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Technical and Economic Evaluation of Selected Compact Drill Rigs for Drilling 10,000-Foot Geothermal Production Wells

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**TECHNICAL AND ECONOMIC
EVALUATION OF SELECTED COMPACT DRILL RIGS
FOR DRILLING 10,000 FOOT
GEOTHERMAL PRODUCTION WELLS**

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Sandia Contracts AR-9603 and AU-0076

ABSTRACT

This report summarizes the investigation and evaluation of several "compact" drill rigs which could be used for drilling geothermal production wells. Use of these smaller rigs would save money by reducing mobilization costs, fuel consumption, crew sizes, and environmental impact. Advantages and disadvantages of currently-manufactured rigs are identified, and desirable characteristics for the "ideal" compact rig are defined.

The report includes a detailed cost estimate of a specific rig, and an evaluation of the cost/benefit ratio of using this rig. Industry contacts for further information are given.

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CONTENTS

PART I. CHARACTERIZATION OF A "COMPACT DRILL"

Introduction	1
Definition of a Compact Drill	1
Objectives	2
Compact drill requirements	2
Manufacturers and candidate rigs	11
Rig suitability summaries	24
Contact list for selected drill-rig manufacturers	25

PART II. REVIEW THE STATE OF THE ART

Objective	27
Review current state-of-the-art	27
Controls and instrumentation	28
Drawworks	31
Mast	32
Pipe handling systems	33
Power systems	34
Pumps	35
Rotary system	35
Substructure	36

PART III. DESIGN AND COST ESTIMATES FOR A COMPACT DRILL RIG

Summary description of the compact geothermal drill	38
Total cost of compact rig and auxiliary equipment	41

PART IV. ECONOMIC ANALYSIS FOR THE PROTOTYPE COMPACT DRILL

Cost-benefit analysis summary description	42
Basic procedures and assumptions	42
Summary of cost savings	44
Recommendations	45

APPENDIX A -- SPECIFICATIONS FOR COMPACT DRILL RIG

Concept	A-1
Specifications	A-1
Design	A-12

APPENDIX B -- DETAILED COST ESTIMATES

Basic procedures and assumptions	B-1
Compact geothermal drill rig costs	B-1
Cost of additional equipment	B-2
Daily costs	B-3
Shipping cost comparison	B-6
Site preparation	B-7
Mob/Demob	B-8
Summary of cost savings	B-8
A business scenario	B-9

PART I. CHARACTERIZATION OF A "COMPACT DRILL"

Introduction

Drilling of moderately deep (~10,000 feet) oil, gas and geothermal wells has historically been done with very large drill rigs. Drilling a geothermal well inherently takes a larger rig than drilling an oil well to the same depth, because the geothermal hole sizes and casings are larger, and rig size is often more strongly driven by the casing loads which must be supported than by the hole size. Typically these large rigs have masts 120-140 feet tall, bulky, built-in-place substructures and multiple large engines to raise and lower drill strings, rotate the bit, circulate drilling fluids and generate electricity. Transport of these machines can require in excess of 100 truck-loads and "rig-up" involves the use of cranes, bulldozers, forklifts, front-end loaders and/or other heavy construction equipment.

Today, the geothermal industry must compete with natural gas when trying to sell electricity to utilities. The highest single cost of geothermally generating power is the drilling of production and injection wells. Important components of the overall drilling costs include the cost of mobilization and demobilization (mob-demob), crew-related charges, fuel, and daily rig rentals. When working overseas (as appears likely to be the trend for the near future), the impact of these particular line items on total costs is even greater than it is in the US. Additionally, environmental concerns associated with the use of large drill rigs are increasing all over the world. These must be addressed if continued geothermal drilling is to be possible at reasonable costs.

The investigation discussed herein has been undertaken on the premise that if a smaller, more easily transportable and less expensive (to run) drill rig can be found or designed and built to drill deep geothermal production and injection wells, overall drilling costs (and electric power costs) can be significantly decreased. The use of compact rigs would help make geothermal resources more competitive as a power generating fuel while at the same time decreasing the environmental impacts of operations conducted using large drill rigs.

Definition of a "Compact Drill"

For the sake of this study, a "compact drill" is defined as one that:

- Has a mast which is self-erecting and is significantly shorter than a "conventional" triples rig.
- Has a footprint that is far smaller than that of "conventional" rigs.
- Has a substructure that is high enough (~20-30 feet) to accommodate the blow-out prevention stacks commonly used in deep, high-temperature geothermal drilling, but which can be erected without the need for heavy equipment.
- Can be transported into steep terrain without the need to widen or reshape roads and without the need to push or pull with heavy equipment.

- Utilizes state-of-the-art technology to minimize bulk and complexity, while still maintaining the capacity to drill production-scale wells safely.
- Requires a small (3-4 man) crew on each tour, rather than the 5 or more man crews commonly employed on "conventional" rigs.
- Can be transported over land or sea using about 20-25 truck loads, in comparison with the 40-60 truck loads required to move "conventional" rigs.

Objectives

The objectives of this investigation are:

1. Determine, via interviews with knowledgeable geothermists, the critical requirements for compact drill rigs used to drill moderately deep geothermal production and injection wells.
2. Identify leading drill rig manufacturers and, through facility visits and interviews with their representatives, determine if "compact" rigs have been built. If so, obtain their design characteristics and the costs related to their operation and transportation. If not, determine the feasibility of and the costs involved in modifying selected existing rigs or building new rigs that will be "compact" and geothermally suitable.
3. Choose an existing design or rig for detailed cost estimates. Re-establish contact with people interviewed in Objective 1, and confirm that this prototype rig meets the stated needs.
4. Perform a cost/benefit analysis to quantify the economic advantage of a compact rig.

Compact drill requirements

Interviews with the persons listed below were held in person, by telephone and/or by Fax between 18 January 1996 and 14 June 1996. Virtually all of those interviewed are geothermists, however two (McDonald and Muncaster) are from the mining industry and one (Mielke) is from the petroleum industry. They were queried because of their familiarity with geothermal project needs and with drilling in general.

David Anderson - Geothermal Resource Council, Davis, CA
 Leon Ballew - Ballew Tool, Cobb, CA
 Louis Capuano - ThermaSource, Inc., Santa Rosa, CA
 Jim Combs - Geo Hills Associates, Los Altos Hills, CA
 John Finger - Sandia National Laboratories, Albuquerque, NM
 Dave Glowka - Sandia National Laboratories, Albuquerque, NM
 Ron Jacobson - Sandia National Laboratories, Albuquerque, NM
 Larry Larson - Nabors Drilling Co., Denver, CO
 B. J. Livesay - Livesay Consultants, Encinitas, CA
 Jim Lovekin - California Energy Corporation, Coso, CA

Kerry McDonald - Caribbean Power, Littleton, CO
Randy Meyer - Lang Exploration Services, Salt Lake City, UT
Ken Mielke - Sedco-Forex, Houston, TX
Neil Muncaster - Lakewood, CO
Nic Nickels - Baker Hughes Inteq, Santa Rosa, CA
Dennis Nielson - ESRI, Salt Lake City, UT
Larry Pisto - Tonto Drilling, Salt Lake City, UT
Marshal Reed, DOE, Washington, DC
Joel Renner, DOE, Idaho National Engineering Laboratory, Idaho Falls, ID
William Rickard - Resource Group, Palm Desert, CA
John Rowley - Pajarito Enterprises, Los Alamos, NM
Marc Steffen - Calpine Corporation, Santa Rosa, CA
Pat Sullivan - Nabors Drilling Co., Bakersfield, CA
Bob Verity - Mesquite Group, Fullerton, CA
Mike Wright - ESRI, Salt Lake City, UT

Through interviews with the people listed above, the following gross design parameters have been identified as being desirable in a compact production drill. In the absence of consensus, ranges or possible options have been listed. This listing has been created as a basis for determination of more detailed design features. It is also intended as a guideline for eventual estimation of the costs involved in the design and construction of an "almost ideal, compact production-scale drill rig". There is no significance to the order in which the various parameters are discussed below.

Rig Style - There are three basic style alternatives: roadable (truck or trailer-mounted), helicopter transportable and built-in-place. If the rig is to be **roadable**, the truck or tractor should have multi-wheel drive and a winch powerful enough to pull itself out of trouble when necessary. The truck or trailer should have a steerable rear axle. The overall wheel-base should be as short as possible so as to allow negotiation of sharp turns and the truck should also be narrow enough (10-12 feet) to fit on most bridges in lesser developed countries (LDCs). The tractor should be diesel-powered (rather than gas-powered) and equipped with mufflers and a scrubber to minimize noise and exhaust emissions.

If the rig is **trailer mounted**, it can be smaller and less expensive since there is no prime mover (engine) on it and the only requirement is that it be built sturdily enough to withstand the rigors of being repeatedly moved. Though trailer-mounted rigs are commonly designed to be self-erecting, inclusion of a gin pole or other similar device on the tractor and/or availability of "Gradall" or "Mantis" types of small, versatile, roadable lifting machines would be advisable.

In the case of a **helicopter-transportable** rig, it would have to be designed to fit, with 6 inches of clearance, in ocean-going containers commonly measuring 8' x 8' x 20' or 8' x 8' x 40'. Three general types of helicopters are available to transport these loads: 1) The smallest, least expensive helicopters (Bell 212 and 214ST) can only lift 4,000 to 5,500 pounds. Though most rig components can be designed in pieces to meet this requirement,

generators pose significant problems. 2) Medium-sized (Puma/Super Puma Classes) helicopters can handle up to 8,000 pound lifts. They cost more, but they can transport most carefully-sized rig and ancillary components (Parker Drilling Co. builds their own 6,800 pound generators). 3) Finally, there are the giant Russian (MI-8 and KA-32) and U.S. military helicopters (Boeing V-107 Vertol and Boeing 234 Chinook Classes) which can lift up to 20,000 pounds. Although their base and operating costs are very high (>\$20,000 per day), their cost-per-transported-pound is often lower than the smaller helicopters and they can be cost-effective if it is not excessively expensive to mobilize these machines to the work location.

To date, no compact, helicopter-transportable drills capable of drilling production-scale geothermal wells have been built. In 1993, Parker Drilling Company designed its RSA4K and RSA6K series of slim-hole heli-rigs. They were never built, but their published specifications include the capability of drilling "conventional" size holes to 11,000 feet. Use of heli-rigs is optimum from an environmental point of view, but after completion of exploration work there are likely to be roads into any area having the potential for commercially viable geothermal development. Heli-rigs might therefore prove to be less cost-effective than a roadable rig, environmental benefits notwithstanding.

Built-in-place (conventional) rigs are normally large, heavy and typical of the kinds of machines that should be replaced by "compact" drill rigs. Accordingly, they will not be considered further in this report.

Depth Capability - The ideal compact geothermal drill should have the power and the lifting/jacking capacity to be able to penetrate any rock type to a nominal depth of 10,000 feet and set casing to whatever depth is indicated. (In drilling parlance this would be a rig "rated" for 12,000 feet). The depth capability is a function of the power and configuration of the drawworks, the strength of the mast, the hook load "overpull" capacity and the torque available to rotate the drill string.

The drawworks pull can be optimized by using a 10 or 12 line pulley system if decreased hoisting rates can be tolerated. Adequate mast strength can be obtained using a relatively light design if the use of jacking systems is planned. (Jacks can push from the substructure to exert upward force on drill rods or on the casing string without the need for pulling from above with consequent imposition of great compressive stresses on a mast). The hook-load overpull capacity can also be decreased by planning on the use of jacks. Finally, generation of adequate torque from light, versatile top head drives (THDs) is absolutely no problem with the advanced generations of THDs now on the market.

Coring Capability - One of the most expensive aspects of geothermal drilling is the need to drill through lost circulation (LC) zones. When such conditions are encountered above the geothermal reservoir, much time and money can be spent regaining circulation with multiple cement jobs to seal the zone without sticking or twisting off the drill string. Core drilling is a proven solution to this problem because it can be done "dry", i.e. without

drilling mud returns to the surface. Accordingly, this compact drill rig should be designed to have both rotary and core drilling capabilities.

