DOE/ID/13989

Development of a Plan to Implement Enhanced Geothermal Systems (EGS) in the Animas Valley, New Mexico

Final Report – 07/26/2000 – 02/01/2001

D. N. Schochet
R. A. Cunniff

February 2001

Work Performed Under Contract No. DE-FG07-00ID13989

For
U.S. Department of Energy
Assistant Secretary for
Energy Efficiency and Renewable Energy
Washington, DC

By
ORMAT International, Inc.
Sparks, NV

Lightning Dock Geothermal, Inc.
Las Cruces, NM

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Summary

United States Department of Energy

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Prepared by:

ORMAT International, Inc.
Sparks, Nevada

And

Lightning Dock Geothermal, Inc.
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February 1, 2001

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Submitted by:

ORMAT International, Inc.
Sparks, Nevada
Daniel N. Schochet, Vice President

And

Lightning Dock Geothermal, Inc.
Las Cruces, New Mexico
Roy A. Cunniff, President

February 1, 2001

DISCLAIMER

PREFACE

This EGS Final Report has been prepared in the format as specified in DOE Letter, Dennis L. Hoffer, Contracting Officer, Subject: Final Report Instructions, dated February 14, 2001, for the final report on the "Phase I - Enhanced Geothermal Systems Project, solicitation DE-PS07-00ID13989."

Geothermal resources, like minerals and hydrocarbons, are more valuable and easier to exploit when they occur as "high-grade", high-temperature hot water or steam reservoirs. Most of the known, accessible reservoirs in the United States and throughout the world have already been discovered and developed. In many cases, most of the heat that is available for development is left in the reservoir rock itself. Secondary enhancement techniques, including fracturing and flooding, which have been successfully applied to waning oil and gas fields, have yet to become standard practices in the geothermal industry. This report proposes a project to develop Enhanced Geothermal System (EGS) technology that incorporates fracturing technology to a relatively shallow depth, moderate temperature geothermal reservoir rock associated with an intermediate depth hydrothermal reservoir. The plan is to integrate conventional hydrothermal technology with EGS to provide a commercial platform to assess the ability of the EGS development to produce geothermal fluids in a commercially sustainable manner. This "Combined Technologies Project" incorporates EGS and hydrothermal reservoir assessment and development techniques to validate the EGS model within the context of commercial electric power production. We believe this approach meets program goals.

Underlying the Phase I study and the Combined Technologies Project, we have considered the criteria established by Dr. John Sass of the United States Geological Survey, consisting of some 20 criteria that a potential site for EGS development must address. Those criteria evaluated against the Lightning Dock Geothermal Resource characteristics are listed in Appendix A. We believe this program satisfies all these criteria and represents an optimum approach to validate EGS technology.

As Project Manager, I would like to thank the many highly skilled professionals who contributed to the Phase I Study and the preparation of this report including Roy A. Cunniff and Roger Bowers, of Lightning Dock Geothermal, Inc. (assisted by Mr. Keith Vickers of Terracon, Inc.); Eduardo Granados, Ann Robertson-Tait, and Dr. Chris Klein of GeothermEx; Dr. David Blackwell and Dr. Ken Wisian of Southern Methodist University; the technical staff of ORMAT International, Inc.; and Thomas Flynn of Mankato Enterprises.

In addition I want to thank ORMAT International, Inc. for sponsoring the Phase I Study, which was conducted as a Co-Venture of ORMAT and Lightning Dock Geothermal, Inc.

Daniel Schochet

Vice President

ORMAT International, Inc.
February 1, 2001

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1.0. INTRODUCTION

The concept of producing energy from hot dry rock (HDR), originally proposed in 1971 at the Los Alamos National Laboratory (LANL), contemplated the generation of electric power by injecting water into artificially created fractures in subsurface rock formations with high heat flow. Water pumped into the injection well would be recovered as steam or hot water in an adjacent production well and delivered to a geothermal power plant at the surface. Although the initial HDR concept was sound, the Fenton Hill program did not produce commercial geothermal power for two fundamental reasons:

- prodigious drilling depths (ca 13,000 feet depth) with very high associated costs; and
- the inability to create sufficient fracture-permeability in the reservoir rock to produce flow rates compatible with the requirements for commercial electricity generation.

Recognizing the inherent difficulties associated with HDR, the concept of Enhanced Geothermal Systems was proposed. This embraces the idea that the amount of permeability and fluid in geothermal resources varies across a spectrum, with HDR at one end, and conventional hydrothermal systems at the other. Instead of approaching the problem of reservoir enhancement from the most difficult end of that spectrum (HDR), as was done at Fenton Hill, the EGS program seeks to enhance systems that may have some natural permeability and fluid content, but not enough for commercial conditions.

This report provides a concept for development of a "Combined Technologies Project" with construction and operation of a 6 MW (net) binary-cycle geothermal power plant that uses both the intermediate-depth hydrothermal system at 1,200 – 3,300 feet and a deeper EGS capable system at 3,000 to 4,000 feet. Both reservoirs have already been identified in an existing deep well (Test For Discovery Well 55-7, drilled by AMAX to 7,000 feet in 1985). After suitable evaluation, the EGS reservoir will be hydraulically fractured. Two production/injection well pairs will be drilled (one couplet for the hydrothermal system, and one for the EGS system); thus, a total of four wells will be required. The two couplets may be pumped; therefore, it is possible that downhole production pumps will be needed in each of the two production wells. Injection pressure for the hydrothermal injector will be achieved using a centrifugal pump as is typical for conventional hydrothermal projects. High-pressure injection may be required to drive fluid through the EGS reservoir from the injection to the production well.

This report is structured to show the progress attained for each of the numbered tasks included with the Cooperative Agreement for this project.

Organizational Plan

Phase I activities were organized and completed according to the task sequence listed in Table 1 below. Each Task was assigned an arbitrary sequence number used in conducting the work; in actual practice, Task 1 is the primary task on which the work product for the remaining tasks is dependant. Discussions of the work product from each Task, No. 2 through 7, are then grouped to depict the actual sequence in which the Tasks were completed.

EGS Task Identification

Tasks defined in Table 1 were defined in the proposal, subsequently accepted by DOE and incorporated into the Cooperative Agreement.

Table 1. Task Sequences for EGS Study

Phase I	**Sub-task 1**	**Sub-task 2**	**Sub-task 3**	**Sub-task 4**
Task 1	Geologic studies	Heat Flow and geologic studies	Geochemistry and hydrology studies	Integrated resource model
Task 2	Drilling Parameters Plan	Fracturing Study and Plan	Surveillance Plan	Well-bore Logging Plan
Task 3	Assess design parameters for power plants	Feasibility Designs, Option #1 power modules	Feasibility Designs, Option #2 power modules	Cost and Economic models
Task 4	Evaluate local electricity needs	Assess grid power potential	Evaluate out-of-state electrical needs	Cost and benefit summary
Task 5	Determine water rights	Assess Environmental. Factors	Prepare Concept Regulatory Plan	Prepare Environmental Assessment Guidelines
Task 6	Draft #1 Plan for Implementation	Draft #2 Plan for Implementation	Draft #3 Plan for Implementation	Final Draft Plan for Implementation
Task 7	Drilling Plan	Fracturing Plan	Drilling Mitigation Plan	Drilling Mitigation Plan
Task 8	Monthly Report	Monthly Report	Monthly Report	Phase One Report

Each of the major tasks, and each of the subtasks were completed. The research path, however, was an iterative process in which salient geophysical, thermal, hydrological, and institutional factors were interplayed. Of necessity, the foundation for the completed work is a thorough and methodical resource assessment to determine the most likely parameters for both the hydrothermal and the conceptual EGS resources. With these parameters fixed, at least to a point at which most likely ranges of values could be established for all of the key unknowns, the degree of uncertainty of key elements then was used to develop the focused resource assessment tasks necessary to completely delineate both resources. Then, to complete the resource assessment and development actions, industry standards were used to develop the most likely parameters for drilling, fracturing, and testing both resources. With these parameters fixed, the institutional and environmental factors were evaluated. This process also was used to develop a time-phased research and development plan leading to power plant construction and operation.

The final work product then was to design a conceptual power plant, and then use that notional design to complete cost and benefit analyses.

2.0. DISCUSSION OF TASK ONE, INTEGRATED RESOURCE MODEL

Project Location and Regional Geology

Animas Valley is located in Hidalgo County in the southwestern corner of New Mexico, approximately 15 miles (24 km) east of the Arizona/New Mexico border (Fig. 1). The valley ranges in width from about 7 to 13 miles (11-21 km) and is almost 90 miles (144 km) long. Starting at the United States/Mexico International border, Animas Valley extends northward to an end just northwest of the city of Lordsburg, New Mexico. The geothermal area lies on the eastern side of the valley at the foot of the Pyramid Mountains, about 10 miles (16 km) south of Interstate Highway 10 and about 19 road miles (30 km) from Lordsburg. More precisely, the geothermal anomaly is centered in Section 7, T25S, R19W, NMPM and is mapped on the Swallow Fork Peak, 7.5-minute series, U.S. Geological Survey topographic map.

Federal geothermal lease NM-34790 (the "Lease") covers 2,500.96 acres in sections 6,7 and 18 of T25S, R19W, and sections 1, 11, 12 and 13 of T25S, R20W. The lease was issued on February 1, 1979 to AMAX Exploration, Inc. of Denver, CO. AMAX, reorganized as Steam Reserve Corp., sold off its geothermal interests and the Lease reverted to Geothermal Properties, Inc., a partner in Steam Reserve. Geothermal Properties sold the Lease in 1986 to Lightning Dock Geothermal, Inc. (LDG) of Las Cruces, New Mexico.

All subsurface mineral rights in the Lease area are owned by the federal government, and the geothermal rights are leased to LDG. Under the terms of the Lease, the lessee (LDG) has exclusive rights to the geothermal resource and the use of the surface for well sites, production facilities, access roads, and related facilities for development and utilization. In addition, LDG, by right of succession as the federal lessee, has in place operating agreements with each of the three surface landowners who own fee simple land overlying the federal lease.

Several published reports provide excellent descriptions of both regional and local geology and the reader is encouraged to study the reports for additional details. The geology described below is summarized from some of those published reports. The southwestern corner of New Mexico is in the Mexican Highland part of the Basin and Range physiographic province characterized by steep, well-dissected mountains separated by flat-floored desert valleys. Both a topographic low and a structural graben, the Animas Valley is bounded on the west by the Peloncillo Mountains and on the east by the Pyramid Mountains (see Figure 1).

At places within the basin, small volcanic hills dot the valley floor. These hills, along with the results of drilling, suggest that the valley fill is not very thick. Quaternary sediments consist of alluvial fans and pediment deposits, fluvial deposits, and modern eolian and sheetwash deposits. In addition, the Animas basin was occupied by Lake Animas in late Pleistocene and Holocene times leaving lacustrine deposits and shoreline features. The Pyramid Mountains are composed primarily of Cretaceous and Tertiary igneous rocks. Recent evidence has shown that Quaternary pediment alluvium has been displaced, thereby making the Animas Valley Fault one of the youngest geologic features in the area.

