	24	44	65	87	110
o With Achievement of Current Federal R&D Objectives	30	26	28	30	31	30	56	84	114	145
<u>New Resource Discoveries</u>										
o Base Case (current technology)	4	3	5	4	5	4	7	12	16	21
o With Achievement of Current Federal R&D Objectives	6	4	6	6	7	6	10	16	22	28
<u>Expected Power Development (MWe)</u>										
o Base Case	670	3,340	540	1,230	1,250	670	4,010	4,550	5,780	7,030
o With Achievement of Current Federal R&D Objectives	690	4,370	990	2,030	2,150	690	5,060	6,050	8,080	10,230
Resource Pricing Assumption II: Fluid Priced Competitive w/Oil-Fired Generation										
<u>Wildcat Wells Drilled</u>										
o Base Case (current technology)	43	39	41	44	46	43	82	123	167	213
o With Achievement of Current Federal R&D Objectives	70	65	71	76	80	70	135	206	282	320
<u>New Resource Discoveries</u>										
o Base Case (current technology)	8	7	9	8	9	7	15	24	32	41
o With Achievement of Current Federal R&D Objectives	13	14	13	15	16	13	27	40	55	71
<u>Expected Power Development (MWe)</u>										
o Base Case	770	3,560	1,270	2,650	2,720	770	4,330	5,600	8,250	10,970
o With Achievement of Current Federal R&D Objectives	775	4,785	8,130	2,230	4,490	775	5,560	13,690	15,920	20,410
Resource Pricing Assumption III: Fluid Priced at "Avoided Cost" Rates										
<u>Wildcat Wells Drilled</u>										
o Base Case (current technology)	33	28	30	30	31	33	61	91	121	154
o With Achievement of Current Federal R&D Objectives	45	38	40	40	41	45	83	123	163	204
<u>New Resource Discoveries</u>										
o Base Case (current technology)	6	6	6	5	6	6	12	18	23	29
o With Achievement of Current Federal R&D Objectives	8	8	8	8	8	8	16	24	32	44
<u>Expected Power Development (MWe)</u>										
o Base Case	770	3,550	940	1,880	2,120	770	4,320	5,260	7,140	9,260
o With Achievement of Current Federal R&D Objectives	780	4,590	1,690	3,680	3,460	780	5,370	7,060	10,740	14,200

Figure 3-2. ESTIMATED ANNUAL FEDERAL ROYALTY INCOME DIFFERENTIAL
COAL-BASED RESOURCE PRICE

3.3.2 Differential Royalty Income Estimate: Oil-Based Resource Price.

If new hydrothermal capacity is permitted by state public utility commissions to be competitive with new oil-fired generation capacity, Federal R&D activities would have an enormous impact on future royalty revenue. As a result of the economic stimulus provided by this pricing assumption, development under current technology is forecast to reach 10,970 MW_e by 2010. With the achievement of Federal R&D objectives, development in 2010 would almost double, totalling 20,410 MWe (see Table 3-5). The net present value of the additional royalty income made possible by Federal R&D accomplishments is estimated to be \$476 million (see Figure 3-3).

As noted in Section 3-2, it is unlikely that state regulatory agencies will, over the long term, license hydrothermal plants with levelized costs equivalent to very expensive oil-fired capacity. Commissions may permit this practice for "ice-breaker" plants at newly discovered resources, and until more experience is gained with hydrothermal utilization technology. The royalty income differential estimated under this assumption is thus an extremely optimistic forecast. It does, however, indicate the importance of resource pricing assumptions in the estimation of future royalty revenues.

3.3.3 Differential Royalty Income Estimate: "Avoided-Cost" Resource Pricing.

As discussed previously, qualified non-utility-owned geothermal power plants may be classified as "Qualifying Facilities" under provisions of the Public Utility Regulatory Policies Act (PURPA). This enables such a facility to sell power to a local utility, at rates approximately equal to the utility's marginal cost of generation. For purposes of this analysis, the avoided cost rates currently offered by Pacific Gas and Electric Company are applied to estimate revenue and royalty income streams.

As shown in Table 3-5, all phases of geothermal development receive a substantial stimulus under this pricing assumption. With current technology, an average of 5 wildcat wells per year are expected to be spudded, resulting in almost 30 new resource discoveries. Expected power is forecast to reach 5,200 MW_e and 9,260 MW_e by 2000 and 2010, respectively. The net present value of Federal royalty receipts total \$728 million under current technology assumptions. (See Figure 3-4).

Figure 3-3. ESTIMATED ANNUAL FEDERAL ROYALTY INCOME DIFFERENTIAL
OIL-BASED RESOURCE PRICE

Figure 3-4. ESTIMATED ANNUAL FEDERAL ROYALTY INCOME DIFFERENTIAL
"AVOIDED COST" BASED RESOURCE PRICE

With achievement of current Federal R&D objectives, an estimated 50 new wildcat wells are forecast, yielding 15 additional resource discoveries by 2009. The net impact of DOE-sponsored cost reductions and performance improvements would dramatically increase the pace of geothermal development, with almost 15,000 MW_e of hydrothermal capacity expected to be on line by 2010. The total net present value of Federal royalty income is estimated to exceed over \$1,000 million, compared to the base case estimate of \$728 million.

3.4 OVERALL EVALUATION SUMMARY

Based on the analysis presented above, the additional royalty returns generated from Federally-supported hydrothermal R&D, appears to be substantial. Achievement of the modest DOE program objectives outlined in Section 3.2 can be expected to increase state and Federal royalty incomes by over \$200 million (in net present value) under even the most pessimistic resource pricing assumptions. If the majority of future power plant development takes place under the aegis of PURPA, additional revenues are likely to exceed \$600 million, distributed evenly between state and Federal governments.

As shown in Table 3-6, the Federal government's share of royalty proceeds could be used to fund major research programs. The net present value of the royalty differential under the coal-based resource pricing assumption totals \$102.3 million. This is equivalent to the net present value of funding an R&D program for 5 years at \$28.7 million per year. With the increased royalty income generated under an avoided cost pricing assumption, a 5-year program of \$70 million/year could be afforded. As emphasized above, other National R&D benefits, not included in the scope of this study, include: (1) the concomitant enhancement of geothermal resource development on non-Federal land; (2) diversification of the Nation's electric generating capacity, (3) reduced dependence on imported fuels, and (4) environmental benefit associated with geothermal energy.

Table 3-6
FEDERAL DIFFERENTIAL ROYALTY INCOME
AND EQUIVALENT ANNUAL PROGRAM FUNDING LEVELS
(Million Dollars)

	Federal Share of NPV of Royalty Income ⁽¹⁾			Equivalent Annual Program Funding Level ⁽²⁾	
	<u>Current Technology</u>	<u>w/Federal R&D</u>	<u>Differential</u>	<u>5-Year Program</u>	<u>10-Year Program</u>
Coal-Based Pricing	\$301.1	\$404.4	\$102.3	\$28.7	\$14.7
Oil-Based Pricing	697.4	1,173.5	476.1	113.9	73.8
Avoided Cost Pricing	728.1	1,028.1	300.0	70.3	46.0

(¹) Includes only the 50% share of royalty income retained by the Federal government.

(²) The net present value of disbursements to a program with the fixed annual budget and duration represented below, will equal the net present value of differential royalty income.

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