Tonto Drilling Services Inc. is now designing an 8-inch core drilling assembly to be used with a THD in 10,000 foot deep holes. Very few modifications to existing rotary rigs will be needed when this system becomes available and the unit can easily be modified for use on a compact drilling rig. The change-over from rotary to core drilling is expected to take only 1-1.5 hours to complete. Because use of a THD eliminates the need to withdraw the drill string the length of a Kelly each time a new drill pipe is added, the THD-compatibility of the Tonto coring assembly is a very important aspect of its utility in penetrating LC zones.

The Mast - The mast should be no taller than necessary to pull "doubles" (two 30 foot long joints of drill rod or casing) while accommodating a THD plus required blocks, swivels and other rigging. It is believed that such a mast could be less than 100 feet high. If jacks are used to remove stuck drill pipe, the mast will only need to be strong enough to support the pulling of about 300,000 pounds, (see overpull/jacking section below). It will probably be built as a steel skeleton, however the use of new composite materials should be considered if they are cost-effective. The skeleton style would be light and versatile with respect to modification and repairs requiring welding.

It is possible that a mast could be designed to be collapsed to "singles" height when especially heavy pulls are required. If this were the case, then the fully extended, "doubles" height mast might be built lighter than otherwise. Consideration should also be given to building the mast only high enough to accommodate the pulling of singles. In this case, automated pipe handling (APH) should be planned if its use would make up for the time lost in not pulling doubles.

If the compact rig is designed to pull doubles, the rig floor and the finger board will have to be designed to hold the 167 60 foot stands needed to drill to 10,000 feet. The drills built for Petrobras by KREMCO in Clearfield, Utah are doubles and they have easily achieved this accommodation. Interestingly, no derrick man is employed on these rigs and the stands are stacked very efficiently by the driller using an APH system operated from the control console.

Primary Power - Power for the drawworks, the THD and rig floor needs should probably be supplied by a DC electric motor with a Silicon Controlled Rectifier (SCR). KREMCO engineers believe that AC motors are now being built that are as versatile as the DC motors; accordingly, some consideration should also be given to use of the less expensive, less complex AC systems. In the long run, weight and size considerations may favor diesel/hydraulic systems over electric motors.

Approximately 1000 horsepower should be adequate to run the drawworks, a THD and floor devices. The speed and torque flexibility of DC/SCR is a desirable advantage as is the smaller size of the motor. If, in addition, this prime mover were to be used to run four

400 HP mud pumps, at least 2600 HP should be planned. If compressors/boosters are to be electric powered, then up to 4000 HP might be needed. Though KREMCO engineers believe that adequate protection could be designed, it seems logical to assume that an electrically powered THD would be vulnerable to serious damage or destruction if live steam were to escape the hole and come into contact with the THD. It should be noted that live steam could also seriously damage or ruin hoses used to run a hydraulic THD.

Though SCR's are quite reliable and long lasting, there is a significant risk that a lot of time would be lost in case of an SCR breakdown far from civilization. An SCR system is not something that can be fixed by an average mechanic. Considerable specialized training is required and a factory representative would probably have to travel to the site from the USA. Availability of some spares would be critical on very remote projects.

Torque - It should be anticipated that the drilling system will be subjected to severe torque shocks when penetrating the variably hard/soft materials typical of volcanic environments and/or through highly fractured rocks of any type. The THD should therefore have a torque capability rating of at least 20-30,000 foot-pounds (27,120-40,680 N-m).

As a guide, the torque rating of a rig designed to drive a 27.5 inch rotary table can be used. This requirement is now being met and exceeded by hydraulic THDs in use on drills run by Lang Exploration Services, Tonto Drilling Services, Inc. and Sedco-Forex Company among others.

Overpull Capability versus Jacking Ability - When drill rod gets stuck, fishing is necessary, casing needs to be pulled out or when other drilling problems occur, the mast, rigging and drawworks must be able to support the weight of the heaviest drill string or casing string. For safety sake, an overpull capability of 25-33% should be provided. Assuming use of 6,000 feet of 47 pound per foot $9\frac{5}{8}$ inch casing having a weight of 282,000 pounds in air, 25-33% overpull capacity would be 352,000-375,000 pounds. The mast rating, with a 10% safety factor, should therefore be 388,000-413,000 pounds.

Some "old school" drillers like to have the ability to "pull their drill pipe in half". Others like to be able to pull the weight of their heaviest tubular, full of water or drilling mud, out of a dry hole. This is all well and good, but the cost, in money and in rig weight, of providing such overpull capacity is extraordinary.

An alternative to provision of overpull capacity is to plan to jack stuck tubulars out of trouble. A four-jack system can be designed to put pressure on the substructure bottom beams or on the rig floor (with jacks pointing either up or down). The hydraulic system needed to put hundreds of tons of upward pressure on wedged tubulars is relatively small and inexpensive and the effect can be dramatic. It is also possible to apply some torque to the tubulars while jacking using the THD. Jacking is slow, but it can work and after the tubulars are loosened, they can be pulled out of the hole rapidly using the drawworks or THD rams. The planned use of jacks can eliminate the need to design this compact rig with a pulling capacity of 400,000 pounds or more.

It should be noted that pulling or jacking alone, without simultaneous rotation, may not free stuck pipe. For this reason, sound arguments can be made **against** having too much pulling capacity and **for** drilling carefully to avoid getting stuck.

Rotating Drive - Despite a cost that is greater than that of rotary-table/kelly systems, the use of a single- or double-ram hydraulic Top Head Drive is recommended. Its main advantages over the conventional rotary table drive are that the drill string does not have to be pulled back while a new joint is added and that rotation and well control are always possible. Though circulation is still interrupted during addition of a new stand of pipe, use of the THD eliminates the possibility of cave-ins that commonly occur in incompetent rock when the kelly is raised.

Though electrically driven THDs are dominant in the petroleum industry, they may not be the best choice for geothermal applications because of their potential vulnerability to damage by escaping steam. The hoses used in hydraulically driven THDs can also be damaged by steam, but their protection and/or replacement is easier and less expensive than for electric systems. THDs are available from at least eight manufacturers, but TESCO Drilling Technology and VARCO Drilling Systems have geothermal application experience and make both electric and hydraulic units. Both companies are based in Houston, Texas.

Rotary Table - Though, strictly speaking, there is no need for a rotary table when a THD is used, consideration has been given by some interviewed geothermists to the merits of having a 27.5 inch table on this rig. Their primary reasoning is that it could be used for very minor rotational adjustments.

Such a table would be very heavy and would require a heavy, bulky drive mechanism on the drill. If minor rotational adjustments are required, e.g., during directional drilling operations, they can be accurately made with today's modern THDs or with the rig's power tongs. Accordingly, the inclusion of a rotary table is not recommended.

Blow-Out Preventer Equipment (BOPE) Accommodation - Though not always required by regulatory agencies in Lesser Developed Countries (LDCs), it will be prudent to anticipate the need to accommodate a BOPE stack including, from the bottom up, a single gate pipe ram, a double gate complete shut off (CSO) ram, a banjo box or flow tee, an annular (bag) preventer and a rotating head. Despite the fact that pipe and CSO rams are now 3-4 feet thinner than they were several years ago, at least 18 feet, and preferably 20 feet of room should be allowed beneath the rig floor for BOPE stack accommodation. (See cellar and substructure headings below).

(With the use of a THD, eliminating the drilling kelly, an annular BOP is no longer needed to seal around its square or hexagonal cross-section, but it is probably desirable to keep an annular BOP in the stack in case it has to be used for stripping pipe or casing or to close over large diameter casing, a drill collar or the bottom hole assembly.)

This project might present an excellent opportunity to completely redesign the currently accepted BOPE stack for decreased height of the substructure. Perhaps a innovative way of attaching smaller, cylindrical BOPEs inside the conductor casing might be possible.

Cellar - In LDCs, the construction of a cellar to reduce required substructure height would be inexpensive, though time consuming. Cellars would have to be 18-20 feet deep to accommodate most of the BOP stack described above, ~6 feet wide (to fit between the rear tires of the drill and 6-8 feet long. The sides would have to be concrete and escape steps would have to be built leading out of the cellar in two directions. If the location were to be on a hill, drain pipes would have to be placed in the bottom of the walls so that fluids could gravity-flow out.

Realistically speaking, the excavation and support of such a large structure would not be cost effective and its use during drilling would not be safe. Air temperatures could get very high in the bottom of the cellar, H₂S and other heavier-than-air poisonous gasses could accumulate, escape would still be difficult despite built-in stairs and hot waters might not drain out as fast as they might flow into a cellar. Though the use of a cellar to minimize the need for a large substructure should not be entirely ruled out, it should be assigned a very low probability.

Substructure - The positive aspects of using a steel substructure, open to the air during good weather, are the access that it provides for maintenance and the relative safety that it provides, with regard to ventilation of poisonous gasses and/or escape of hot water flows. The negative aspects are its size and the need to use at least one dedicated vehicle load to get it on site. If one is required, it should be 18-20 feet high to allow use of the BOPE stack described above. It should also be strong enough to support jacking stresses (either on its top surface [the rig floor] or on its bottom beams) and to support the weight of the heaviest stacked string of drill rod and/or casing plus other equipment.

It could be advantageous to have substructures built of native materials using inexpensive local labor in certain selected sites to save transportation costs. On the other hand, there are available self raising (jack-up, "slingshot") substructures, like the ones on the Nabors Drilling Company "SHADS" rigs, on the rigs built by KREMCO for Petrobras and on many other petroleum rigs designed for use in remote locations. Their simplicity, ease of erection and reliability is so great that they are worth the higher associated expenses.

Crew Size - For minimum impact on project economics, the crew should comprise no more than 3 workers and a driller/tool pusher per shift. In LDCs, local workers trained up to a certain skill level are often reluctant to do any other job, especially one with lower skill demands. This lack of versatility means that more crew must be employed than would be in the USA or in Canada. On the other hand, the wages earned by these local workers are far lower than those that would be paid in the USA or Canada, their living and food requirements are less stringent and their transportation is virtually no issue. Thus from a cost standpoint, the use of native crews numbering more than 3-4 may be justified. In the

beginning of an overseas geothermal project, 2-3 expatriate helpers will probably be needed on site for several months to train the local crews.

The effect of Automated Pipe Handling (APH) on crew size, operational speed and crew safety must be studied. Can local crews be trained to work with the APH? Is it still cheaper to hire, house and feed local crews than to try relatively complicated techniques to minimize their numbers? In order to answer this question, design studies are needed and the opinions of drillers experienced in LDCs and with APH should be gathered and given considerable credibility.

DRECO and KREMCO engineers are switching to APH on many of their new rigs. They use only 2 men per shift plus the driller. The drill pipe is rarely touched by the crew and there is no derrick man because all pick ups, connections, make-ups, disconnects, and racking or lay downs are done by the APH. (Even pipe dope can be applied automatically if necessary). If drill crews can be reduced to 2-3 per shift using APH, safety will be improved and very significant savings can accrue in the forms of reduced salaries, lodging, food, and transportation.

Mud Tanks - When drilling to 10,000 feet, the use of compartmentalized steel mud tank(s) will be desirable even though each tank requires a dedicated vehicle load. The desander/desilters, shale shakers, sand/silt separators, mud moving accessories, degassers and centrifuges are available in relatively small packages that fit over the tank when in use and in the tank for transportation. A leading manufacturer of unitized mud systems is Tri-Flo International, Inc. of Conroe, Texas. The Sedco-Forex "SIMPLER" drill also includes a closed circuit, self cleaning mud system. The Tri-Flo and Sedco-Forex systems, among others, should be examined and a determination made as to how best to adapt them for geothermal drilling.

Air Compressors and Boosters - Except when large water inflows occur and in unstable rock formations, it is preferable to drill underbalanced with air or air-foam mixtures. The availability of adequate air flow and pressure can make this procedure viable until the hole is well below the static water table. Portable, diesel (electric?) powered 1000 scfm compressors and boosters capable of up to 2000 psi can be linked in series. Two units can be transported on one 20 ton truck load but the machines currently in use are not designed for helicopter transport. The desirability of using rotary or scroll compressors instead of reciprocating machines should be investigated. Perhaps weight and space could be saved without significant loss of efficiencies. MI (Houston), Northwest Air Drilling (Grand Junction, Colorado) or Air Drilling (Denver, Colorado) should be contacted.