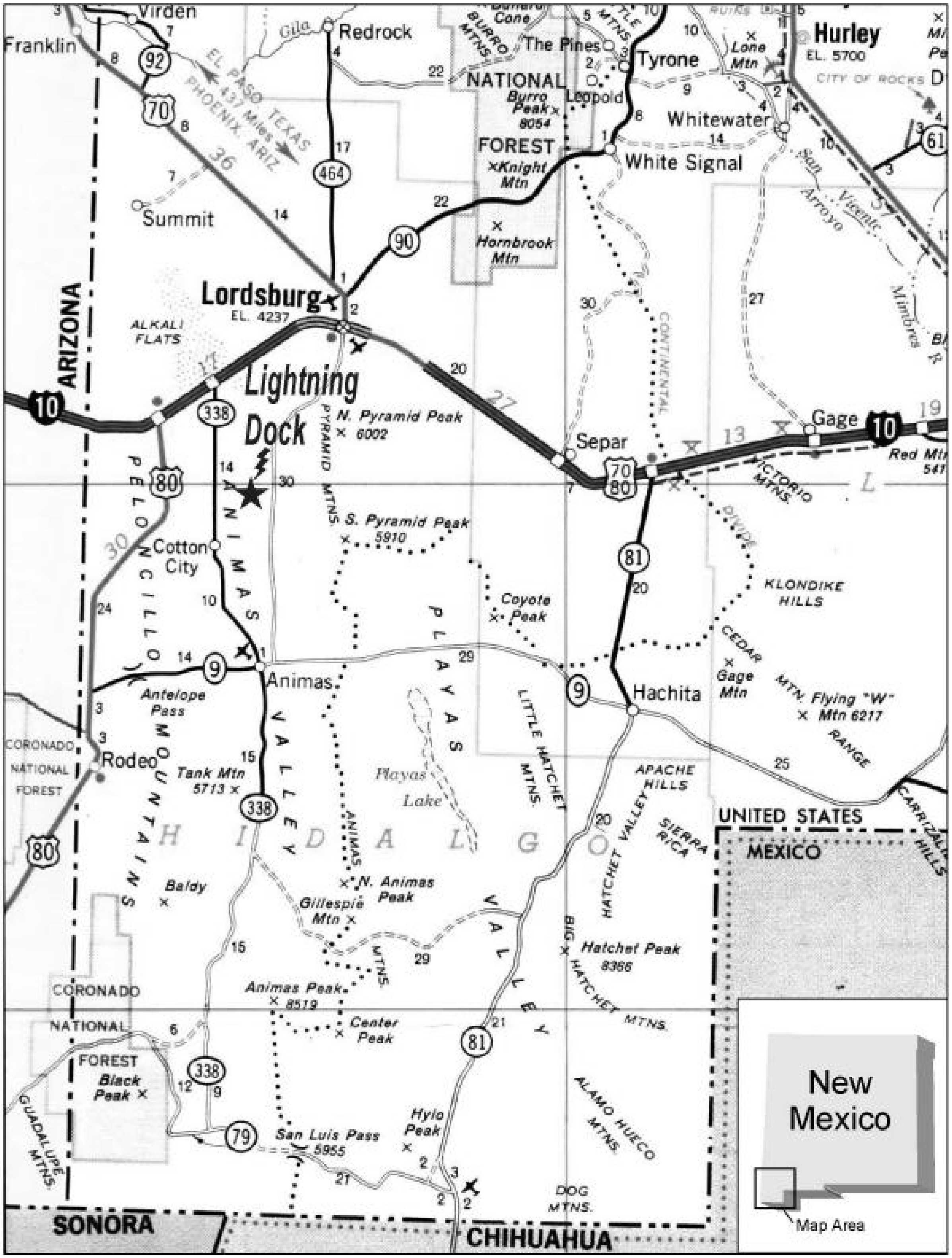

Figure 1. Location of Lightning Dock Geothermal Area, Animas Valley, New Mexico.

Thermal Data

Kintzinger (1956) was the first to identify and delineate the shallow hot water anomaly centered in Section 7, T 25 S, R 19 W. His contoured temperatures one meter below ground surface showed a somewhat elliptical anomaly elongated in a northerly direction. Reeder (1957) briefly discussed the hot wells and suggested that the hot water system was fault controlled. He also released a temperature survey of 135 water wells, with almost all temperature measurements made at the end of the irrigation discharge line. Summers (1976) provided temperature information from six wells. He also released a map showing ground water temperatures (from water well measurements) in a 35 square mile area centered on the hot wells.

Temperature data evaluated in this report were obtained from various sources. A total of 96 wells in the region had sufficient data that could be used to construct a shallow subsurface temperature map (Figure 2). Most of these wells are temperature gradient holes primarily drilled for geothermal exploration purposes about 20 years ago, although the temperature database also contains temperature data from some 22 shallow geothermal production wells, most of which have been drilled in the past 15 years. These shallow temperatures show a tightly focused anomaly at the location of the current greenhouse development. While the data are concentrated around the greenhouses, there are sufficient outlying data to rule out large-scale temperature anomalies in the area that are bigger than several square miles (at least at shallow depths). Areas bounded by 21°C (70°F) isotherms may delineate areas of recharge into the groundwater system. Because the wells are shallow, this down flow could be very thin-skinned and is not necessarily recharge for the deep flow system.

To test for the presence of a geothermal reservoir, a deep test well was drilled by Steam Reserve Corporation (SRC) in Section 7, T. 25 S., R. 19 W, on December 27, 1984. The well was located approximately 800 meters west of the surface trace of the Animas Valley Fault. From SRC notes, one objective of the well was to intersect the Animas Valley Fault, which was believed to dip westward. Only two temperature surveys were originally reported for well 55-7; the first was conducted on February 14,1985 by Schlumberger within 24 hours after drilling ceased at the total depth of 7,000 feet. The Schlumberger log shows a temperature peak of about 170°F (77°C) at approximately 1,200 feet, followed by a temperature reversal and an essentially isothermal zone from 1,800 to 2,600 feet. A second temperature survey was run on April 3, 1985 to a depth of 6,919 feet with a reported bottom-hole temperature of 326°F (163.3°C). The upper part of the well, from the surface to approximately 1,400 feet, exhibits an extremely high thermal gradient to a peak temperature of 304°F (151°C) before the profile reverses below 1,400 feet and has a negative gradient to about 2,500 feet. Below 2,500 feet to total depth, the thermal gradient profile appears to be generally conductive with only minor disturbances.

In late 1996, the well was re-entered by drilling out the surface plug, the plug at the bottom of the casing from 1,000 –1,050 feet, and possibly some of the plug from 1,400 to 1,500 feet. A temperature survey was run on October 18, 1996 to a recorded, but unverified, depth of 1,476 feet (450 m). A second temperature survey was run more than a year later on December 30, 1997 to a recorded depth of 1,355 feet (413 m). At least one short-term flow test was conducted on the well in 1998, and the produced fluid at 475 gpm maintained a steady wellhead temperature of 307°F (152°C). The well is currently shut in and sealed. Figure 3 is a composite log of TFD 55-7 that shows lithology, selected geophysical logs, and data from temperature surveys.

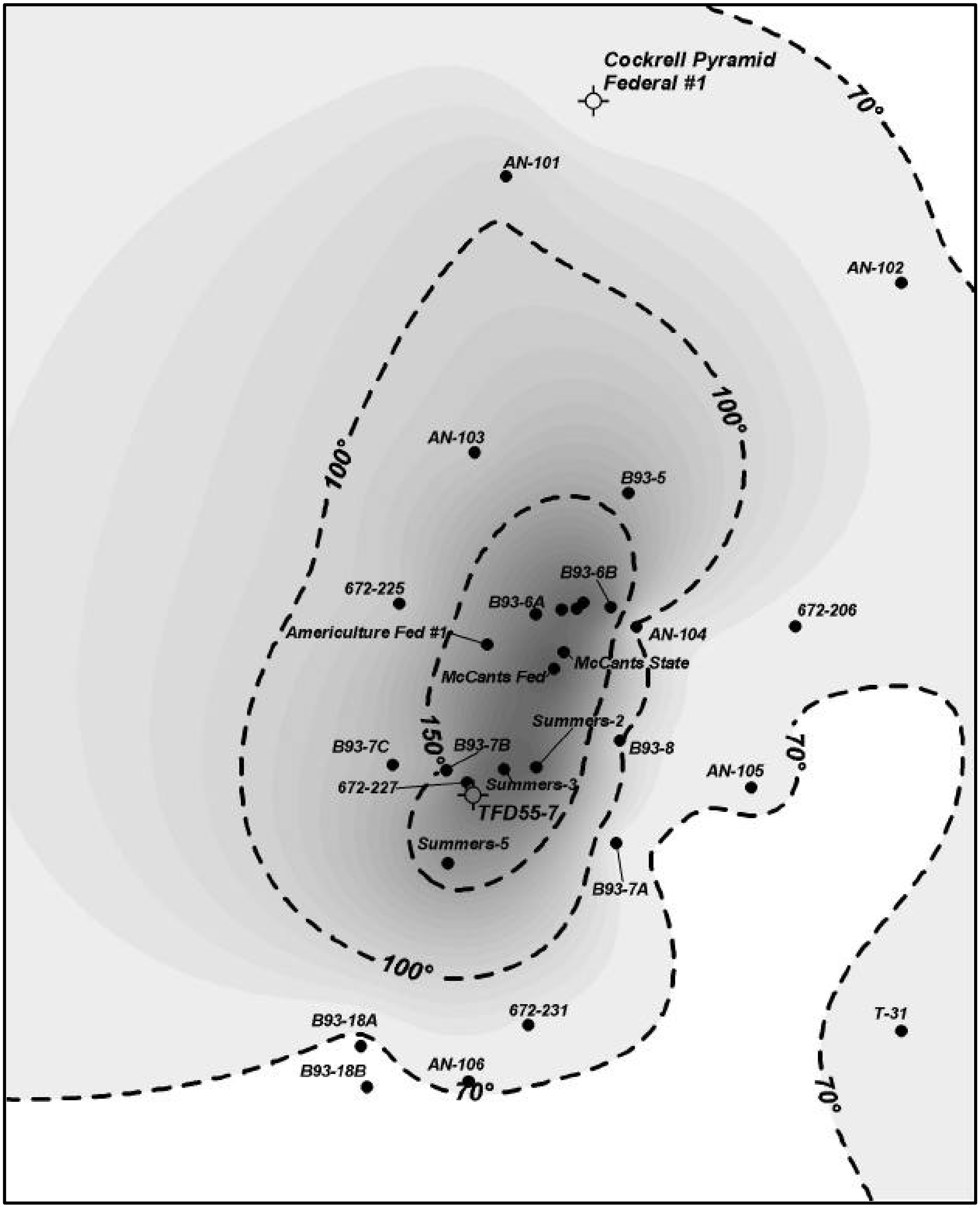

Figure 2. Distribution of temperatures in shallow subsurface, Animas Valley, New Mexico. (Data source, Bowers, 2001c)