Also, the use of "ConCor" type reverse circulation drill pipe should be considered. By pumping air down the annulus between an inner and outer pipe, the volume of air needed is greatly reduced (though pressure requirements are increased). Unfortunately, most reverse circulation pipe is currently used by the mining industry to drill relatively shallow holes. It has not yet been made strong enough to withstand heat and corrosion in drilling for geothermal resources to depths of 10,000 feet.

Tubulars - Drill rods (primarily 5 inch), collars, stabilizers, reamers and subs of all types, bits of various sizes and designs, and casing of all anticipated sizes comprise the tubulars that will have to be transported to a drill site. It is likely that 1-2 trucks will be required for this and that these vehicles would shuttle between a port-side storage area and the drill-site, bringing tubulars as required. Consideration should be given to: 1) the use of reverse circulation pipe (see Compressor section above), and 2) use of a tapered drill string with 5 inch class G, 16.25 pound per foot pipe (instead of 19.5 pound per foot class E) tapering to 3.5 inch pipe at the bottom.

The diameter of the drill pipe to be used is not so much a function of the strength of the pipe (though this is very important) as it is of how much mud is needed at the bottom of the hole to circulate out the drill cuttings and support the hole. If drilling is relatively easy and the formation is competent, 4" drill pipe should be adequate. If high torque and sloughing conditions are anticipated, 5" drill pipe should be transported to the site regardless of the transportation costs.

Power Plant - A diesel powered 1000 horsepower motor and a DC generator will require 2 dedicated vehicle loads to get to a site. If it is determined that electric power should be used to run the mud pumps as well as the rig and if compressors/boosters could also be electrically powered, then a much bigger (possibly 4,000 HP) diesel motor would be needed.

Running the drawworks, winch motor, tongs, THD, an APH unit, and several mud pumps hydraulically may have advantages but a large (3,000-4,000 HP) diesel motor would still be needed to power the hydraulic units.

Mud Pumps and Motors - When drilling with mud to depths of 10,000 feet, at least four mud pumps operating in parallel will be required. They should be Triplex types and have ratings of about 400 horsepower each (1,600 HP total). The pumps and their two 800 HP diesel powered motors are large and they will require 2 dedicated vehicle loads to get all the components to a site. (Note that these two 800 HP motors are included in the 3000-4000 HP mentioned in the Power Plant section above).

Fuel Tanks and Reserve Mud Tanks - In remote drilling sites, availability of one or more diesel fuel tanks aggregating 4,000-6,000 gallons of capacity will be desirable. Transportation of fuel from local seaports may be unreliable for weather and other reasons and therefore reserves for use with all motors should be kept on site. Fuel tank transportation will require one dedicated truckload (assuming that collapsible bladders are used) unless tanker trucks can be hired locally and kept on site until their loads are exhausted. Four steel, 50-barrel, reserve mud tanks should also be available. Though some may fit on a vehicle with the fuel bladders, a second truckload will likely be needed.

Transportation - The whole concept of the compact drill rig is based on reduction of: 1) the rig size, 2) the number of containers needed for ocean transport of the rig and all

supplies/equipment, and 3) the number of vehicle loads required to get everything to a land site from a seaport. The very large drills currently used to drill 10,000 foot geothermal production wells typically require more than 70 vehicle loads every time that they move. The objective of this project is to assess the possibility of reducing this number to about 20 - 25 loads and less than 2000 revenue tons for shipping.

Using the basic information listed in the preceding paragraphs, the current load tally is as follows:

<u>Item</u>	<u>Number of Loads</u>
Mud tank & desander/desilter...etc.	1
1000 HP generator and motor	2
Mud pumps and motors	2
Compressors and boosters	2
Tubulars	2 (shuttle)
Substructure	1
Mast	1
Fuel tank (unless tanker trucks are used)	1
Reserve mud tanks	1
BOPE and fittings	1
Unspecified extra loads	<u>6</u>
Total Loads	20

Note that this does not include camp buildings or other portable structures for sanitation, changing, equipment repair, storage or office space unless some of these could be on one or more of the 6 "unspecified extra truckloads". It is assumed that front-end loaders, "Gradalls", or other vehicles (if needed) will be locally rented and driven to the sites from sea-port areas. Water is assumed to be available locally via surface streams or via tanker truck emptying into a locally-rented storage tank or an imported bladder.

Manufacturers and candidate rigs

Leading drill manufacturers (and two contractors) identified and visited are listed below. Contact names, addresses, and phone numbers are on page 25. The list was compiled following advice given by many of the geothermists interviewed and it was supplemented by suggestions from some of the manufacturers' representatives.

<i>Manufacturer/Contractor</i>	<i>City</i>	<i>Visit Date</i>
Lang Exploratory Drilling , A Division of Boart Longyear	Salt Lake City, Utah	5 March 1996
Boart Longyear	Salt Lake City, Utah	5 March 1996
Tonto Drilling Services, Inc.	Salt Lake City, Utah	6 March 1996

Cooper Manufacturing Corporation	Houston, Texas	27 March 1996
Anadrill, A Division of Schlumberger	Sugar Land, Texas	27 March 1996
IRI International Corporation	Houston, Texas	28 March 1996
DRECO, Inc.	Houston, Texas	28 March 1996
Precision Drilling Corporation	Calgary, Alberta, Canada	30 April 1996
Veteran Resources, Inc.	Calgary, Alberta, Canada	30 April 1996
KREMCO, A DRECO Company	Clearfield, Utah	1 May 1996
Helmerich & Payne International		
Drilling Company	Tulsa, Oklahoma	14 May 1996
Parker Drilling Company	Tulsa, Oklahoma	15 May 1996

Addresses, phone numbers, and contact persons for detailed information from selected manufacturers are listed on page 25.

Visits to the above listed manufacturers and contractors revealed that there are at least seven small to medium sized drill rigs within the petroleum industry that come close to fitting the specifications discussed above for a compact rig able to drill 10,000 foot deep geothermal production wells. The most common deficiencies are their designs to use 3.5 or 4.5 inch drill pipe, substructures that are too short by a few feet to accommodate geothermal BOPE stacks and/or trucks (with mast stick-outs) that are too long to readily negotiate mountain roads in steep volcanic terrain.

The four rigs coming closest to the compact rig specifications are:

1. The KREMCO drills being built for PetroBras,
2. The Lang/Longyear Rig #605,
3. The Nabors Drilling International Slim Hole Drilling System Rig #170, and
4. The Parker Drilling Company RSA6K

Descriptions of these four rigs follow. Selected characteristics of each machine are given, the deficiencies are highlighted and the costs to transport and operate are listed.

1. KREMCO/PetroBras drills

DRECO KREMCO of Clearfield, Utah has built two drills for PetroBras/Brazil which have characteristics that are very similar to those identified as being necessary for a compact rig capable of drilling geothermal production wells to 10,000 feet.

A. The basic rigs can be transported in three truckloads:

1. A 74 foot long drawworks trailer supported by a "5th wheel" on the front and having four-axle duals holding up the back,
2. A substructure trailer with the same support and running gear but which is 16 feet high in traveling configuration and
3. A truckload of miscellaneous gear (ladders, steps, extra tools, etc.) Additional loads are required for the mud system, tubulars, bits, sheds, parts etc.

- B. The mast is 95 feet high from rig floor to crown and comes in two parts that are pinned together. No crane is required to erect the mast. The hook load capacity is 383,000 pounds. Depth capability is 10,000 feet with an 8.5 inch bottom-hole diameter.
- C. The hydraulic system needed to self erect is run by a 156 HP diesel. A slightly larger diesel is used to run the top-of-mast hydraulics including the THD. KREMCO engineers claim that an electric THD could be designed to be steam-proof.
- D. The rig footprint is only 100 feet by 30 feet and the rig breaks down for shipping into the following maximum dimensions: 31.5 feet x 7.5 feet x 7.9 feet. The slingshot style substructure is 22 feet high (ample for a geothermal BOPE stack). The entire rig can be containerized for on-deck shipping overseas.
- E. The drillers station features a console that is completely computerized. All functions can be run remotely if necessary and "joy sticks" plus gauges regulate every rig action including the brakes. The system is self-diagnostic and includes chip-boards that are easily replaceable. In case of problems while operating in a remote location, repair information could be sent via satellite to KREMCO in the US or in Canada.
- F. Many aspects of the rig are fully automated including the tongs, the slips, the elevators and the entire pipe handling system. The standard crew comprises the driller, a motorman and one floor hand. There is no need for a derrick man as the 168 stands of doubles needed to drill to 10,000 feet can be set back by the APH. The fingerboard is designed to hold stands of 9.5 inch collar doubles as well as up to 6 inch drill rod. Any excess stands can always be laid down using the APH.
- G. The drawworks are powered by a 500 HP Caterpillar Diesel, however either DC drive with SCR control or an AC motor could be substituted. The AC motor is smaller than the DC, but it would still require one dedicated truckload to move.
- H. There are some problems with these rigs:
 - 1. The height of the substructure trailer is 16 feet. This is difficult to get underneath power lines in LDCs and it makes the trailer top heavy and dangerous to operate on slanted or crowned roads.
 - 2. The weight, at 20,000 pounds per axle (80,000 pounds total), may be too heavy for roads and/or bridges in some LDCs.
 - 3. The turning radius of the truck/trailer combinations is very poor. Though the design can be changed so that articulation is possible, some mountain switchbacks would still have to be negotiated by "back and fill" methods.
 - 4. A geothermal rig of this style would have to have a wider mast base to accommodate 27.5 to 36 inch conductor pipe.
 - 5. The APH would have to be modified to handle 20 inch casing and the slips, tongs, spiders etc. would all have to be larger.

- I. The costs for moving these rigs is quite reasonable and far cheaper than for moving conventional geothermal rigs.
1. Land moves from Salt Lake City to Houston cost \$5,000 per truckload or less than \$30,000 total.
 2. Overseas shipping, at about \$115 per cubic meter, equates to about \$100,000 plus the costs for the mud system, tubulars and generators. The total estimated by KREMCO is less than \$250,000. This compares well with \$800,000 - \$1,000,000 for a conventional rig.
 3. KREMCO estimates that a geothermal drill rig similar to these rigs would cost \$3,000,000 to build plus the cost for pumps and tubulars. It could be built in about 6 months.
 4. Precise operating costs were not available, but estimates are \$7,000 - \$9,000 per day including the crew, fuel, extra parts, and lubricants but not including bits and other expendables.

2. The Lang/Longyear Rig #605

This rig, as presently configured, is slightly too small for geothermal production well drilling to 10,000 feet. Rig #605 was designed to be helicopter portable and capable of rotary slim-hole or core drilling to a maximum depth of 14,000 feet (with 2.75 inch drill pipe). It has therefore been built fairly lightly, with a modest (180,000 pound) hook load capacity, a substructure that at 15 feet is slightly too low, a hydraulic THD having a relatively low (22,000 ft-lb. maximum) torque output and a rather tall mast.

On the positive side, the 118 foot mast and substructure are self erecting, the rig footprint measures only 150 feet by 82 feet (~0.3 acres), it does have a THD that is quite versatile and it runs with only 3 helpers, a driller and a supervisor.

Lang/Longyear said that Rig #605 cost about \$1.7 million to build. They estimated that to design and build a similar rig suitable for the geothermal industry would now cost \$3-4 million and take about 6 months.

Rig #605 daily operating costs overseas are about \$4,425. The rig, which weighs about 200 tons without tubulars or camp and which requires 17 - 20 truckloads to move, can be shipped overseas for about \$230,000 plus charges for tubulars, a camp and other expendables. Selected Rig #605 specifications are presented below.

Mast:

200,000 pound crown block rating.

4,000 pound heli-lift configuration.

Pipe racking capacity.

- 8,000 feet of 5 inch drill pipe.
- 12,000 feet of 3.5 inch drill pipe.
- 14,000 feet of 2.75 inch drill pipe.

Drawworks

DRECO model KH 400 PSD.
4,000 pound heli-lift configuration.
180,000 pound hook load rating with 1 inch, 6 part line.

Top Head Drive

Two each 14 cubic inch hydraulic motors.
Low range: 0-150 RPM; 22,000 ft.-lb. torque output.
High range: 0-700 RPM; 5,500 ft.-lb. torque output.

Substructure

15 feet clear height.
Modular 4,000 pound sections.
500,000 pound set back capacity.

Power

Two each 3406B Caterpillar diesels.

Drilling Fluid System

6 each 60 barrel tanks; 4,000 pound units

- 3 each 60 barrel active tanks.
- 1 - 60 barrel dual compartment pre-mix tank.
- 2 - 60 barrel reserve tanks.
- High shear, centrifugal mud mixer.

Solids Control System

Two each Swaco Mark 1 - 100 GPM centrifuges.
Swaco 4 x 8 adjustable deck high speed linear shale shaker.
6 inch, 4 inch, and 2 inch hydro-cyclones.

Mud Pumps

Two FMC model 16 triplexes
277 GPM maximum displacement each with 4 inch plungers.
1990 PSI maximum working pressure with 2.5 inch plungers.

3. The Nabors Drilling International, Limited, Slim Hole Drilling System - Rig #170

The first drill built under Amoco's "Stratigraphic High-speed Advanced Drilling System" program, SHADS #1, was built by Longyear in 1984. It was designated Rig # 604 by Longyear and was the predecessor of Rig #605 (see previous report section). SHADS #1 was tested briefly but very successfully in Wyoming by Amoco before they discontinued their SHADS program for "internal political reasons" in 1989.

Rig #170 is the second SHADS-type rig. It and a third SHADS rig, #180, were commissioned by Nabors Drilling International Limited and built by DRECO. Both Rig

#170 and Rig #180 are now in Venezuela where Nabors has been drilling a large number of highly successful slim exploration and development wells for PDVSA's subsidiary firms Mariven and Corpoven.

Because SHADS #1 has been completely dismantled and because Rigs #170 and 180 are in Venezuela, personal inspection of a SHADS rig was not possible. However, an informative brochure concerning Rig #170 was made available by Nabors' Denver, Colorado office. The data presented below has been selectively paraphrased and/or copied from this document. This data source is hereby gratefully acknowledged by the author.

Selected Rig #170 Specifications

The selected specifications listed below confirm that the SHADS drills are similar to the Lang/Longyear Rig #605 in that both are slightly too small to fit the ideal profile of a compact geothermal production well drilling rig. They could however be suitable nuclei from which a compact geothermal rig might be created by carefully planned modification.

Mast

API static hook capacity is 215,000 pounds.

85 foot working clearance.

Racking capacity: 7,500 feet of 5 inch drill pipe; 12,000 feet of 3.7 inch drill pipe.

Drawworks

DRECO model 350 HD; 350 horsepower.

Two high-torque hydraulic motors driving into a single reduction to the drum.

Top Head Drive

Universal 5000 hydraulic; hinged drive/swivel dolly and mud swivel.

Ratings: 150 rpm -10,000 ft.-lb.; 500 rpm - 3,000 ft.-lb.; 1000 rpm -1200 ft.-lb.

Maximum pull out: 180,000 pounds.

Substructure

DRECO slingshot type.

15 foot floor height.

20 feet long by 12 feet wide.

Casing load capacity: 160,000 pounds; setback load capacity: 125,000 pounds.

Power system

Two Caterpillar 4306 diesels producing 325 HP at 1800 rpm each.

Connected to two variable-volume hydraulic pumps for powering all rig functions.

Drilling Fluid System

One centrifuge suction tank.

One shaker tank.

One suction tank.

One mixing tank.

Total active system is 50 barrels.
One cement mixer tank.
Four 50 barrel reserve tanks for a total capacity of 250 barrels.

Solids Control Equipment

One Sharples PM 20,000 centrifuge.
One Sharples P-3000 centrifuge.
One Derrick flowline cleaner.

Mud Pumps

Two Gardner-Denver model TEE, 165 HP, 3 inch x 5 inch triplex pumps.

The costs of transporting the SHADS rigs have not been obtained from Nabors, however the information contained in the brochure suggests that they are much less than the costs of transporting a "conventional" rig. On a 10,000 foot hole, Nabors estimates total costs for a conventional rig to approximate \$1.46 million while for the SHADS rig their estimates range from \$0.94 million to \$1.02 million. Savings would thus range from 30-36%. Because the SHADS rigs are much like the Lang/Longyear Rig #605, shipping costs should approximate \$250,000 plus charges for tubulars, a camp and expendables and the daily operating cost should be about \$4,500.

4. The Parker Drilling Company RSA6K

In 1993, the Parker Drilling Company completely designed two slim-hole, heli-portable rigs designated RSA6K and RSA4K. The rigs were designed to drill to 18,000 feet using 3.65 inch pipe or to 11,000 feet using 4.5 inch pipe. The rigs were never built, but Parker still distributes literature describing the rigs and from the text, it is apparent that the RSA6K, with some modifications, could be the compact rig sought to drill 10,000 foot geothermal production wells.

Because no rigs exist, the information presented below has been excerpted from the contents of a single descriptive brochure. This data source is gratefully acknowledged.

Mast

API static hook capacity is 325,000 pounds.
85 foot working clearance.
No drill pipe is stored in the mast; all pipe is moved with an "elbow" style APH.

Drawworks

Single-speed, automatic speed and torque control.
Hydraulics are delivered by two flyable 500 HP triplex pumps.

Top Head Drive

Two speed electric drive.

Ratings: 115 rpm - 30,000 ft.-lb.; 700 rpm - 5,000 ft.-lb..

Substructure

Slingshot type.
16 foot floor height.

Power system

Diesel/electric, 750 HP with a four bay SCR system.
Controlled from an enclosed, heated or cooled drillers console.
Automatic driller maintains precise weight on bit.

Drilling Fluid System

200 barrel active system.
Four 50 barrel compartments for incremental increases of mud volume as needed.
5,000 psi choke manifold.

Solids Control Equipment

High quality consistent with the need to have ultra-clean mud for core drilling.
Precise equipment not specified.

Other attributes of these rigs include:

- The ability to drill slim holes, wireline core holes or conventional rotary holes.
- A very small (0.5 acre) location size required.
- A need for only 16 truckloads or 79 helicopter loads.
- Ability to handle either 30 foot or 45 foot drill pipe (with a mast extension).
- Great degree of environmental sensitivity.
- Operation by a 4 man crew; no derrickman needed; all floor equipment is automated.

Because these rigs were never built, there are no operating cost figures available. However, the total rig weight is only about 500,000 pounds thus, at \$1.15 per metric ton, overseas transportation should cost about \$260,000 plus the costs for tubulars, sheds and other expendables. This cost is at least 60% less than the cost to ship a conventional rig weighing in at 1.35 million pounds or more.

The deficiencies of these designed-but-never-built rigs are theoretically few. They should be strengthened to be able to drill 8 inch bottom-hole diameter wells, their substructures should be about 2-3 feet higher and the use of a hydraulic THD rather than an electric one should be considered for safety reasons in case of a steam escape. Because the designs have been kept by Parker, these deficiencies could be easily remedied and a compact geothermal design created at little cost.

A second tier of rigs having specifications slightly less appropriate for drilling 10,000 foot deep geothermal production wells than the four listed above includes:

5. The Sedco-Forex SIMPLER Rig #101
6. The Cooper Manufacturing Company LTO 1000
7. The IRI International Corporation Cabot 1100 Series.

Presented below are discussions concerning these three rigs. The basic characteristics of each machine are given, the deficiencies are highlighted and the costs to transport and operate are listed to the extent that they are available.

5. The Sedco-Forex SIMPLER Rig #101

Despite its name, the SIMPLER drill is a complex, state-of-the-art machine that is somewhat over-designed in an effort to make drilling faster, cleaner and less expensive. The acronym SIMPLER stands for Safe Integrated Modular Performant Lean Environment Rig. The rig has all of these attributes, but it cost Sedco-Forex about \$12 million to design and build and was made possible only because the first customer was the Shell Company, operating with very deep pockets on a long term project in Gabon, Africa.

The SIMPLER rig is designed to drill to 11,480 feet with a 6.13 inch bottom hole diameter or to 9,200 feet with a 26 inch top hole diameter and an 8.5 inch bottom hole diameter. It can be transported with 32 truckloads and uses 20% fewer rig personnel than a "conventional rig". The slingshot substructure and the mast can be moved in two truckloads and the entire rig is standardized and modularized to fit into 20 foot or 40 foot containers. A specific design goal was to be able to move the rig 15 kilometers in 12 to 24 hours of continuous work. Some of the important SIMPLER parameters are presented below.

Mast

Telescoping; 1,000,000 pound capacity.

Pulls doubles.

No drill pipe is stored in the mast; all pipe is made up horizontally on the catwalk; APH raises and lays down all pipe; wheeled system moves pipe from bins to the pipe ramp. Drill pipe auto-positioned to within 0.01 feet of set point.

Drawworks

DC electric; 750 HP with SCR system.

800,000 pound hook load capacity.

Top Head Drive

Varco model TDS-9S; 400 ton capacity

Two AC 350 HP motors

Ratings: 114 rpm -32,000 ft.-lb.; 228 rpm - 18,300 ft.-lb..

Substructure

Slingshot type.

25 foot floor height.

Power system

Diesel/electric, 750 HP with a four bay SCR system.
Controlled from an enclosed, heated or cooled drillers console.

Drilling Fluid System

Two 1000 HP triplex mud pumps.
Mechanized 20 foot mixing tank; one man operation without lifting machines.
Dust-free, self-contained, high-energy venturi mixer and screw conveyor. No pits.

Solids Control Equipment

Treatment tank with 3 cylindrical sections
Three linear motion shale shakers; one 16 x 4" desilter; one 150 GPM centrifuge.

Selected Other Features

High pressure cleaning system on rig.
Sophisticated BOPE handling equipment on substructure.
Permanent sensors and Rig Area Network to provide key drilling data to all service companies direct to their notebook computers.
Rig operations soundproofed to 85 dB at 1 meter from any running equipment.

The SIMPLER rig is an example of how high tech improvements can be made in the drilling industry. Unfortunately, this rig is too large for what the geothermal industry needs and it is too sophisticated to be cost-effective. It is smaller than the conventional rigs, with a very small (100 foot by 100 foot) footprint, but it still requires a relatively large, highly skilled crew and, for the time being, it is overly (and very expensively) equipped with regard to environmentally related concerns and to data collection/dissemination.

Though the transportation costs from Houston to Gabon were mid-range (~\$600,000, including tubulars), the cost to build and operate a SIMPLER rig were very high. The machine was designed and built between 1993 and 1995 at a cost of about \$12 million. Because some of these costs were one-time expenditures, another rig could probably be built today for about \$9 million. The daily operating costs billed to Shell in Gabon were more than \$20,000. This included a camp for 24 men (two 12 man tours) at \$3,000 per day but did not include the full time services of Dowell engineers and technicians for mud and cementing operations or those of the men needed for logging and directional drilling. Obviously, the SIMPLER rig is compact and powerful, but it is **not** the cost-effective machine that the geothermal industry needs.

6. The Cooper Manufacturing Company LTO 1000

Cooper Manufacturing plans to make a line of truck-mounted and trailer-mounted drills that come fairly close to meeting the requirements for a rig able to drill a 10,000 foot geothermal production well. The LTO-1000 will be the flagship of their line when it is

built. It is actually a beefed-up version of the LTO-750 (a machine that does exist) and the specifications for the LTO-1000 have been published.

There are several positive and negative aspects of the Cooper rigs. On the positive side, the rigs are self propelled, light (126,000 pounds without tubulars) and surprisingly powerful. On the negative side, THDs are not available, substructures have to be built to order and the mud system/solids control system have to be ordered separately.

The LTO-1000 will be able to drill to 12,000 feet with 4.5 inch drill pipe and 8 inch collars, stabilizers and bits. The turning radius for the truck mounted version is 160 feet, which is too great for switchbacks in mountainous terrain. Substructures 20 feet high can be built by Cooper so that they are self erecting (slingshot or jack-up types). The standard drive train configuration has power going to 2 of the 3 rear axles, however front-wheel drive is an offered option.