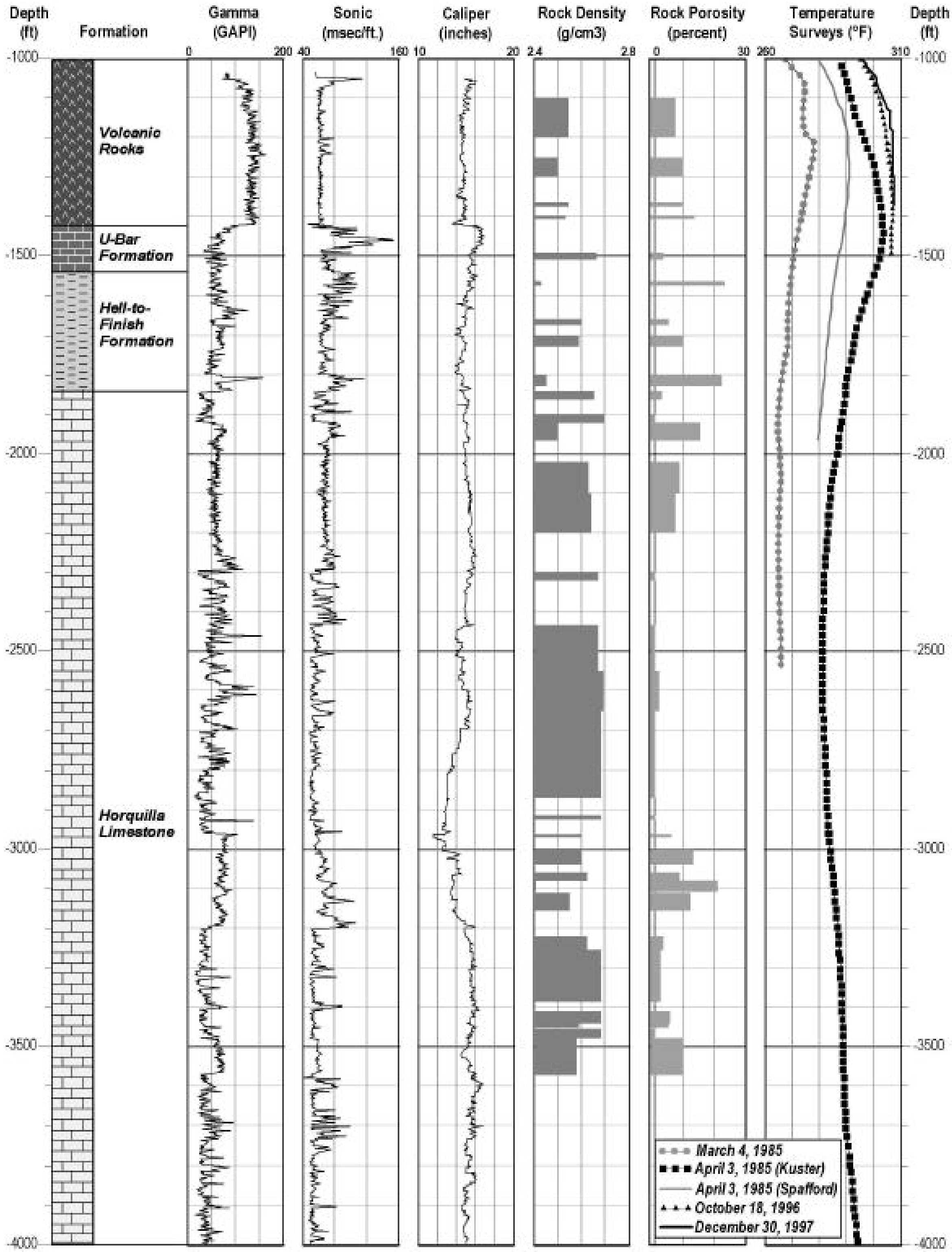

Figure 3. Composite log of well TDF-55-7, Lightning Dock Geothermal Area. (Data Source, Bowers, 2001c)

Structural Data and Interpretations

Bowers (2001b), with the assistance of Schlumberger, reanalyzed the geophysical logs acquired after drilling of well 55-7 . In addition, using data supplied by Cunniff (2001a), Bowers reinterpreted the likely structural controls for the shallow hydrothermal resource. Concerning the deeper structures and formations, particularly the Horquilla limestone from 2,000 to 4,000 feet of depth, Bowers (2001c) deduced that the subsurface structures and formations appear to be consistent with the mapped northern extent of the Cordilleran Overthrust Belt which Corbitt and Woodward (1973) depicted as terminating just north of well 55-7. In addition, Bowers (2001a), reanalyzed aerial photographs of the Animas Valley acquired in 1956, and showed that a number of linear features are clearly visible; this factor suggests that the "hot well" area likely is marked by a large number of northward trending faults or fractures.

Blackwell and Wisian (2001) reanalyzed and reinterpreted gravity measurements in the vicinity of the "hot wells" (Smith, 1978) together with regional gravity values to depict a pattern of probable faults and fault intersections. Their analyses indicate that a major lineament, striking roughly WSW to ENE appears to have displaced and rotated the upper Animas Valley. In addition, this lineament appears to intersect the likely strike of the Animas Valley Fault near the "hot wells" area.

Electromagnetic data (resistivity, telluric, magnetotelluric), and magnetic data summarized by Smith (1978) provide little insight onto the deeper parts of the system, but are consistent with a horst block associated with the geothermal system. Quadripole resistivity shows valley structure that agrees with the gravity interpretation above, and reveals a small low resistivity area to the north, east, and south of the shallow geothermal production wells. Assuming low resistivity equals hot water (at least in the shallow subsurface near the anomaly), the hot water might rise at least as far to the east as the low resistivity zone (about 0.5 km, 1,640 ft, east of well 55-7). Sketchy electrical data hint at a magma body 7 km (~23,000 ft) below the geothermal site (Jiracek, 1981), but this magma body is unsupported by other data and seems geologically very unlikely.

Hydrology and Geochemistry Data and Interpretations

As reported by Cunniff (2001b), shallow geothermal production wells have demonstrated a well specific yield of about 100 gallons per minute (gpm) per foot of drawdown which correlates to a transmissivity value of about 20,000 gallons per day (gpd) per foot of saturated thickness. Irrigation wells have a transmissivity value of about 50,000 gpd (O'Brien and Stone, 1984). The single deep well, 55-7, has produced a well specific yield of about 3.4 gpm per foot of drawdown, but this production is from a few, very minor fractures at about 1,250 feet, and this yield is much smaller than would occur for a properly sited deep well which would intersect one of the major fault structures serving as a conduit for ascending geothermal water. It is reasonable to expect relatively high fracture permeability, and new hydrothermal wells could be expected to produce specific yields in the range of 30 to 40 gpm per foot of drawdown, or even higher.

Production of shallow geothermal water has been used for more than 20 years, and current production for greenhouse heating and other purposes is about 4,000 gpm at peak load. All of this production is permitted for surface disposal; currently, reinjection is not practiced nor required.

There are no indications that this extensive usage has caused permanent draw down of the shallow geothermal system. The average static water level at the hot wells was 30 feet in 1948 (Kintzinger, 1956), and this same water level was estimated by O'Brien and Stone (1984) to have existed in 1916 when Schwennesen (1918) performed his initial hydrological studies in the Animas Valley. However, also by 1948, over pumping of irrigation wells had created a groundwater low of about 96 feet below historical levels in an area centered about 2 km southwest of the hot wells (O'Brien and Stone, 1984). Current static water level at the hot wells is about 70 feet and this level has been maintained for about 10 years. This lowered static water level in the shallow geothermal wells is believed to represent a natural, valley-wide process in which new equilibrium levels have been reached as production from irrigation wells has been sharply reduced as the agriculture industry has declined from its 1948 historic high.

Klein (2001), evaluated chemical and temperature data for roughly 80 wells in the geothermal region. Combined chemical and temperature data indicate that the hot wells of the Lightning Dock area are fed by a shallow component of the geothermal aquifer at a temperature of about 115°C (240°F) which contains $Na\text{-}SO_4$ water of a type that is generally characteristic of moderate-temperature geothermal systems (roughly below a maximum of 180°C). Cation geothermometers are consistent with equilibration of this water at about 150°C (300°F) in a deeper aquifer (which correlates with temperature of 307 °F measured in pumped flow in well 55-7 produced from a depth of about 1,250 ft), and at yet higher temperatures of about 175°C (350°F) in some as yet undefined but still deeper source.

Thermal water ascends in the vicinity of the hot wells and then disperses and cools in the shallow valley aquifer primarily to the north-northeast, and slightly to the southwest. Figure 4 depicts the probable shallow surface flow patterns from the shallow geothermal anomaly.

Integrated Resource Model of the Lightning Dock Resource

High temperatures in the 400 m (1,320 ft) depth range imply circulation of the geothermal fluid to great depth before it is discharged. This theory is supported by geochemistry, which gives no indication of magmatic waters, and the lack of any other geological or geophysical evidence of a magmatic heat source. Elston et al. (1983) have suggested, based on fluid geochemistry, that deeper fluid has temperatures of 250°C (482°F). This would require water circulation to depths between 6 and 8 km (about 20,000-26,000 ft), depending on assumptions, and correspondingly deep, continuous structures. Other interpretations of the geochemistry favor temperatures not much higher than presently observed in well 55-7. In either case, circulation to a depth of at least 5 km (16,500 ft) is required. As stated above, there is no evidence that young magmatic activity contributes to the heating of the water. Thus deep circulation and upflow along major structures is the best model for the deep system. The question for resource development is what are these deep structures?