The trailer mounted versions of the LTO-1000 are designed to back up to the substructure and then tilt the 118 foot mast 2-3° backward so that the crown block is over the drill hole. Cooper representatives said that this is standard practice, but my intuition is that it might be precarious when dealing with the high torque drilling conditions often encountered in geothermal environments. Selected specifications are presented below.

Mast

Four-leg fixed base.

Pulls triples.

Clear height is 120 feet below the crown.

Racking capacity is 10,800 feet of 4.5 inch drill pipe.

Drawworks

Model 1000/4212-42

Rotary drive torque shaft from right angle box

400,000 pound hook load capacity.

Top Head Drive

None

Rotary Table

27.5 inch available.

Power provided by combination right angle box/drop box from primary power source.

Substructure

Can be built by Cooper to order

Slingshot type.

Any height specified; plans for a 20 foot floor height are in hand.

Power system

Two Caterpillar 3406-C DITA
Two Allison CL(B)T 5861 transmissions.
Cooper gear driven compound.
All components mounted above deck for easy access.

Drilling Fluid System

None furnished.
Can be bought to order in style compatible with rig capabilities.

Solids Control Equipment

None furnished.
Can be bought to order in style compatible with rig and mud system capabilities.

Cooper can issue a detailed bid package in one month and they claim to be able to build a rig in 6 months or less. The November 1995 price quoted for a new LTO-1000 "loaded" with all possible options was \$1,029,930 not including tubulars, a substructure, a mud system, BOPEs, extra parts or a solids control system. A refurbished rig (unlikely to be available for some time since no new rigs have been built yet) is quoted at \$660,910. Daily rates for an LTO-1000 have been estimated at about \$5,000 plus charges for consumables.

7. The IRI International Corporation Cabot 1100 Series.

IRI International is a privately held company that has consolidated the holdings of the Ingersoll-Rand, IDECO, Cabot and Franks drilling companies. Accordingly, IRI has a very large fleet of rigs in operation around the world and they have in-house capability to build, refurbish or modify rigs to suit any specifications.

The IRI drill that appears to be closest to being able to meet the specifications for drilling deep geothermal production wells is the Cabot Series 1100 that can reach 12,000 feet with 4.5 inch drill pipe. The Cabot 1100 is a trailer mounted machine that is designed to back up to a substructure and self-erect its 127 foot mast on top of the substructure (unlike the Cooper LTO-1000 rigs that tilt backward over the hole). A typical 25 mile move can be accomplished in 12 hours or less and requires only the following 5 truck loads:

1. The drawworks, power source and the elevated rotary drive,
2. The telescoping mast, strung-up block, reserve line spool and raising arms,
3. The BOPE and dolly assembly,
4. The hydraulically-raised substructure and
5. The rig base, hydraulic power unit and the pipe ramp.

IRI has the capability of modifying any rig. To the standard Cabot 1100 rig, they can add a THD and hydraulics, an electric/SCR or diesel power source, a unitized mud system with 1000 HP electric or diesel pumps and any type of solids control system. Selected specifications are presented below.

Mast

Transported via 57-foot-long trailer supported by a fifth wheel and a 3-axle dolly.
Self-erecting; pulls triples, capacity 500,000 pounds.
Clear height is 127 feet below the crown. Square tubular construction.
Racking capacity is 10,800 feet of 4.5 inch drill pipe.

Drawworks

Models: DC Electric or Hydraulic 2346 SHL
1000 HP; 10 line string-up.
500,000 pound hook load capacity.

Top Head Drive

None

Rotary Table

Up to 49.5 inch available including 27.5 inch "geothermal standard" size.

Substructure

Can be built by IRI to order
Pinned together at ground level; raised by internal hydraulic cylinders.
Any height specified; 17 foot height is standard.

Power system

Two Caterpillar 3412-DITT
All components mounted above deck for easy access.

Drilling Fluid System

Can be bought to order in style compatible with rig capabilities.

Solids Control Equipment

Can be bought to order in style compatible with rig and mud system capabilities.

IRI manufactures its own masts, substructures, drawworks, mud pumps, rotary tables, swivels, traveling blocks, disc brakes and specialty steels. Accordingly, all drilling equipment not specified on the Cabot 1100 rig can be built to order or selected from IRI stock.

The IRI Cabot 1100 has few deficiencies. The lack of a THD is one and it can be remedied. The excessive height and weight of a 127 foot mast is another, but since it telescopes and still fits on one truckload, it may not be too important. The lack of specified mud and solids control systems may be considered a deficiency, but it might also be a positive factor since IRI can furnish virtually all kinds of systems so as to optimize cost-effectiveness.

The Cabot 1100 can not be containerized for overseas shipment, but it can be driven below decks. IRI claims that they can ship the rig for about \$100,000 but it is likely that this figure excludes a substructure, the mud system, tubulars and consumables. A more accurate estimate would be \$250,000 to \$300,000. The cost of a Cabot 1100 is quoted at about \$1.5 million without pumps, but "loaded" it could reach \$5.0 million. There is probably a happy medium attainable. No operating costs were provided, but this type of rig commonly is contracted at about \$6,000 per day not including consumables.

Rig Suitability Summaries - Of the many rigs discussed during meetings with manufacturers and contractors, the seven listed above seem to have the greatest potential for serving as "nuclei" for a true dedicated compact geothermal rig. For convenience, their salient characteristics are summarized below.

- **The KREMCO rigs recently built for PetroBras** come closer to matching the specifications for a compact geothermal rig able to drill to 10,000 feet than do any other rigs identified during this project phase. They have small footprints, can travel in less than 10 truckloads all inclusive, have THDs, APH and the most modern of drilling hard- and soft-ware so that crew requirements are minimal. They are not the least expensive rigs, but they fall within the "medium price range" (~\$3.6 million base price) and are thus affordable and highly cost-effective.
- **The Lang/Longyear rig #605** is also reasonably close to the geothermal rig sought. It is a little too small, having a hook load capacity of only 180,000 pounds, but it is helicopter transportable, has a small footprint, does have a THD and uses a small crew. Rig #605 requires 17-20 truckloads to move, so it is truly a compact rig.
- **The Nabors SHADS rigs** were designed as slim hole drills and they are performing well as such in Venezuela. They, too, are somewhat small for the geothermal duties specified with only 215,000 pounds of hook load capacity. Nevertheless, the design of the SHADS rigs (that evolved from Rig # 605) could comprise an excellent nucleus from which to build a compact geothermal rig.
- **The Parker Drilling Company RSA6K** is one of the best rigs, *in concept*, for use as a compact geothermal drill. Unfortunately it was never built, but the design does exist and with very few modifications, it could be the very closest fit to the envisioned geothermal rig. It has adequate hook capacity at 325,000 pounds, a THD, a slingshot substructure, a very small footprint, a small operating crew and it can be moved in only 16 truckloads. Shipping costs, as for the previous three rigs, is estimated to be less than \$300,000.
- **The SIMPLER rig built by Sedco-Forex** is an excellent medium-sized rig. It has the mast capacity to pull 1,000,000 pounds and it has many sophisticated, remote control, computerized systems. Accordingly, though the concept under which it was built was excellent, the SIMPLER rig is a product of "major oil company thinking and spending" and is therefore still too large to be called compact and too "futuristic" to be the cost-effective compact rig needed by the geothermal industry.
- **The Cooper LTO 1000** is a truck or trailer mounted rig that comes close to meeting the requirements for a compact geothermal rig. It is easy to move, but it has a high

mast, a large turning radius, no THD and the design calls for the mast to tilt backward over the substructure at 2-3° in a somewhat precarious way. With some relatively simple modifications and additions, this rig could become a compact geothermal machine.

- Finally, there is the **IRI Cabot 1100** rig. It is quite large, has a 127 foot mast and no THD as presently configured. However, the rig can be moved 25 miles in only 5 truck loads in 12 hours or less, is self erecting, has a small footprint and a small crew. The design changes needed to allow it to conform to the compact geothermal specifications are not difficult and IRI International has the ability to make all required modifications.

The rigs listed above have been evaluated to the point of selecting one for further and more detailed examination. That further analysis will comprise a relatively complete design, a cost estimate (by component), and an economic analysis of the rig's cost/benefit ratio.

Contact list for selected drill-rig manufacturers

Boart-Longyear

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Salt Lake City, UT 84127

Phone: (801) 972-6430
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Cooper Manufacturing Co.

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8400 Breen Drive
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PART II. REVIEW THE STATE OF THE ART

Objectives - The objective of Part II of this study was to quantify the benefits that may become available to the geothermal industry through the use of compact drill rigs for geothermal production wells. To accurately analyze costs, the current state of the art was evaluated and a hypothetical drill was designed: all major components were selected; the rig lay-out was planned; a construction-cost quotation was obtained; and operating cost estimates were made. In Part III the costs of building, transporting and using the compact geothermal drill were compared with those related to "conventional drills" having similar capabilities. This was done to identify cost savings and the return on investment possible for geothermal developers and drill manufacturers through their adoption of compact drills. Finally, recommendations were made regarding a business scenario and marketing efforts.

Review current state of the art

To review the current state-of-the-art (SOTA), the following process was used:

- Field facilities of KREMCO in Clearfield, UT were re-visited, so that the PetroBras rigs could be re-examined. Author met with the rig's designer Baldwin Zahn.
- The offices of Lang Exploration Drilling in Salt Lake City, UT were re-visited. President Alan Lang and Marketing Director Randy Meyer were interviewed at length to obtain their input regarding SOTA technology.
- A visit was paid to Sandia National Laboratories to interview John Finger, David Glowka, Ron Jacobson, and Ken Pierce and to search the Geothermal Research Department library for information related to this objective.
- Telephone conversations were held with Roger Rinaldi of Willbros Butler Engineering in Tulsa, OK to obtain his opinions regarding SOTA rig technology. Rinaldi is unique because of his involvement in building "automatic drilling machines" in the late 1960's and early 1970's. These machines incorporated many innovations that worked, but which, for several reasons, were not immediately accepted by the drilling industry. Today, 25 years after Rinaldi's rigs were built, some of his systems are finally being adopted and their use (appropriately modified) may be desirable in the compact geothermal drilling rig that is the subject of this project.
- A telephone conversation was held with Charles Springett, Vice President of Technical Operations for Santa Fe International Corporation. Mr. Springett is very knowledgeable regarding SOTA rig technology being used on offshore drills. Since offshore operations are so expensive (rig day-rates of \$180-200k/day), this is where the very latest equipment is being introduced. Accordingly, Mr. Springett was quite helpful in identifying offshore SOTA hardware and software (and manufacturers) that might be applicable, suitably modified, to the compact geothermal drill project.
- Based on information obtained from interviewees, ten companies manufacturing SOTA equipment were identified.

- Finally, calls were placed to each of these companies and the qualified recommendations of their representatives were obtained regarding the newest and/or best of their products for use on a compact geothermal drilling rig. Because of the limited time available during these telephone conversations to discuss compact geothermal rig requirements and the imprecise knowledge of these requirements at this time, firm recommendations were neither sought nor offered.

State-of-the Art for Major Rig Components - Though drilling rigs have many vital parts that must be carefully specified or designed and then integrated in order to create an optimally efficient, cost-effective, easily maintained, easily operated, economical machine, the following eight units are designated here as "major components":

- | | |
|---------------------------------|------------------|
| 1. Controls and Instrumentation | 5. Power Systems |
| 2. Drawworks | 6. Pumps |
| 3. Mast | 7. Rotary System |
| 4. Pipe Handling Systems | 8. Substructures |

1. Controls and Instrumentation

Traditionally, drilling controls comprised levers, foot pedals, hand-operated valves and electric switches or buttons. Drillers worked largely by "feel" and all drilling operations, on the floor and aloft, were conducted by crews of men who, often risking injury, moved heavy drill pipe, casing and tools into place using sheer strength, massive tools, chains and hand operated "cathead" winches. Instrumentation consisted primarily of gauges that indicated weights, pressures, flow rates and electrical parameters. In the course of drilling, such instruments were commonly broken and not promptly replaced.

During the last 25 years or so, both controls and instrumentation have evolved rapidly as innovative electronic systems, computer technologies and materials have been applied to drilling functions. Today, SOTA is moving towards total automation of drilling procedures. The virtual elimination of floor hands and mast men is possible and drilling can be done by one or two operators working in space-conditioned cabins located adjacent to the rig floor so that drilling safety and efficiency can be increased significantly.

It is important to note that these improvements are rapidly being accepted in the offshore part of the drilling industry, but on land they have still not been universally adopted for at least two reasons: 1) the continuing oversupply of traditionally equipped drills that can be hired at prices far lower than those that would be charged for a new SOTA rig, and 2) the reluctance by "old time" companies and drillers, to use the modern equipment and techniques. This situation is correcting itself as the older generation retires and younger, computer oriented engineer/technicians/operators and managers take their places.

Four companies have been identified as leaders in SOTA controls and instrumentation:

- **HITEC AS** of Stavanger, Norway with North American offices at 3827 98 Street, Edmonton, Alberta, T6E 5V4, Canada; Phone: (403)461-6300, FAX: (403)435-7496.

- **Maritime Hydraulics AS** of Kristiansand, Norway, with North American offices at 11961-A F.M 529, Houston, TX 77041; Phone: (713) 849-0707, FAX: (713) 849-0808.
- **DRECO Inc.** - PO Box 36619, Houston, TX 77236; Phone: (713)965-9122, FAX: (713)232-2875. Note that **KREMCO**, a DRECO subsidiary that has access to all DRECO products, can also be contacted through this address.
- **RIGSERV™** - 1 Hanover Street, Aberdeen AB2 1AE Scotland, United Kingdom; Phone: (44-01224) 571659, FAX: (44-01224) 582934.

These firms offer controls and instrumentation which include:

Cabins - Space conditioning, sound proofing to < 65 dB, ergonomically designed chair(s), room for one or two operators, hand or finger-operated electric and/or hydraulic control operations, and multiple safety back-ups for critical functions.

Controls and Data Acquisition - Simulated drilling activities visible on multiple monitor screens, joystick and keyboard controls, easy maintenance and/or replacement of modular components including sensing devices installed on various rig components, automatic record-keeping of all operations, dissemination of information to interested workers off the drill floor.

Sub-systems include:

Auto driller - Automatically senses hook load and weight on bit so that drawworks brakes can be suitably engaged or released.

Drawworks control - AC or DC drawworks can be efficiently accelerated and decelerated. SCR speed and torque can be monitored and controlled precisely.

Rotary System control - All rotational speed and direction controls can be accomplished by fingertip actions. This can be true for rotary table, top head drives or diamond coring situations.

Automatic Pipe Handling - Hands-off, rapid (~ one stand per minute), accurate movement of pipe and casing from the pipe racks, the mousehole or the racking stand into or out of position. Stands can be made up or broken down while drilling is in progress. (One- or two-man operation.)

Iron Roughneck tool and accessory uses - From the driller's cabin, 1) an automatic mud bucket can be used so as to keep the drill floor clean and conserve mud, 2) pipe and casing threads can be doped accurately and quickly and 3) automatic tongs and slips can be actuated.

Equipment protection - With all this automatic equipment able to move around on and above the floor there is a possibility of collisions. From the control cabin, the driller can actuate or over-ride systems that sense the location of all tools in use and prevent such collisions. Two of these systems are a ton-mile indicator that senses when drilling cables need to be replaced and floor and crown savers that stop traveling blocks from moving too far in either direction.

The following drilling-console gauges and controls can be installed by these manufacturers in addition to, or as parts of, those required for the sub-systems listed above:

Gauges

Exchange filter indicator
Rack back pressure
Hydraulic oil pressure
Engine oil lube pressure
Engine temperature
Pilot oil pressure
Volt or alternator meter
Hour meter
Rotation head lube pressure
Main winch lube pressure
Rotation head RPM

Down hole air pressure
Main pump system pressure
Rod make-up torque
Hold back pressure (weight on bit)
Pull down pressure
Water pump RPM
Water pump prime pressure
Engine RPM
Water (drilling fluid) pressure
Level bubble

Controls

Water feed valve on/off
Water pump speed control
Air dump valve
Mast lights
Engine stop
Engine start
Engine ignition and ignition light
Engine throttle
Water pump on/off
Mist pump on/off
Main circuit on/off
Mist injection metering control
Hold back control
Micro feed control
Pull down control

Micro feed direction
Front Jack legs
Rod clamp
Rear Jack legs
Rod break out and spinner (power tongs)
Vent
Slow rotation
Breakout boost
Head traverse boost
Head traverse
Rotation
Wireline winch
Main winch
Mast raise

RIGSERVE™ is a well established company that manufactures drilling instrumentation and control systems primarily for offshore rigs. Their systems are extremely complete and can include communication of data to a mud mixing center, a mud logger, a company man or geologist, the toolpushers and to a central printer. They can supply all required instruments, logging tools, sensors and recorders. It is not known whether their services and products are cost competitive with similar ones available in the US.

Summary - State-of-the-art controls and instrumentation are now being customized to suit the owner and the planned use of the drill. The four companies listed above have off-the-shelf basic designs for cabins and consoles that can be modified in many ways. For the compact geothermal drill, it will be important to limit the specification of controls and instrumentation to those that will be most cost-effective.

2. Drawworks

Many companies manufacture drawworks and few innovations have been documented recently in drawworks technology. Four companies have been identified as leaders in the field. All four offer both mechanical and electric drives and all offer AC drives within certain limitations. The four companies recommended as excellent sources for drawworks for a compact geothermal drill are:

- **Continental Emsco Company** - Box 1522, Houston, TX 77251-1522; Phone: (713)640-7400, FAX: (713)643-7508.
- **DRECO Inc.** - PO Box 36619, Houston, TX 77236; Phone: (713)965-9122, FAX: (713)232-2875. Note that **KREMCO**, a DRECO subsidiary that has access to all DRECO products, can also be contacted through this address.
- **National Oilwell** - 5555 San Fillipe Road, Suite 1600, Houston, TX 77056-2726; Phone: (713)960-5100, FAX: (713)960-5428.
- **Parker Technology, Inc.** - 4501 S. County Road 1310, Odessa, TX 79765; Phone: (915)563-2236, FAX: (915)561-9406.

The drawworks available from **Continental Emsco** that appears to be most appropriate for the geothermal drill is their Model D-3. It has 1000 HP, is rated for 10,000 to 14,000 feet, can handle 6, 8, 10 or 12 1⁵/₈ inch diameter wirelines each having a 65,000 pound hook load capacity. The electric version has 4 forward and 2 reverse hoisting speeds and 2 forward and 2 reverse rotating speeds. The mechanical version has 6 forward and 2 reverse hoisting speeds and 3 forward and 1 reverse rotating speeds. The machines weigh about 51,000 pounds and are rated for 780,000 pounds.

Continental Emsco also makes models designated D-2. They have adequately high hook load capacities (up to 480,000 pounds, but they come equipped with 750 HP motors and are rated for only 7,000 to 12,000 feet. These may be slightly underpowered for tough geothermal drilling.

For rigs equipped with top head drives, **DRECO** offers their D1000E DC powered drawworks. This machine has 1000 HP, can hoist 4¹/₂ inch drill pipe from 14,000 feet and accommodates 1¹/₄ inch wireline in 6, 8 or 10 line configurations. The hook load rating is 456,000 pounds using 8 lines and low gear. The D1000E has 4 hoisting and 2 rotating speeds; reverse gear is electric. DRECO also makes AC drawworks, but their smallest unit is the D1500AC, which is too large for the compact drill.

DRECO also makes drawworks in their "Unitized Electric (UE)" series. These would be adequate in all ways for the geothermal drill, but they come with a built-on rotary table. Since the use of a top head drive is planned on the compact drill, the table is undesirable.

National Oilwell has an excellent reputation for manufacture of superior drawworks. In the size needed for the compact geothermal drill, National has mechanically driven units designated 80-B and NE 1000 and also their electrically driven 80 UE and NE 1000 UDB machines.

All of these come with 1000 HP motors and are rated for 7,000 to 12,000 feet. The mechanical drawworks have 6 hoisting speeds while the electric machines have 4 hoisting speeds. The weights of these drawworks ranges from 45,000 to 50,000 pounds. National advertises the availability of AC electric drawworks, but gives no specifications.

Parker Technology Inc. makes mechanical and electric drawworks having motors in sizes up to 3000 HP.

3. Mast

For a compact geothermal drill, the primary requirements for a mast are that it be as short as possible, that it be fully self-erecting and that its capacity be more than 350,000 pounds. Otherwise, it can be telescoping or one-piece cantilever, A-Frame or triangular side frame style. Four companies have been identified as industry leaders, though masts can be obtained from many other firms. The four are:

- **DRECO Inc.** - PO Box 36619, Houston, TX 77236; Phone: (713)965-9122, FAX: (713)232-2875.
- **KREMCO**, a DRECO subsidiary - PO Box 36619, Houston, TX 77236; Phone: (713)965-9122, FAX: (713)232-2875.
- **Parker Technology, Inc.** - 4501 S. County Road 1310, Odessa, TX 79765; Phone: (915)563-2236, FAX: (915)561-9406.
- **Pyramid Manufacturing Company** - Box 691328, 10960 Millridge North, Suite 111, Houston, TX 77269; Phone: (713)445-8000; FAX: (713)894-0059.

One of the masts that fits all of the requirements for a compact geothermal drill is the **DRECO** model M10012. This 100 foot tall mast has a gross capacity of 500,000 pounds, a hook load capacity of 300,000 pounds when 6 lines are used and a 333,000 hook load capacity when 8 lines are reeved. The "Beam Leg Floor Mount Cantilever" mast is made of a steel type that is strong yet amenable to welding with low hydrogen techniques and it reduces to a cube that is smaller than those possible with other mast styles. The DRECO masts are compatible with DRECO-KREMCO "Slingshot" type substructures (discussed later in this report section).

KREMCO makes three masts that are also suitable for use on the contemplated compact geothermal drill. These are their models K160M, K170M and K180M. The mast capacities range from 352,000 to 396,000 pounds. Their heights range from 111 to 118 feet and all can use 8 or 10 lines of 1 $\frac{1}{8}$ inch diameter.

The **Parker Drilling Company** custom builds masts for drilling 10,000 to 30,000 feet. Their masts can incorporate various moving systems and top head drives, etc. Their cantilever, raised floor style masts come in six basic designs with hook load ratings from 350,000 pounds up and self erecting substructures. Parker also makes traditional box-on-box masts in 7 sizes beginning at 350,000 pounds capacity. Though these are excellent

masts, they do require crane erection and they are therefore not optimal for use on the compact geothermal drill.

The **Pyramid Manufacturing Company** specializes in masts for large offshore projects, however they do also make small masts. Pyramid masts are of the two piece, swing up types. They are erected in two lifts using a sheave and wireline system rather than a hydraulic system. Though no crane is required, a gin pole truck must be available. One Pyramid mast that might be suitable for the compact geothermal drill is 132 feet high, has a 10-line static hook load capacity of 390,000 pounds, a 22 foot high substructure and a drilling depth range of from 9,000 to 12,000 feet. Pyramid also makes helicopter portable masts that can be broken down into 4,000 pound lifts. Of interest for this project may be their 100 foot high mast having a static hook load capacity of 300,000 pounds. This unit may be slightly small as available off-the-shelf, but its capacity can probably be increased by 30% at reasonable cost.

Summary - Choosing a mast for the compact geothermal drill should not be difficult. There is little SOTA innovation available, thus equipment from any of the four firms listed above should be suitable. Cost will likely be the primary factor in identifying the ultimate supplier and product.