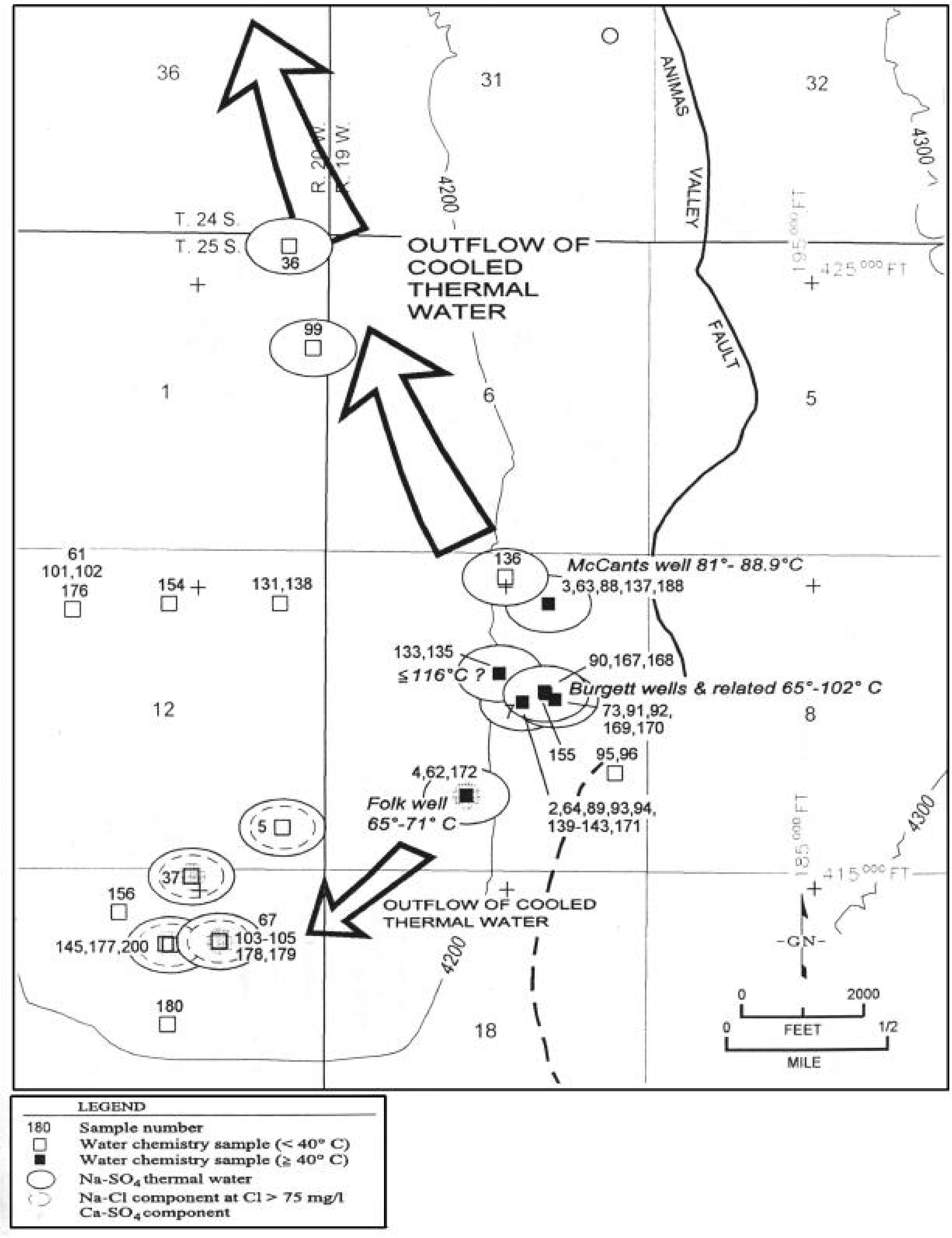

Figure 4. Flow patterns of shallow geothermal waters. (Data Source, Klein, 2001)

From available data and interpretations, the Animas geothermal resource originates in an extremely complex geologic setting. Together with regional overthrust blocks, extensional forces, Tertiary structures, volcanics and cauldrons, and a pattern of very recent faults and fractures, there has been a series of igneous intrusions into the subsurface formations. Certain of the linear features identified on air photos are likely to be extremely young because they appear to displace modern arroyos which formed since Lake Animas receded in the past few thousand years.

In this complex geologic setting, one prominent feature is the Animas Valley Fault as mapped by numerous geologists. Given the apparent complex faulted structure that now has been identified, more properly this should be considered to be a fault zone, in which several en echelon faults may serve as near-vertical conduits for geothermal water ascending from a probable recirculating heat-flow-equivalent depth of 5 km (16,500 ft).

Blackwell and Wisian (2001) proposed the preferred conceptual model for the Animas geothermal system. In this model, geothermal fluid upflow is postulated from depth along an extensional structure(s) striking north-northwest and/or northeast (or some combination) with unknown dip, probably to the north or northwest, with major outflow into the shallow subsurface. The likely structural configuration could produce significant volumes of geothermal fluid ascending in fault conduits at a temperature higher than 150°C (300°F) at relatively shallow depths (less than one km).

One significance of the proposed model is that well 55-7 was not optimally sited so as to intersect one of the major ascending fluid conduits; however, it likely was drilled within about 0.5 km from one of the probable major fault conduits, but did not intersect it. In addition, the postulated model suggests there is reasonable confidence that a properly sited well would intersect a major fault conduit for ascending fluid at high production rates and at a temperature of about 155-160°C (310-320°F) at depths shallower than one km.

The preferred model consists of the following features:

- Flow up a steeply dipping fault or fault intersection (dip to the northwest or west-northwest), not intersecting, but passing under well 55-7,
- Discharge (at 150°C. 300°F) in an aquifer at about 400 m (1,320 ft)
- Discharge (at 110-120°C, 230-248°F) into a permeable zone slightly below the water table, movement down slope to the northwest and further cooling and dilution.
- Animas Valley Fault is located to the east of the well.

Figure 5 portrays the preferred Blackwell and Wisian model. This represents what we term as the Integrated Resources Model.

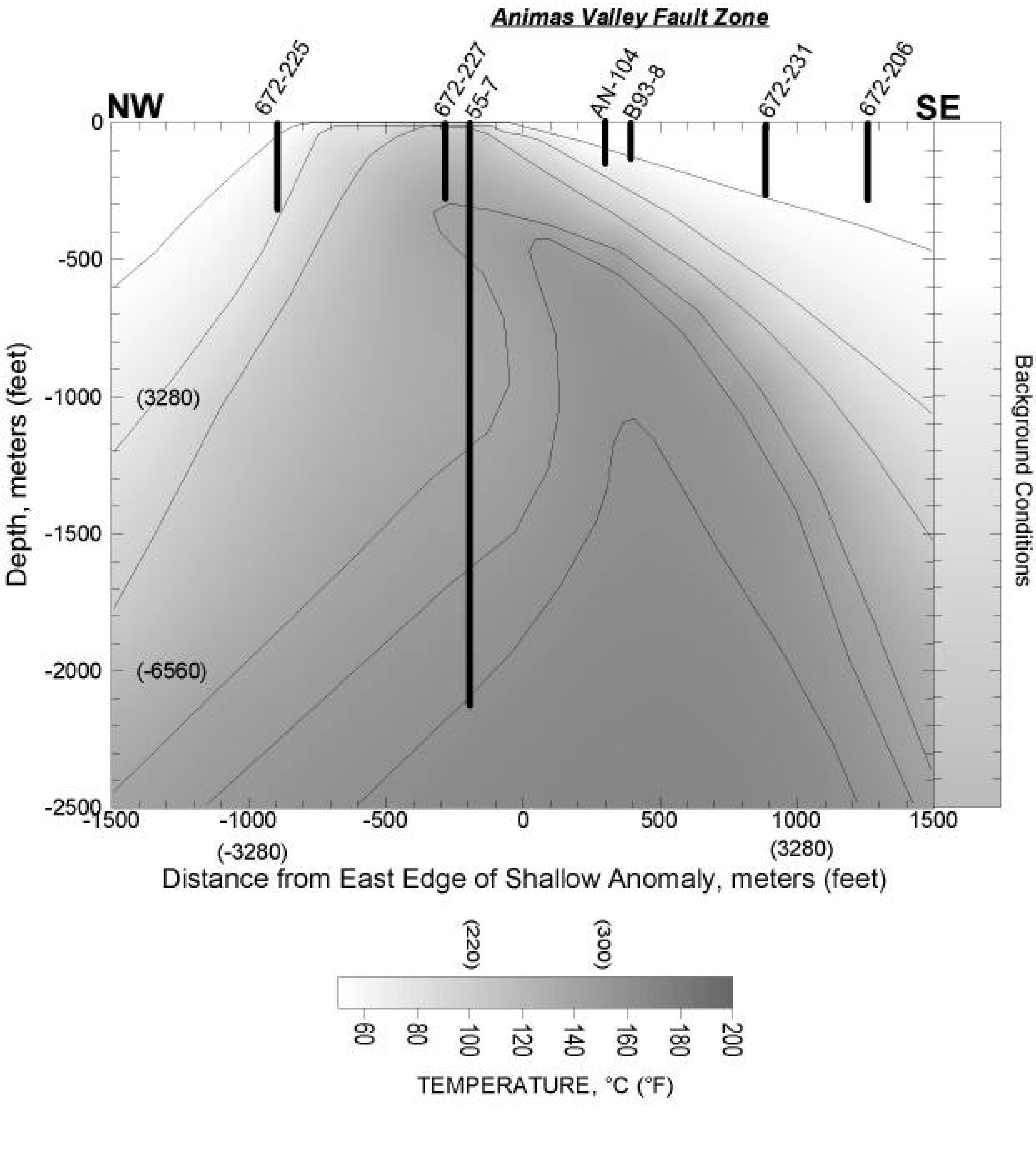

Figure 5. Cross section of a conceptual model of the Lightning Dock Geothermal System. (Data Source, Blackwell and Wisian, 2001)

The available data set from Lightning Dock is useful in defining the extent of the shallow and intermediate hydrothermal systems, to a depth of approximately 3,500 feet, but there are very few data on the conceptual EGS reservoir, the Horquilla limestone formation encountered in Well 5-7 from roughly 2,000 to 4,000 feet of depth. Since only one well (55-7) penetrates this formation, its extent and geometry can be inferred only from regional geology and data from the geophysical logs run in well 55-7. Examination of Figure 5 suggests that the Horquilla limestone formation likely is at a temperature in the range of 280 to 320 °F. Moreover, from Figure 5, the lateral extent of this formation conservatively can be assumed to be at least 3 km wide, and presumably can extend northward for at least two km. Hence, this massive limestone formation has a likely volume of about 6 cubic km, and the prospective reservoir volume easily could be double that value.

Granados (2001), used accepted volumetric reserves estimating methodology (following Muffler, 1978) to estimate potential productivity of this conceptual EGS reservoir. Granados improved this estimate by using a probabilistic approach to account for uncertainties in some estimated parameters. His Monte Carlo estimating techniques suggest, conservatively, that the EGS reservoir has the geologic potential to produce a most likely value of 9.3 MW of electricity, with an 88 percent probability that the recoverable resource will exceed 6 MW.

A similar, but less rigorous analysis was done by Cunniff, 2001e, following Muffler's methodology, and the hydrothermal resource of the Animas Valley potentially could produce between 45 and 55 MW, with a high percentage probability that the recoverable resource would exceed 25 MW. The hydrothermal resource is estimated to be much larger than the conceptual EGS resource primarily because the EGS resource is limited by the thickness of the Horquilla Formation (from Well 55-7 data), and also limited by the northerly extent of the Cordilleran Overthrust Belt. In the Peloncillo and Animas Mountains, the Horquilla limestone is as thick as 3,000 feet. Hence, the northerly extent of the Horquilla is very much undetermined at depth; the width (E-W axis) at 4,000 feet of depth likely is wider than the 3 km width depicted in Figure 5, but the true width is unknown. A further cause for the much larger estimate for the hydrothermal resource is based on the fact that the hydrothermal resource extends to a confirmed depth of 7,000 feet, so the potential reservoir volume is much larger.

Given the Integrated Resource Model defined above, subsequent sections of this report summarize the key research elements defined for the remaining EGS Project tasks. The overall theme of this research plan is to demonstrate that a Combined Technologies Power Plant (EGS and hydrothermal) in the size range of about one MW from the EGS resource and 5.5 MW from the hydrothermal resource (6.5 MW, with 6 MW net to the grid) would produce a commercially viable project that would demonstrate the commercial usability of both the EGS resource and the hydrothermal resource. Hence, the research plan is focused on the need to explore for and develop both the hydrothermal and the EGS potential resources.

3.0. DISCUSSION OF TASKS TWO, SIX, AND SEVEN: EXPLORATION AND DEVELOPMENT PLANS

Research Concept

Discussion in this section of the report is used to summarize the research work defined in completion of the Task Two activities to develop the Drilling Plan, Fracturing Plan, Surveillance Plan, the Well-bore Logging Plan; the Task Six activities including developing the final draft of the Implementation Plan; and the Task Seven activities including the Fracturing Plan, the Drilling and the Drilling Mitigation Plans.

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The Lightning Dock Combined Technologies EGS Project seeks to optimize the extraction of geothermal energy from two relatively shallow, moderate-temperature reservoirs: a conventional hydrothermal reservoir at 1,200 to 3,300 feet, and an EGS reservoir at 3,000 to 4,000 feet. The ***explored*** portion of the Lightning Dock hydrothermal resource is relatively small; however, reservoir evaluation studies suggest the realistic potential for recoverable hydrothermal/EGS energy could be in the range of 25 to 50 MW. Accordingly, a significant amount of heat is present in both the hydrothermal and the conceptual EGS reservoir. The proposed project takes advantage of both resources

The extent and geometry of the Horquilla Formation are proposed to be resolved by a comprehensive exploration plan that includes the acquisition and evaluation of additional surface geophysical data, coupled with a drilling program that includes intermediate depth (~2,500-foot) temperature gradient holes, deeper (3,500 to 4,000-foot) core holes, and ultimately, full-diameter wells drilled to the EGS reservoir (3,000 - 4,000 feet in depth). A full suite of data will be collected from these wells, combining conventional well logging techniques with modern, digital methods. Concurrently, an active exploration program will be completed to define the extent and productivity of the intermediate depth hydrothermal reservoir.

The validation plan for the proposed project is based on exploring and defining the productivity of: (i) the hydrothermal resource at a depth of approximately 1,200 to 3,300 feet, and (ii) the EGS resource at a depth of about 3,000 to 4,000 feet. For both geothermal reservoirs, these depths are shallower than many commercial hydrothermal prospects. The wells will be sited on the basis of the geological models prepared during this Phase I Study, to be confirmed during subsequent exploration activities by the acquisition of additional surface geophysical measurements, data from intermediate depth temperature gradient holes and core holes, completion of a slim hydrothermal well to 3,300 feet, and long term pumped flow tests on the existing deep well 55-7.

Research and Development Planning

A thorough research plan was developed by the project team, and is included in Cunniff, et. al. (2001), and Granados (2001). Key elements of this plan were the time-phasing of critical tasks so that a logical sequence of research elements required successful completion before the program could be allowed to continue to the next sequential research element. This integrated Milestone Exploration and Development Plan is depicted in Table 2.

Table 2. Milestone Exploration and Development Plan.

<table>
<tr><th>TASK</th><th>COMPLETION (Months)</th></tr>
<tr><td>Basic Research
Structure Definition
Project Report</td><td>Nine Months
(Starts April 1, 2001)
Delivered December 1, 2001</td></tr>
<tr><td>EGS Task One
Permitting
Environmental Clearances
Start Power Sales Marketing
Project Coordination
Technical Task No. One
a. Reenter well 55-7 to 1,400 feet and log
b. Conduct 24 to 48-hour flow test
c. Well remediation
d. Conduct new temperature surveys
e. Reenter Cockrell Pyramid Fed #1 to 4,000 ft, acquire new geophysical logs
f. Acquire new temperature logs
g. Reenter well 55-7 and open it to 4,000 feet; acquire new geophysical logs
h. Revise Structural Interpretation
Prepare Task Report</td><td>Seven Months
(Starts June 1, 2001)
Delivered December 31, 2001</td></tr>
<tr><td>EGS Task Two
Permitting
Environmental Clearances
Continue Power Sales Marketing
Project Coordination
Technical Task No. Two
Drill 3 gradient holes to 2,500 ft
Geo and temperature logging
Structure evaluation
Prepare Task Report</td><td>Five Months
Delivered May 31, 2001</td></tr>
<tr><td>Completion of Sequence One</td><td>Complete May 31, 2002</td></tr>
</table>

Table 2. Milestone Exploration and Development Plan (Continued)

EGS Task Three; Permitting Environmental Clearances Continue Power Sales Marketing Project Coordination *Technical Task No. Three* Drill 2 core holes to 4,000 feet Evaluate by logging and testing Conduct core analyses Prepare fracturing plan Prepare Task Report	Six Months Start Aug 31, 2002 **Delivered February 28, 2002**
EGS Task Four; Permitting Environmental Clearances Continue Power Sales Marketing Project Coordination *Technical Task No. Four* Drill Slim Hydrothermal Test Well Prepare Task Report	Two Months **Delivered April 30, 2002**
EGS Task Five; Permitting Environmental Clearances Continue Power Sales Marketing Project Coordination *Technical Task No. Five* 48-hour flow test slim hydrothermal well Prepare Task Report	One Month **Delivered May 31, 2002**
EGS Task Six; Permitting Environmental Clearances Finalize Power Sales Agreement Prepare Power Plant Design Prepare Financing Plan for Project Project Coordination *Technical Task No. Six* 30-day flow test of 55-7 Prepare Task Report	Two Months Two Months **Delivered September 30, 2002**
Completion of Sequence Two	**Complete September 30, 2002**

Table 2. Milestone Exploration and Development Plan (Continued)

EGS Task Seven; Permitting Environmental Clearances Finalize Power Sales Agreement Project Coordination Technical Task No. Seven Drill EGS Production well Prepare Task Report	**Starts November 1, 2003** Two months Two months **Delivered March 1, 2003**
EGS Task Eight; Permitting Environmental Clearances Execute Power Sales Agreement Project Coordination Technical Task No. Eight Fracture EGS production well Imaging Logs Fracture support operations Prepare Task Report	Four months Two months **Delivered September 1, 2003**
EGS Task Nine; Permitting Environmental Clearances Coordination Technical Task No. Nine Drill EGS Injection well Prepare Task Report	Two months One month **Delivered December 1, 2003**
EGS Task Ten; Permitting Environmental Clearances Project Coordination Technical Task No. Ten Flow Test EGS Well set Prepare Task Report	Two Months Three Months **Delivered May 1, 2004**
Completion of Sequence Three	**Completed May 1, 2004**
EGS PHASE III	
Combined Technologies Power Plant, 6 MW (Net)	One-year construction. **Completion planned for May 1, 2005** Two years operation; to be operated through May 1, 2007

4.0. DISCUSSION OF TASKS 4 AND 5: POWER SALES, WATER AND ENVIRONMENTAL

This section of the report covers a summary of work completed to assess local area electrical loads and the prospects for developing a power sales agreement. In addition, this section provides a summary assessment of the water requirements and controlling regulatory concerns relative to the issues of water rights.

A major work effort for Task 5 was the evaluation of potential environmental concerns, and a summary of that work is included herein.

Evaluation of potential electricity sales

Existing Electrical Service: Burgett's greenhouse complex is served by a separate service connection from Columbus Electric and Distribution Cooperative Inc. (CEDC). This service terminates in a distribution bus from which Burgett has installed and owns separate inter connections for his primary uses, including; irrigation wells, air cooling operations; geothermal wells and his greenhouse complex. The AmeriCulture, Inc. fish operation has separate connections from CEDC at the fish farm, and the well used to supply fresh water for the fish farm and for domestic consumption. The McCants operation is limited to a service connection for his residential use.

Potential Electricity Sales to Local Users: The Burgett operation is the largest load in the immediate area: with a total connected load of about 1,000 KW; however, they would like to have more power for "grow lights" to increase overall growing productivity, and would do so if there was a reliable source of lower cost electricity. The AmeriCulture fish farm located near the Burgett greenhouse complex has a very small connected load for their current operations: probably not more than 75 KW. The firm has developed plans for a major expansion, which would entail the use of up to 2.0 MW.

Other Industry near the Animas Valley: Industry consists of several seasonal cotton gins, several small manufacturing businesses, and a seasonal chile processing plant. The major industry near the Valley was the Phelps Dodge Corporation smelter located about 20 miles southeast, which was placed on standby two years ago, and in full operation used 10 MW of firm power and about 8–10 MW of interruptible power. The smelter is serviced by a 150 Kva transmission line, originally built and owned by Plains Electrical Production and Distribution Cooperative. This transmission line was sold to Public Service Company (PNM) of New Mexico in 2000 when Plains was acquired by TriWest in 2000. Selling electricity to any local users in the Animas Valley would entail a cooperative agreement with CEDC, and also with TriWest, because the latter is the only authorized producer of electricity for all the cooperatives in New Mexico. All of the distribution cooperatives in New Mexico must purchase power only from Plains (now TriWest).

Electrical transmission lines: In the vicinity of the site, output from a geothermal power plant can interconnect the proposed geothermal power plant directly with Columbus Electric Cooperative, the local electricity provider. Transmission is available to Public Service of New Mexico, El Paso Electric and Arizona Public Service. The site can supply power into three states as well as the local area. Power line rights of way: Any new interconnecting power lines would follow existing rights-of-way for existing county and state roads in the area, or within the same corridor for which environmental clearance has already been given for Columbus Electric power lines. If the entire output of electrical power is sold to local and contiguous users, the intertie lines would connect with the Columbus Electric Cooperative, Inc. If it is necessary to construct a new interconnecting power line, the nearest major intertie point is located northwest of Lordsburg, entailing about 20 miles of power line construction.

Selling Electrical Power to the Grid: Public Service Company of New Mexico (PNM) owns and operates a 345 Kva transmission line in the vicinity of Lordsburg. This power line is shared with El Paso Electric Company (EPEC) and Texas New Mexico Power Company (TNP). Also interconnecting in Lordsburg is a 115 Kva line owned and operated by TNP and which provides service to Central, New Mexico, located about 50 miles to the NE. These companies will be the targets for marketing the power from the commercial scale geothermal facility.

Current Electricity Cost: Rates in the local service area as of December 31, 2000, with an average consumer cost across all rate classes of $0.0927 per KWH, clearly indicate that geothermal power will be cost effective when compared to the prices the consumers in the area are actually paying. It should be noted that the CEDC filed a rate plan with the New Mexico Public Regulatory Commission for a rate reduction. When that plan is adopted, a representative of CEDC advised that there will be a reduction of about 5 percent across all rate classes.