4. Pipe Handling Systems

Pipe handling systems include machines that can move drill pipe, collars and casing from their horizontal shipping position into vertical position over the drill hole or over a mousehole and vice-versa. They also include systems for breaking out and making up stands, slips for holding stands, and elevators for picking up pipe. There are many manufacturers of automated pipe handling systems. Four firms identified via interviews with knowledgeable industry representatives are:

- **DRECO Inc.** - PO Box 36619, Houston, TX 77236; Phone: (713)965-9122, FAX: (713)232-2875.
- **KREMCO**, a DRECO subsidiary - PO Box 36619, Houston, TX 77236; Phone: (713)965-9122, FAX: (713)232-2875.
- **Maritime Hydraulics AS** of Kristiansand, Norway, with North American offices at 11961 - A F.M 529, Houston, TX 77041; Phone: (713)849-0707, FAX: (713)849-0808.
- **Varco Drilling Systems** - 743 North Eckhoff Street, Orange, CA 92613-6626; Phone: (714)978-1900, FAX: (714)937-5029.

DRECO makes two basic types of pipe handling machines: their Javelin and their Side Arm Racker (SAR). The former is larger and is intended for use on all rig sizes. The latter is the machine used on the **KREMCO** PetroBras drills, which may be excellent for use on the compact geothermal drill. The SAR can handle up to 16 inch diameter pipe, casing or collars and is designed to coordinate with automatic iron roughnecks, slips and elevators.

the compact geothermal drill. The SAR can handle up to 16 inch diameter pipe, casing or collars and is designed to coordinate with automatic iron roughnecks, slips and elevators. It can rack pipe using rectangular or polar coordinates at rates as fast as one stand per minute.

Maritime Hydraulics makes the "Eagle", the "Eagle Light", the "Hole-in-One", a Catwalk Machine, Piperack Cranes, Bridge Cranes, 3-Arm systems Monkey Hands and Drillfloor Manipulator Arms. They also have lines of Iron Roughnecks, hydraulic and pneumatic elevators, power slips and Casing Modems.

Of all of these, the "Eagle Light" seems most suited to use on the compact geothermal drill. It can accommodate 47 foot long drill pipe with diameters ranging from $2\frac{7}{8}$ inch to 30 inch weighing up to 7,770 pounds. The unit can move 35 joints per hour and requires 3,000 psi of hydraulic power at 75 GPM.

Varco Drilling Systems makes more than 15 pipe handling machines and several racking systems. All of their pipe handlers are fully automatic and can handle any drill pipe, casing or collars that might be used on the geothermal drill. Of all their products, the PRS-1 or 2 models seem most appropriate for the size of the rig contemplated. These models can work with Star or conventional racking boards and they are designed to interface with the Varco AR-3200 Iron Roughneck and other automatic tools. Though Varco specializes in equipment for offshore drills, they do have machines suitable for the relatively small (10,000 foot) compact geothermal drill.

5. Power Systems

Many companies make reliable power systems, but Caterpillar is internationally considered to be the leader. They have service outlets all over the world, a widespread parts distribution network and superior maintenance availability. They can be reached at:

Caterpillar - Mossville, IL; Phone: (309)578-3736

For the compact geothermal drill drawworks and wireline spool, where approximately 1000 HP is anticipated to be needed, the SOTA **Caterpillar model 3512 AT** may be best. This diesel machine can produce 761 kW or 1020 HP at 1200 RPM for pumping or drilling types of intermittent use. This engine can run a 50 or 60 Hz generator and will produce 700 kW for "standby" (short duration loads) purposes, and 650 kW for "prime" (intermediate duration loads) or "continuous" loads. If a final design favored the use of two primary power sources totaling about 1000 HP, then the 500 HP model 3408 AT might fill the bill.

Note that this 1000 HP of power is intended only for the drawworks and a wireline spool. Additional power will be needed for the top head drive (about 750 HP), and for the mud pumps (1600 to 2000 HP). The latter two power requirements are discussed in the pump and rotary system report sections below.

6. Pumps

To maximize flexibility, reliability and versatility, it will be advisable to have four 400-500 HP Triplex mud pumps on the compact geothermal drill. Two companies lead in the manufacture of such medium sized pumps:

- **Continental Emsco Company** - Box 1522, Houston, TX 77251-1522; Phone: (713)640-7400, FAX: (713)643-7508.
- **National Oilwell** - 5555 San Fillipe Road, Suite 1600, Houston, TX 77056-2726; Phone: (713)960-5100, FAX: (713)960-5428.

Continental Emsco makes a model F-350 that produces 350 HP at 175 strokes per minute. It has a maximum bore of $6\frac{3}{4}$ inch and a stroke of 7 inches. The pump weighs ~17, 140 pounds. The output ranges from 569 GPM at $6\frac{3}{4}$ inches with a pressure of 949 psi to 200 GPM at 4 inches with 2705 psi. Though this pump may be slightly small, it might be usable in tandem with the National Oilwell 500 HP pump described below.

The **National Oilwell** pump most likely to be used, in a group of four or together with smaller Continental Emsco pumps, is the model 7-P-50. It is rated at 500 HP at 165 strokes per minute and has maximum bore and stroke dimensions of $6\frac{1}{4}$ and $7\frac{3}{4}$ inches respectively. This pump's output ranges from 510 GPM and 1515 psi at $6\frac{1}{4}$ inches to 160 GPM and 4830 psi at $3\frac{1}{2}$ inches.

As mentioned at the end of the preceding report section on power systems, the use of separate engines to run the mud pumps is anticipated. For this purpose one could use two **Caterpillar** model 3512 TAs (totaling 2000 HP) or four V12 style Caterpillar model 3412 TDs that output 500 HP each at 1800 RPM.

7. Rotary System

Interviews with geothermal and drilling industry representatives have gathered uniform recommendations that the compact geothermal drill be equipped with a top head drive rather than a rotary table/kelly or even a power swivel. DRECO and Varco were identified as the two manufacturers from whom top head drives of SOTA quality should be sought. These two firms can be reached as follows:

- **DRECO Inc.** - PO Box 36619, Houston, TX 77236; Phone: (713)965-9122, FAX: (713)232-2875.
- **Varco Drilling Systems** - 743 North Eckhoff Street, Orange, CA 92613-6626; Phone: (714)978-1900, FAX: (714)937-5029.

DRECO makes a model TD&H that is being used by its subsidiary KREMCO on the two drills being built for PetroBras in Clearfield, Utah. This top head drive has two, 200 HP two-speed Rexroth hydraulic motors. These have 3 motor settings, 6 torque ranges from

6,000 to 23,000 ft.-lb. and 6 speed ranges from 0 to 380 RPM. The static load capacity of the unit is 297,000 pounds while the dynamic load capacity is 198,000 pounds. These are slightly low for the geothermal drill and so DRECO would have to be contacted to learn if modifications could be made to increase the load-bearing capacity. Of significant benefit is the incorporation, in the drive, of a Griffith model 722 safety valve rated at 5,000 psi. This, in effect, adds to the BOPE below the drill floor.

Varco makes several top head drive models. The one best suited for use on the compact geothermal drill is the TDS-10S. This 500,000 pound capacity unit is run by two 200 HP single speed, Reliance AC variable frequency motors. These produce continuous torque ranging from 10,200 to 20,300 ft.-lb. and intermittent torque of 30,430 ft.-lb. at engine speeds that can be varied between 110 and 208 RPM.

The TDS-10S has a working height of 15.3 feet. It is fully compatible with Varco's PH-35 pipe handling system which uses 35,000 ft.-lb. of torque at 2000 psi to break out or make up connections of drill pipes having diameters ranging from 3½ to 5 inches.

The only problem with the Varco systems is that they are fairly tall as compared with the DRECO units. The TDS-10S requires a 136 foot mast if it is to pull triples. Varco will have to be asked specifically if the TDS-10S can be used in a doubles machine such as the theoretical compact geothermal drill.

8. Substructures

The primary requirements for the substructure for a compact geothermal drill are that it be self-erecting, that it have enough space and supporting capacity for 10,000 feet of drill pipe (racked as doubles) and that it have enough clearance for the "standard" ~18 foot high BOPE stack commonly used on geothermal production wells. At least three reputable companies make substructures to go along with the masts that they build, they are:

- **DRECO Inc.** - PO Box 36619, Houston, TX 77236; Phone: (713)965-9122, FAX: (713)232-2875.
- **Parker Technology, Inc.** - 4501 S. County Road 1310, Odessa, TX 79765; Phone: (915)563-2236, FAX: (915)561-9406.
- **Pyramid Manufacturing Company** - Box 691328, 10960 Millridge North, Suite 111, Houston, TX 77269; Phone: (713)445-8000; FAX: (713)894-0059.

The best SOTA substructure identified to date is the "Slingshot" style unit built by **DRECO** and used by its subsidiary on the PetroBras drills being built in Clearfield, Utah. This substructure travels on one trailer, is totally self-erecting in 9 minutes and has a small (75' x 100') footprint. The clear height below the drill floor is 18 feet and it can support 222,000 pounds (adequate for 10,000 feet of 4½ inch drill pipe and several drill collars. The substructure accommodates a DRECO M10510-450 mast and a hydraulic winch with an 8,800 pound capacity. It also has trolley beams on the underside that are capable of supporting and moving a BOPE stack weighing up to 44,000 pounds.

Parker builds substructures to specification or can supply one from among the many styles that it has designed. Their substructures are self-erecting or helicopter transportable.

Pyramid builds substructures that are 22 feet high and which can be erected with a gin-pole truck or with a helicopter. Few details are available for Parker or Pyramid units.

PART III. DESIGN AND COST ESTIMATES FOR A PROTOTYPE COMPACT DRILL

Following the SOTA review, a set of design criteria were established for a compact drill rig and these criteria were used to generate a set of questions which must be answered in designing any rig, but specifically the compact rig. These design guidelines and the rationale for them are given in detail in Appendix A.

Having established the design criteria, a company (DRECO) was selected and an actual rig design and cost estimate were done in preparation for the economic analysis. A summary description of the drill is given below, and a much more detailed description of the design is also found in Appendix A.

This drill has been designed to minimize the number of truck loads required to transport it from site to site while remaining powerful, safe and possessing environmentally desirable characteristics. Its use is foreseen to be predominantly in Lesser Developed Countries, where the roads can be "trails", steep and/or tortuous, the terrain rough, the wharf, bridge and culvert loads limited, cranes may not be readily available and where rig maneuverability and stability will be of special importance.

This drill, as designed, meets all of these requirements and can still drill geothermal production-scale wells to about 10,000 feet. It has enough power to drill through the tough rocks and challenging drilling conditions commonly encountered in geothermal fields and it has the hoisting power (with some extra) needed to lift and set the drill rods, collars, stabilizers and casings generally used by the geothermal industry.

Summary Description of the Compact Geothermal Drill

This drill has been designed to minimize the number of truck loads required to transport it from site to site and to be operable by two to three persons while remaining powerful, safe and possessing environmentally desirable characteristics. Its use is foreseen to be predominantly in Lesser Developed Countries, where the roads can be steep and/or tortuous "trails", the terrain rough, the wharf, bridge and culvert loads limited, cranes may not be readily available and where rig maneuverability and stability will be of special importance.

This drill, as designed, meets all of these requirements and can still drill geothermal production-scale wells to about 10,000 feet. It has enough power to drill through the tough rocks and challenging drilling conditions commonly encountered in geothermal fields and it has the hoisting power (with some extra) needed to lift and set the drill rods, collars, stabilizers and casings generally used by the geothermal industry.

The drill rig itself is designed to fit on three (3) trailers. A total of only **16 truck loads** will be required to transport the drill and all ancillary equipment. **The drawworks** is a 700

HP diesel-mechanical unit with 6 forward speeds, a maximum single line pull of 55,000 pounds and a maximum line speed of 2,474 feet per minute.

The main engine is a Caterpillar 3412 DI-TA diesel rated for 700 HP at 2,100 RPM. A second, supplemental 300 HP engine is provided to help run hydraulic power units. **The mast** is 100 feet high, has a gross capacity of 600,000 pounds and a static hook capacity of 400,000 pounds with 8 lines strung. The mast is built in three sections that are assembled on the ground and then raised without the need for cranes. The racking board is designed to hold 10,000 feet of drill pipe and collars.

The substructure is of the "slingshot" type, is transported on two trailers and is raised hydraulically from a single station control. It is 22 feet high to accommodate a full geothermal BOPE stack, 35 feet long and 20 feet wide. With accompanying mud pits, pipe racks, mud pump engines, miscellaneous equipment and storage sheds, a drill site of less than 200 feet by 200 feet (less than 1 acre) will suffice for this compact drill.