Market Development

The preceding information summarizes the Hidalgo County marketing opportunities for electrical power generated at the Lightning Dock resource area. Legislation at the state and federal level is trending toward the encouragement of the use of renewable energy either by the use of Renewable Energy Portfolio Standards, System Benefits payments, or Green Power Initiatives. In addition the US Government is requiring its facilities to obtain more of their power from renewable energy sources. All potential users will be contacted in an effort to establish a power sales arrangement, at a price that supports the project's economic feasibility.

Coincident with project exploration and development, ORMAT and LDG will approach all of the private sector entities named above as well as the state, local and federal governmental agencies to market the power from the Combined Technologies power plant, either as a single block or in multiple blocks this has been made possible by recent legislation. The New Mexico Legislature enacted The Electric Utility Industry Restructuring Act of 1999, with partial implementation beginning in January 2001. As part of this statute, the Legislature directed that the New Mexico Public Regulatory Commission establish rules and procedures leading to the development of the renewables power resources in New Mexico. Geothermal energy was specifically identified as a renewable resource in this statute. Pursuant to this statute, the Commission has developed and published a Final Order as Utility Case 3102. Under the provisions of this Order, the Commission has directed that the following actions shall be taken:

- Define a group of consumers who are subject to the Renewables Portfolio Standard Offer. In this case, that group consists of residential consumers and small power users (less than 50 KW connected load.
- Require electric utility companies to purchase a minimum of 5 percent of the power for customers in the Standard Offer categories from renewable energy sources produced within New Mexico.

- Establish a pricing cap on the power purchased from renewable sources in New Mexico to be not more than $0.001 (one mil) per KWH larger than the power available from other non-renewable resources.

<u>Long-Term Potential for Power Market</u>

Analyses of the current price paid by Standard Offer customers in New Mexico indicates that, depending on the supplying utility company, the price paid by these customers is in the range of $0.095 to $0.1331 per KWH. Thus, to qualify under Case 3102, the renewable resource must sell the power at a price not more than $0.001 per KWH higher than the existing price. The PRC Final Order on Case 3102 has not yet been fully implemented pending a decision in March 2001 by the NM Legislature to delay implementation of the Electric Utility Industry Restructuring Act for five years. In addition the following actions have been initiated to establish the potential for a long-term power market:

- Coordination for renewable sales has been made with each of the four utility companies who provide service affected by the Standard Offer: Public Service Company of New Mexico (PNM), El Paso Electric Company (EPEC), Southwestern Public Service Company (SWPS), and Texas New Mexico Power Company (SWPS). Electricity Distribution Cooperatives specifically were exempted by the new statute from the requirements of the Standard Offer. In aggregate, these four companies are providing about 1,000 MW to Standard Offer Customers. Accordingly, within the provisions of Case 3102, an immediate potential exists for sale of up to 50 MW of renewable power generated in New Mexico. Only geothermal power can effectively meet this requirement in the coming period.

- Specific marketing approaches were made to PNM and SWPS. In the case of the latter company, they currently are selling about 1.0 MW of wind energy produced in New Mexico to Colorado customers who have agreed to pay a premium of an extra of $0.015 to $0.02 per KWH for "Green Power". (The NM Restructuring Act makes provision for a similar premium offer for NM consumers, and this factor also is identified in the Commission's Final Order on Case 3102.) If geothermal energy were available right now at a price lower than $.065 per KWH, a power sales contract likely would be possible with SWPS. In a coordination meeting with the Chief Executive Officer for PNM, we were reassured that PNM has a long history of supporting geothermal power in New Mexico, and if we had 50 MW immediately available, they would buy it at the current market price for sale to other states. This conference concluded with an understanding that Ormat/LDG would submit a specific proposal to PNM. It should be noted that if the federal renewable production tax credit, currently available to wind energy projects, is extended to geothermal, as proposed by both political parties in the US Senate, the price of power from the Combined Technologies power plant could be sold at a net 2001 price of less than $0.060/KWH!

- A coordination meeting was held with a representative of the DOE Albuquerque Operations Office (AAO) concerning the possibility of selling renewable power to DOE. The AOO recently completed contract negotiations for 1.0 MW of wind power to be sold by SWPS to the DOE Waste Isolation Pilot Plant. The DOE AOO was able to establish the contractual sale solely because they were able to show within the budget that the purchase of this renewable electricity was "revenue neutral" based on an offset in cost provided by Sandia National Laboratories. (The price per KWH was not disclosed, but is believed to be about $0.085 per KWH.) This budgetary fluke could be a one-time transaction. However, the DOE

AOO representative did provide information that the combined electricity load for SNL and Kirtland Air Force Base was 40 MW, and the representative encouraged an action to follow up in the near future to determine if geothermal power sales could make reasonable market penetration of this sizeable demand.

Evaluation of project water requirements

The Combined Technologies Power Project would require consumptive water rights to be used for drilling make-up water, and water for reinjection into the subsurface formations as part of the EGS well set operation. Drilling make-up water needs are relatively small, and necessary water can be bought from the surface landowners. A much larger volume of water might be required for operation of the EGS well sets. Since all of the production from the hydrothermal wells sets would be reinjected as spent effluent from the power plant, then required amounts for the EGS well sets easily can be made available from the hydrothermal operations.

Reinjection wells permitted under the Underground Injection Control Program require completion of a formidable documentation package. The applicant must submit an inventory of all wells located within one mile of the proposed injection well. As part of this inventory, existing water quality must be documented. In addition, the applicant must satisfy regulatory concerns relative to the geological and hydrological structure in which the reinjection is proposed. To satisfy the information needs of the regulators, the submittal must include relevant documentary evidence to show that the formation is capable of safely accepting the injected fluids, and that the injection will be placed into a formation containing water of equal or greater dissolved mineral content. If the applicant is proposing pressurized reinjection, the applicant must provide documentation that the pressure will not cause either well or formation breakout. In addition, the applicant must provide documentation that supports the assertion that the injected fluids will not degrade potable ground water resources. As part of the application, the applicant must establish that all well owners within the one-mile radius have been notified. A public hearing will then be held at which any potentially affected well owner may state his objections to the process, and the applicant must provide compelling documentation that the protest, if any, can be accommodated.

The Ormat/LDG team has previous experience with this regulatory process, and has successfully permitted reinjection wells for other geothermal developments in the States of Nevada, Hawaii, and California. We understand the process, understand the need for documentation, and are confident that regulatory approval will be granted basis on a thorough and professional application.

In addition to the regulatory oversight maintained by the Underground Injection Control Program with the NM Environmental Branch of the Oil Conservation Commission, the NM State Engineer also has an oversight responsibility. The Animas Valley has been designated as a Closed Basin and also has been designated as the Animas Valley Declared Underground Water Basin by the State Engineer. These are administrative controls to assure that the State Engineer views the Animas Valley as fully appropriated, and has set in place special controls. First, the designation denotes that the Basin is fully appropriated, and no new appropriations will be issued. Secondly, any new applications for remedial water wells, replacement water wells, or new irrigation wells must use previously approved appropriation claims. In addition, all existing wells may be required to be equipped with meters to show proof of use. This latter step, termed perfecting the appropriation, is a control to assure that appropriations are proved out to the satisfaction of the State Engineer. When a situation arises in which the claimed appropriations exceed the carrying capacity of the basin, the State Engineer is empowered to adjudicate the basin. Under this procedure, as is now underway in the Lower Rio Grande Declared Underground Water Basin, the State Engineer carefully reviews all appropriations to determine the date of the appropriation, the documentation as to the degree of actual historical use shown by the applicant, and any special uses. Under the Special Hearing provisions, the State Engineer can approve, disapprove, or modify the claimed appropriations.

All of this State Engineer regulatory oversight plays an important role in reinjection wells. If the well is already permitted under the State Engineer as an irrigation well, then those ground water appropriations identified and linked to that well must be transferred to another well or retired.

The Ormat/LDG team has considerable experience working with the State Engineer, and we are confident we can provide adequate documentation to assure State Engineer approval of the required injection well or wells.

Another institutional problem could arise because of the ownership of the geothermal resource. As defined earlier in this report, the current LDG geothermal lease is a federal lease; additional applications have been submitted for State of New Mexico geothermal leases. The 20-year pattern of demonstrated use of the shallow geothermal resources has clearly shown that the resource exists in both the federal and state lands. There is no evidence to suggest that the federal and state geothermal resources are separate; rather, the geological, geophysical, and hydrological evidence already available clearly shows that there is only one geothermal reservoir.

It is conceivable that continued development of the Animas Valley resource could lead to potential conflicts between the federal and state leases driven by potential complaints that one or the other lessee is depriving another lessee of geothermal rights. An administrative solution to this potential problem lies in the Unitized Basin concept, under which each user has the right to a portion of the resource as controlled by surface land ownership, geological and hydrological factors. As the federal lessee, LDG has primacy on time of acquisition, as well as being the majority leaseholder in the area. Until such time as additional State leases are issued, LDG still holds the dominant lease position with 2,501 acres under lease out of a total of 2,854 acres now under lease between the federal and state leases. Thus, the LDG lease position represent current control of almost 88 percent of the currently issued leases.

One major area of institutional approval again involves the State Engineer. As discussed above, the State Engineer controls the issuance of appropriations for underground water resources in the Animas Valley. New Mexico follows the legal doctrine of prior appropriations, and under this doctrine, the oldest appropriations take precedence if an actual shortfall arises between claimed appropriations and actual beneficial use. Production of geothermal water from either the EGS well set or the hydrothermal wells will necessitate State Engineer approved permits and also must require State Engineer approval of the issue of subsurface water rights. Although use of the heat content of the water is governed by federal statutes, the use of the water conveying the heat represents an issue within the purview of the NM State Engineer.

The issue of consumptive water rights is very circuitous, and will require the services of a legal firm with sufficient experience and knowledge of NM water law. Ormat/LDG have retained the services of a competent attorney skilled in the nuances of water law. In addition, the use of negotiated use agreements along the lines as discussed above should serve as both preventative actions as well as a built-in cure for any disputes that might arise. Accordingly, although this is a potentially contentious issue, Ormat/LDG believe that we have both the appropriation rights as well as the administrative controls to assure that the issue of consumptive water rights does not adversely affect geothermal development of the Animas Valley resources.

Develop NEPA Compliance Plan

Thorough and complete environmental planning was reported by Cunniff, 2001e. Included in the overall environmental studies was a comprehensive Environmental Checklist, together with a definition of the regulatory path to be followed for NEPA compliance. The Environmental Checklist evaluated some nineteen different environmental categories, and provided a complete evaluation of possible environmental hazards. For none of the categories was there any significant environmental degradation expected for the exploration, development, and completion of the conceptual Combined Technologies Power Plant. Separate categories were evaluated for the projected emissions, geothermal effluent disposal, and drilling mitigation planning. In addition, Safety and OSHA potential issues were evaluated.

Also included by Cunniff (2001e) was a comprehensive evaluation of regulatory procedures to be followed in completing the exploration, development, construction, and operating activities associated with the conceptual Combined Technologies Power Plant. The proposed project would comply with procedures established by the Bureau of Land Management and the State of New Mexico. In the latter category, compliance must be attained with provisions of New Mexico statutes and regulations overseen by the New Mexico Engineer, New Mexico Environmental Department, New Mexico Office of Cultural Affairs, the New Mexico State Land Office, and the Geological Branch of the New Mexico Oil Conservation Commission which regulates underground injection control. The project would comply with Federal and New Mexico permitting requirements.

As project planning continues, all of the potential regulatory and environmental concerns will receive continued evaluation. It can be expected that for a project as large as the conceptual Combined Technologies Power Plant, with potential for considerable environmental disturbances, that a forma Environmental Assessment would be required by either the Federal or State of New Mexico.

5.0. DISCUSSION OF TASK 3: POWER PLANT AND ECONOMIC MODEL

This task uses information developed by analyses completed in the other tasks. The parameters governing geothermal fluid temperature and flow rates; well siting, drilling, completion and testing, and access to land surface and interconnecting electric utility lines have been developed in other tasks. Based on these parameters, a conceptual power plant module has been developed, along with the geothermal well field to support the power plant. This section of the report then provides a definition of key parameters, with the resulting power plant and well field cost estimates, followed by an evaluation of the projected busbar selling price for geothermal power.

Because of its similarity to many other geothermal systems in the western United States, the development program for Lightning Dock could represent the template for development of a high number of similar geothermal targets throughout the western United States. Based on existing drilling data, Blackwell *et al.* (2001) identified 18 undeveloped geothermal systems in Nevada and three in Utah that have a high probability of equaling or exceeding the size, temperature, and/or production rate of the Lightning Dock geothermal system. In addition, successful EGS development at Lightning Dock could open the way for exploration and development of up to 100 as-yet undiscovered sites that are believed to exist in the Basin and Range Province. Therefore, the advancement of this project could significantly support expanding the U.S. supple of hydrothermal electricity.

Developing both the hydrothermal and EGS components of the Lightning Dock system has resource development implications of at least one to two orders of magnitude beyond the hydrothermal system alone. Economic analysis indicates that the system, as presently known, would support a commercial hydrothermal development. With relatively small enhancements, the Lightning Dock resource (and many similar systems in the Basin and Range Province) will become economic under present, or near future, market conditions. Furthermore, intermediate and deep drilling into these as-yet untapped geothermal systems, which were not explored or drilled owing to the electrical power market uncertainties of the last decade, may reveal higher temperatures and more extensive reservoirs from existing shallow data.

Successful commercialization of EGS requires that the productivity of the EGS reservoir be comparable to the productivity of natural hydrothermal reservoirs. In addition, drilling depths and costs must be compatible with commercially acceptable renewable power generation economics, and surface development equipment must be proven, reliable, and cost effective. The development plan proposed for the Lightning Dock resource addresses these issues directly.

The EGS injection/production well-set in this limestone formation should produce at least 1,000 gallons per minute of EGS fluid at well head temperatures between 280 and 320°F. Production losses of the EGS fluid into the limestone formation is estimated, based on the experience of others, to be less than 10 percent and possibly as low as 5 percent. This amount easily is available using cooled effluent from the hydrothermal power plant. For the anticipated temperature range, the geothermal power plant will use field proven ORMAT air cooled, binary modular power plant technology, which has near zero emissions with 10 percent injection of all fluids and gases from moderate temperature geothermal resources.

This study has focused on the generation of power for commercial sale to New Mexico electricity suppliers as well as possible on-site use for agricultural industry. For comparison of capital costs of various size Combined Technology geothermal power plants, capacities of 3,000 and 6,000 kW have been considered.

Table 3. Capital Cost of Combined Technologies-EGS Power Project Facilities.

Net Power Output (kW) (Nominal)	**3,000**	**6,000**
Flow Rate (#/h) at 280^{o} F	1,860,000	3,700,000
Flow Rate (gal/min)	3,990	7,940
Total Cost of EGS Well Set (note 1)	4,000,000	4,000,000
No of Hydrothermal Wells @ $500,000 each	2 prod./1 inj.	5 prod./2 inj.
Total Well Costs in (US $)	5,500,000	7,500,000
Estimated Power Plant Cost (US $) (note3)	6,090,000	10,600,000
Estimated Additional Development Costs (US$)	1,500,000	2,000,000
Total Plant and Field Cost (US$)	**13,090,000**	**20,100,000**
Flow Rate (#/h) at 300^{o} F	1,420,000	2,490,000
Flow Rate (gal/min) (note 2)	3,100	5,420
Total Cost of EGS Well Set	4,000,000	4,000,000
No. of Hydrothermal Wells @ $500,000 each	1 prod./1 inj.	3 prod./2 inj.
Total Well Costs in (US $),	5,000,000	6,500,000
Estimated Power Plant Cost (US$)	5,940,000	10,100,000
Estimated Additional Development Costs (US$)	1,500,000	2,000,000
Total Plant and Field Cost (US$)	**12,440,000**	**18,600,000**
Flow Rate (#/h) at 320^{o} F	1,170,000	2,090,000
Flow Rate (gal/min)	2,580	4,610
Total Cost of EGS Well Set	4,000,000	4,000,000
No. of Hydrothermal Wells @ $500,000 each	1 prod./1 inj.	3 prod./2 inj.
Total Well Costs in (US$)	5,000,000	6,500,000
Estimated Power Plant Cost (US$)	5,400,000	9,700,000
Estimated Additional Development Costs (US$)	1,500,000	2,000,000
Total Plant and Field Cost (US$)	**11,900,000**	**17,900,000**

NOTES to TABLE 3

1. *EGS well sets consist of one production well and one man-made fractured injection well.*
2. *It is assumed that the EGS well sets will produce 1,000 and each hydrothermal production well will produce approximately 1,500 gpm. These are very conservative values, and realistic production rates could be much higher.*
3. *The power plant costs are based on prices from ORMAT Industries, Ltd. and include all items for an EPC turnkey supply and installation of the complete facility, including well field piping pumps etc. Additional development costs include utility interconnection costs, transmission lines and finance soft costs. These will be defined during the design tasks for Phase II.*

For the 6 MW plant the capital cost of the Combined Technology power project facility ranges from $ 3,230/kW to $ 2,950/kW. However a pure EGS power plant would have an installed cost of approximately $ 28,000,000 to $30,000,000, or $5,000/kW. The financial parameters for the Combined Technology Plant as proposed herein, with a projected power sales price of $0.075 in 2001 is approximately 80% of the average power price to consumers in Hidalgo County. At $0.135/kWh, the price of power from an EGS power plant could be economical within the overall time frame proposed for this project.

Table 4. Financial Model Assumptions – Combined Technologies Plant

Financed Capital Cost:

-Power price in 2001:		$0.075/kWh
-Annual escalation:	Power price	2.0 %
	O&M	3.0 %
-Royalties as a % of gross revenues:		4,5 %
-Plant capacity: (net to the grid)		6,000 kW @ 95% capacity factor
-Capital financed cost:		$14,600,000

Estimated Annual First Year Revenue & Operating Expenses:

-Annual Revenue:	$3,719,000
-Operations & Maintenance, Plant & other Surface	834,000
Well-Field & Pumps	260,000
-Property Taxes: County	151,000
-Royalties @ 4.5% of gross Revenues:	167,000
-Insurance: Property and casualty	78,000
-New Mexico Gross Receipts Tax:	196,000
-Administrative Costs:	51,000

Financing Parameters:

-Debt/ORMAT Equity Ratio:	60%/35%
-DOE Grant:	5%
-Repayment Term:	12 years
-Primary Debt Interest:	11%
-Debt Coverage Ratio:	1.36 min
-Return on Equity:	23%

6.0. CONCLUSIONS

With the anticipated power sales price from the Combined Technologies facility expected to be in the range of less than 80% of current commercial and residential power prices in southwest New Mexico, it is assumed that with the current regulatory and energy supply climate in New Mexico, the electricity producer will be able to attain a long term market opportunity under a financible Power Purchase Agreement.

In considering the environmental impacts of this project, we note that since the Lightning Dock geothermal system lies in a sparsely populated agricultural area with existing geothermal development, no adverse environmental impacts are envisioned. Furthermore the use of closed loop binary power plant technology results in near zero emissions facility, and therefore the overall impact of the validation plan is not expected to produce any negative environmental impacts.

The EGS Combined Technologies Project thus combines proven "off the shelf" technologies and methods, with the lessons learned from Fenton Hill, to demonstrate the potential for commercial EGS power generation technology. Furthermore, the implementation of the Lightning Dock EGS validation plan, subject to funding and approval considerations, can be accomplished within an overall projected time frame of 36 months to 48 months from initiation of exploration activities through start up of the Combined Technologies power plant

Meeting the Program Objectives

Historically, commercial geothermal development has relied on tapping high-temperature resources at relatively shallow depths, thus minimizing drilling risks and drilling costs. Electrical power was traditionally produced by either dry steam or flashed steam power plants, which were based on conventional thermal power plant technology with geothermal steam replacing boiler-generated steam.

Over time, though, geothermal wells were drilled deeper, the number of high-temperature geothermal areas capable of sustaining dry steam or flash-power plants dwindled. The development and commercialization of binary-technology permitted the commercial exploitation of the more frequently occurring moderate temperature geothermal resources, with temperatures ranging from 250°F to 350°F. The ability to utilize EGS technology to exploit the nearly ubiquitous hot, but relatively dry, geological formations is expected to vastly increase commercial geothermal power generation worldwide.

The analysis of existing data shows that the Lightning Dock geothermal resource contains the attributes of both a hydrothermal and an EGS resource. The successful commercial development of the EGS portion of the system will depend on mitigating the risks associated with the resource, including its depth, dimension and temperature distribution, and the ability to create a fracture network that provides the required reservoir size and transmissivity. Once these resource uncertainties have been mitigated, the focus will shift from resource development to EGS fluid production, power plant output, and reservoir sustainability. The resulting development would be validated using the standards established for hydrothermal project development business practices and commercial considerations.

The proposed project uses both the EGS and hydrothermal reservoirs at Lightning Dock to fuel a commercial binary geothermal power plant with a capacity of 6 MW (net to the grid).

Risk is minimized by incorporating conventional hydrothermal technology, and EGS technology is advanced by validating the economics and viability of using EGS fluids to produce commercial electricity. The plant will utilize 300 to 320 °F hydrothermal fluids produced from the shallow hydrothermal resource and 280 to 320°F EGS fluids produced from the deeper EGS resource, which will be fractured and pressurized with fluids injected from the surface facilities. This combined EGS/hydrothermal power plant achieves several important objectives:

- it establishes a commercial platform to validate the viability and sustainability of EGS technology using field proven commercial binary power plant technology;
- it provides a proven, viable methodology to integrate EGS and hydrothermal power generation technologies;
- it provides a methodology to develop and measure the performance of an EGS fluid production system in a geological setting commonly occurring in the western United States;
- it provides a method to evaluate the long term sustainability of an EGS well pair and its thermal reservoir; and
- it would be the first geothermal power project in New Mexico.

Validation of Program Objectives

The Lightning Dock Combined Technologies EGS Project is expected to provide the basis for a viable commercial demonstration of moderate temperature EGS technology with widely applicable results.

The Lightning Dock Combined Technologies EGS Project will optimize the extraction of geothermal energy from the two shallow-depth, moderate temperature rock formations. This program could represent the template for development of a high number of similar geologic targets throughout the western United States The Lightning Dock system, in the combined hydrothermal/EGS mode has resource development implications of at least one to two orders of magnitude beyond the hydrothermal system itself. The fact that economic analysis indicates that the system is nearly economic in its hydrothermal state as presently known, suggests that relatively small enhancements in system knowledge and management may make many other systems in the Basin and Range economic under present, or near future, market conditions.

The success of the Lightning Dock Combined Technologies EGS project will validate the objectives of the program as follows:

1. The basic EGS conceptual two well injection/production model for producing sustainable commercial-grade geothermal energy, will have been validated at moderate temperatures and relatively shallow depths.
2. Large amounts of previously unusable geothermal resources will be open for consideration as commercial development prospects at power prices possibly considered as economic within this decade.
3. Additional research into lowering the costs of exploration, deeper drilling and fracturing technologies, to access hotter EGS resources, will be more readily justified as the natural extension of this program.

4. The validation program is based on a three-year, program of research and development with GO NO/GO criteria built in to guide the progress. This allows the flexibility of discontinuing any phase of the program that does not satisfy the ultimate goal of the program – the technical and economic development of EGS technology.

Summary of Findings

To be a viable candidate site for application of EGS technology, the geothermal resources must provide the potential for in-situ elevated temperature in the range of 300°to 400°F. Reservoir rock must be highly fractured or amenable to the application of fracture stimulation techniques to enhance extend natural fractures. Sufficient fluids must be available for injection and production from the EGS reservoir. The Lightning Dock Geothermal Area, and particularly the approximately 2,500 acre Federal Geothermal Lease NM-34790, held by Lightning Dock Geothermal, Inc. (LDG), has a defined shallow hydrothermal resource at a depth of 1,200 to 3,300 feet, with fluid temperatures of approximately 300 to 320°F. Previous geochemical research indicates that water pumped from the shallow hydrothermal regime (at a typical depth of about 300 feet) is a mixture of cooler normal groundwater with hotter geothermal waters originating from a deeper source. Silica geothermometers, derived by using various mixing models, define this hotter geothermal fluid component potentially at an estimated temperature of 240°C (460°F). This indication of a deeper and hotter, but possibly fluid-deficient geothermal source provides the basis for the Lightning Dock Hybrid-EGS project.

There are six key technical assumptions in this project that, together, are designed to commercialize EGS within the confines of standard business practices and at the lowest possible risk to the overall project success.

1. Existing geologic, geochemical, geophysical and drill hole data strongly suggest that combined hydrothermal-EGS resource exists in the Lightning Dock area and that this resource is capable of sustaining at least a 6.5 MW (Net) commercial geothermal power plant. This assumption is based on historical productivity of shallow geothermal wells in the area and the resemblance to other geothermal prospects in the Basin and Range.

2. Combined technologies proposed for this project offers the best, and perhaps only, method to develop and evaluate the commercial viability of the EGS portion of the reservoir. Commercial productivity requires that both fluid flow and temperatures to be sustained over a period of years. Fluid production from both the hydrothermal and EGS reservoirs reduces the risk of failure of any critical component of the system, which is an essential component of successful commercial geothermal power plants.

3. Combining surface geophysical survey techniques with drilling and numerical modeling provides a low risk resource assessment method.

4. Drilling, completion, and stimulation techniques proposed for this project are low-risk methods, which have been proved extensively in the petroleum industry.

5. Power plant equipment is designed to accommodate a wide range of fluid temperatures, flow rates, pressures, and chemical compositions. Since the EGS must be evaluated over a sustained period of time, and since the EGS reservoir properties may change over time, the surface equipment should be able to automatically adjust.

6. The productivity of the hydrothermal and conceptual EGS reservoirs will meet certain definable parameters in order to assure program success.

7.0. PROJECT TEAM

The Phase I EGS Study was managed by Ormat International, Inc. (Ormat), as a Co-venture with Lightning Dock Geothermal, Inc (LDG), and completed by a highly experienced and professional team.

Ormat International, Inc.

ORMAT has for over three decades been recognized for its research, development and manufacturer of innovative electrical power generating equipment and systems. Since the early 1980s ORMAT has been the world leader in the design and development of binary geothermal power plants based on the organic Rankine cycle. The company has supplied over 700 MW of geothermal power plants world wide (Table 5), ranging from 300kW to 125 MW, with temperatures from 200 to over 600^{o} F. The ORMAT engineering department has the technical expertise for the geothermal power applications and design, and has been responsible for overall project management of the Phase I Study Report as well as the Phase II Implementation Plan.

Table 5. ORMAT Power Plants World Wide.

Country	No. of Plants	Size in kW/MW	Total Installed Capacity
USA	14	600 kW to 42 MW	204.0 MW
Mexico	5	300 kW to 2.5 MW	4.0 MW
Argentina	1	600 kW	0.6 MW
Guatemala	1	25 MW	25.0 MW
Nicaragua	1	70 MW	70.0 MW
Philippines	7	12 MW to 125 MW	205.0 MW
New Zealand	5	2.5 MW to 57 MW	98.0 MW
R. of China	1	1.2 MW	1.2 MW
Taiwan	1	400 kW	0.4 MW
Thailand	1	300 kW	0.3 MW
Azores/Portugal	2	5.0 MW to 10 MW	15.0 MW
Iceland	2	2.5 MW to 6.5 MW	9.0 MW
Italy	2	300 kW to 9 MW	9.3 MW
Ethiopia	1	9.0 MW	9.0 MW
Kenya	1	12.0 MW	12.0 MW
TOTAL	**41**		**662.8 MW**

Lightning Dock Geothermal, Inc.

Lightning Dock geothermal, Inc. (LDG) was formed to develop the Federal Lease at the Lightning Dock KGRA. It has held this lease since 1986. Its principals are the following highly experienced professionals who have the specialized expertise and experience for this project, as follows:

1. Roy A. Cunniff, President of LDG, Inc. is a Registered Professional Engineer with more than 23 years experience in geothermal direct heat usage, hydrology, and environmental engineering, and geothermal assessments, including Project Manger for three major Environmental Impact Statements, more than 25 environmental assessments, and

engineering design and construction engineering supervision for 12 geothermal direct heat projects. He has more than 16 years experience in geothermal hydrology, environmental, and regulatory issues for geothermal usage in the Lightning Dock KGRA.

2. Roger L. Bowers, Vice-President of LDG, Inc., has more than 27 years experience in geothermal resource assessments, geologic studies and direct experience covering geothermal assessments of more than 2.0 million acres in over 100 projects in eight Western States. As a consultant since 1987, he has studied geothermal resources around the world, including the Caribbean, Guatemala, Europe, and New Zealand and has 16 years' experience in geological and geophysical studies of the Lightning Dock KGRA.

Southern Methodist University Geological Sciences

Dr. David Blackwell, Dr. Ken Wisian and staff at Southern Methodist University: Dr. Blackwell has more than 33 years experience in thermal analyses, and he and his staff performed the integrated thermal, geological, geophysical, and hydrological heat flow analyses. Dr. Blackwell holds a BS in Geology and Mathematics from Southern Methodist University and a MS and Ph.D. in Geophysics from Harvard University. Dr. Blackwell and Dr. Wisian have performed heat flow studies of geothermal areas throughout the western United States, especially the Basin and Range Province and the Pacific Northwest.

GeothermEx, Inc.

GeothermEx has achieved a worldwide reputation as the leading consultant in the field of geothermal reservoir assessment, reservoir modeling, fracture assessment, well drilling and stimulation and resource management. This project made use of all of the GeothermEx senior personnel who have the specific fields of expertise required for this project, including the following:

1. Dr. Subir Sanyal, President of GeothermEx, is one of the leading authorities in geothermal reservoir engineering. His career spans 30 years and includes both academic and industrial assignments. As President of GeothermEx he has had technical oversight on some US$ 10 Billion in geothermal projects, including all phases of hydrothermal development, technology transfer and EGS evaluation.

2. Mr. Eduardo E. Granados, Vice President of GeothermEx, has been active in geothermal exploration and drilling for over 25 years. His experience, worldwide includes design of drilling programs, supervision of operations, fracturing and well stimulation.

3. Ms. Ann Robertson-Tait, Business Manager and Senior Geologist, has been involved in geological and geothermal studies for over 15 years. Her expertise includes development of hydrological and EGS models and interpretation of data and reservoir performance.

4. Dr. Christopher W. Klein, Senior Geochemist has been with GeothermEx since 1974. His expertise includes fluid and isotope geochemistry of geothermal and volcanic regions, well testing, fluid sampling, analysis, scaling and numerical simulation of reservoir chemistry. He has a Ph.D. in Geology from Harvard University and a Bachelor's degree in Chemistry from the University of California, Berkeley.

Mankato Enterprises

Mr. Thomas Flynn, President of Mankato Enterprises, a geological consulting firm in Reno, Nevada, assisted in the geothermal energy assessment.

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APPENDIX A

Comparison of DOE EGS Selection Criteria with Lightning Dock Site

DOE Criteria for Site Selection	Lightning Dock Characteristics
1. Public acceptance	At local and at State level
2. Near established hydrothermal resource	Numerous geothermal wells
3. Field has low and high productivity wells	High production from shallow wells Low production from limestone
4. Transmission lines close	Electricity powers greenhouses
5. Commercially viable, industrial interest	Agriculture industry is interested
6. Easily accessible, roads, services	Paved roads throughout the valley
7. Water available for reinjection	Water available from irrigation wells
8. Single lithology reservoir, well-defined	Horquilla Limestone; 2,000 ft thick
9. Mechanically well characterized	Fractures in exploration well 55-7
10. Existing wells are available	Shallow wells produce 4,000 GPM
11. Site is not "unique, one-of-a-kind.	Site is "typical Basin and Range"
12. Extensional stress regime	Basin and Range, extensional terrain
13. Temperature is high (>400°F?)	300°F to 320°F, binary power plant
14. Relatively large reservoir	Size consistent with B&R reservoirs
15. Geology and hydrology well known	Oil & gas, geothermal exploration.
16. Lithology, stratigraphy, structure	Tertiary volcanics overlie Paleozoics
17. Young volcanics with high heat flow	Quaternary basalt, Oligocene caldera
18. Water and water rights available	Available from shallow wells
19. Mineralogy of reservoir rock	Thick Paleozoic limestone
20. Political considerations	No geothermal plants in New Mexico
21. No large-scale hydrothermal operations	Only direct use – greenhouse heating
22. Green power sales agreement possible	New Mexico, Colorado, California