The drill is equipped with DRECO's DTD-H-200-25-350-G hydraulic **top head drive**. Its 400 HP is generated using two 200 HP variable displacement, 5,000 psi hydraulic piston motors. The 200 ton capacity, two speed unit has a maximum torque of 25,000 ft.-lb. and speed ranges from 0 to 350 RPM.

This drill has an **automated Side-Arm Racker** comprising a hinged arm mounted on a dolly that can move up and down along the driller's side of the mast. The arm, which can pivot from horizontal to vertical and swing from side to side, has two telescoping pipe grippers for holding and moving the tubulars. The racker can handle tubulars from 3¹/₂ inch to 9¹/₂ inch, collars to 13³/₈ inch and core barrels. In case of a malfunction, the arm can be manually manipulated.

The racker can perform three operations: 1) it can pick up tubulars from a pipe rack, pipe bin or a truck to stab them directly into the tubular in the slips or reverse this procedure, 2) it can move tubulars from storage into the automatic mousehole for makeup into doubles or reverse this procedure and 3) it can remove doubles from the mousehole and stab them into the tubulars in the slips or place them in the rack. This flexibility allows makeup and breakdown of doubles while drilling or tripping and minimizes tubular wear and tear due to frequent lay-downs.

Other parts of the **tubular handling system** include hydraulic slips, hydraulic power tongs, an automated, "Phantom Mouse" mousehole manufactured by International Tool Co., and an auxiliary 4 ton, hydraulic, mast-mounted handling boom with floor-mounted controls.

An **operator's cabin**, approximately 5 feet wide and 6 feet high is provided. The cabin and the contained ergonomically designed console are located so that all rig activities can be seen. The controls are computer interfaced and each function can be customized to varying degrees. Though there is considerably more **instrumentation** on the driller's

control panel, the following is a list of some important instruments included with the compact drill:

- A 200 ton electric weight indicator
- A hydraulic pressure activated drilling torque indicator reading in ft.-lb.
- A THD RPM digital indicator.
- Two M/D Totco mud pump stroke counters with a range of 0-200 strokes per minute.
- A M/D Totco mud pressure gauge that receives its signal from a 2 inch 6,000 psi sensor on the mud standpipe manifold. The gauge is 6 inches in diameter, measures to 5,000 psi and comes with a hand pump and filling fluid.
- Two 10 foot mud tank level indicators with 250 feet of cable.
- An air receiver tank, 0-300 psi pressure gauge.
- A make-up/break-out, hydraulic pressure activated, 0-110,000 ft.-lb. torque gauge for use with either the hydraulic power tongs or the back-up hydraulic cathead tongs.
- A power tong, hydraulic pressure activated clamping pressure gauge.
- A hydraulic system tank level indicator and
- A hydraulic system oil temperature gauge.

The **hydraulic power systems** are driven by 2 diesel prime movers: one is the 700 HP Caterpillar 3412 main engine and the other is a skid-mounted Caterpillar 3306 300 HP engine. **Multiple hydraulic pumps** with axial pistons and variable displacement are used for high horsepower drivers. Gear driven pumps are used for the lower horsepower drives. The **hydraulic fluid tank** is baffled, has a removable top, a low-point drain, maintenance shut-off valves, a filler/breather cap and an oil-level sight gauge. Four levels of fluid filtration are provided.

Two DRECO 9015-D5 **hydraulic catheads** are mounted on the mast legs for breakout duty or for other stand-by service. A make-up and a break-out cathead are included. Their line pull capability is 32,900 pounds at 2,500 psi for break-out purposes. A hydraulic-powered **wireline spooler** is also provided. Its reel comes loaded to capacity with 11,500 feet of 1 $\frac{1}{8}$ inch diameter 6 x 19 EWRC XIPS wireline. Finally, a **hydraulic back-up wrench** is mounted below the THD.

Supply of the following items was not requested from DRECO, yet they are needed to make the compact drill operational: the **mud pumps** and other **high pressure equipment**, the **mud conditioning equipment**, the **BOPE** and controls, the **drill strings** and **bottom hole assembly** and miscellaneous tanks, sheds, pumps and tools.

The total rig and optional wrench cost used for working calculations is \$3,620,000.

DRECO's proposal was based on a "bare drill rig" because all other equipment needed to drill a well would be the same for this drill rig as for a "conventional" drill. Following original submittal of this report to Sandia, however, discussions concerning its contents were held with geothermal drilling industry experts during an "Advanced Drilling

Workshop” sponsored by Sandia and held in Berkeley, CA on April 14 and 15, 1997. In accordance with their recommendations, the following additions to the cost estimate were made.

Mud pumps and high pressure equipment	\$750,000
Mud conditioning equipment	300,000
BOP equipment	875,000
Miscellaneous (fuel and water tanks, sheds, pumps, tools etc.) .	300,000
Drill string and BHA	<u>433,000</u>
Additional Total	\$2,658,000

Estimated Total Cost for a Compact Geothermal Drill

DRECO quotation for the basic drill	\$ 3,620,000
Additional Total from above	<u>2,658,000</u>
Subtotal	\$ 6,278,000
Contingency (5%)	314,000
Taxes (8%)	<u>502,000</u>
Total cost	\$ 7,094,000

Expendable costs (Short Term Debt) - (Drill pipe and BHA)	\$ 433,000
Capital Costs (Long Term Debt) - (\$6,278,000-\$433,000)	\$ 5,845,000

PART IV. ECONOMIC ANALYSIS OF A COMPACT DRILL RIG

Cost Benefit Analysis Summary Description

The compact geothermal drill described here is smaller, easier to erect, operable by a very small crew and easier on the environment than "conventional drills" currently used by the geothermal industry to drill 10,000 foot deep production scale wells outside the US.

The cost-benefit analysis summarized below has been based on a comparison of the costs of building, shipping, constructing well locations operating and rapidly rigging up/rigging down a compact geothermal drill rig with the same costs for a new "conventional" drill rig. The underlying assumption is that, in the relatively short term, the drills now being used will reach the end of their useful lives and then decisions will have to be made whether to buy a new "conventional" drill or a compact geothermal drill. Details of cost estimates for each item in the analysis below are given in Appendix B.

The objective of the analysis is to determine if savings in the compact drill transportation, daily rate, well site construction and operational efficiency can be great enough to persuade geothermal contractors to build and geothermal developers to use the compact drill after the current availability of inexpensive drill rigs ends.

Basic procedures and assumptions used in the cost benefit analysis were as follows:

1. After obtaining a quotation from DRECO, Inc. for construction and testing of a compact geothermal drill closely following the specifications in Appendix A, prices were estimated for all additional equipment not provided by DRECO and needed to make the compact geothermal drill operational.
2. Daily rental rates for the geothermal drill were calculated, using as a base and appropriately modifying, selected figures and rationales contained in Pierce, Finger and Livesay, May 1996 concerning a hypothetical 18,000 foot capacity drill. After the number of Revenue Tons and the estimated daily rental rate for a new 1000-1500 horsepower "conventional" triples drill with capabilities similar to those of the compact geothermal drill were obtained from a reputable drill manufacturer, these figures were compared with those for the compact geothermal drill in order to calculate savings in the daily rate and in shipping costs from Houston, TX to Jakarta, Indonesia.
3. Information concerning the typical size of geothermal well sites and the cost to construct them was obtained from geothermal industry sources. Knowing the difference between the well site needs for the compact geothermal drill and those of "conventional" drills enabled estimates of possible well site construction savings.
4. Savings attributable to the efficiency with which the compact geothermal drill can be moved in and out of well sites and be rigged up and down were calculated.
5. Total annual savings were calculated for the compact geothermal drill assuming that four 10,000 foot deep wells would be drilled, in 60 days each (not including

MIRU/RDMO) in a foreign country, with the drill working only 75% of the time (9 months of the year).

6. A return on investment was calculated by determining the number of years required to pay off the initial investment in the compact geothermal drill.

Finally, a business scenario was described through which a drilling contractor and one or more geothermal project developers could take advantage of the savings due to use of a compact geothermal drill to improve profits and their competitiveness in electricity (or steam) sales markets.

The **estimated total cost for a compact geothermal drill**, including the DRECO-supplied components, the "add-ons" needed to be operational, a 5% contingency and 8% sales tax are as follows:

DRECO quotation for the basic drill	\$ 3,620,000
Mud pumps and high pressure equipment	750,000
Mud conditioning equipment	300,000
BOPE and controls	875,000
Miscellaneous equipment	300,000
A 4½ inch drill string and a full bottom hole assembly	<u>433,000</u>
Subtotal	\$ 6,278,000
Contingency (5%)	314,000
Taxes (8%)	<u>502,000</u>
Total cost	\$ 7,094,000

From the drill costs listed above, long and short term debt components were identified as:

Expendable/Short Term Debt - (Drill pipe and BHA)	\$ 433,000
Capital Costs/Long Term Debt - (\$6,278,000-\$433,000)	\$ 5,845,000

Following procedures and rationales described in Appendix B, the **daily rental rate** components for the following compact geothermal drill parameters and the total daily rate were calculated as:

• Long Term Debt	\$3,100
• Short Term Debt	2,700
• Maintenance	1,700
• Labor	2,250
• Office Support	350
• Insurance	190
• Fuel	<u>2,375</u>
Daily Rate Total	\$10,825

The daily rental rate for a new conventional drill having the same or similar capabilities as the compact geothermal drill has been informally quoted at **\$14,000 to \$15,000**.

Accordingly, the savings in the daily rate possible via use of the compact geothermal drill would be at least **\$3,175**. For a 60 day, 10,000 foot well this would aggregate **\$190,500** and by drilling 4 wells per year, **\$762,000 could be saved annually**.

To calculate **shipping cost savings**, the fees for shipping a conventional drill totaling 4,500 revenue tons were compared with those for shipping a 1,351 revenue ton compact geothermal drill. At \$160 per revenue ton, first year savings of **\$503,840** are possible. One of the chief benefits of the compact geothermal drill is that the **size of the well site** required is 70% smaller than that needed for a conventional drill (3.67 acres versus **1.0 acre** or less). The costs to prepare an average well site for a conventional drill is \$50,000 to \$150,000. In foreign countries, adverse terrain and road conditions can increase this to \$300,000.

Though a compact geothermal drill will require only about 1 acre per well site, the costs to build it will not be 70% less than those required to build a 3.67 acre site. It is estimated that the 1 acre well site will still cost about \$200,000 so that savings of \$100,000 per site can be realized. If four well sites are built per year, **annual well site construction savings accruing to the compact geothermal drill will total \$400,000**.

One of the greatest advantages in the use of a compact geothermal drill is the speed with which it can be moved in and rigged up at the start of a well and then rigged down and moved out to the next location upon well completion. MIRU/RDMO on a conventional drill averages 8 to 10 days. The time needed for the DRECO compact geothermal drill can be 2 to 3 days.

The standby rate (commonly charged during MIRU/RDMO) for a conventional drill averages about 75% of the operating day rate or \$9,546 for a new conventional drill. If use of the compact geothermal drill will save only 4 days each way on MIRU/RDMO, then for 4 wells per year, **\$305,472 could be saved by the assembly/disassembly efficiency of the compact geothermal drill**.

It should be noted that neither savings that might accrue to the compact drill during intra-field moves nor those possible due to decreased costs of shipping the drill back to the US eventually have been considered in this analysis. (Rationales for these omissions are given in Appendix B).

Summary of Cost Savings Possible via Use of a Compact Geothermal Drill - In the preceding report sections, calculations have been made of cost savings that may be possible by drilling 4 wells per year using a compact geothermal drill instead of a conventional drill having the same capabilities.

Table 1, below lists the annual savings accrued through use of an efficient compact geothermal drill to set up and drill 4 wells per year compared with a "conventional drill" having the same capabilities.

TABLE 1

<u>YEAR</u>	<u>SAVINGS</u>	<u>CUMULATIVE SAVINGS</u>
1	\$ 1,971,312	\$ 1,971,312
2	1,467,472	3,438,784
3	1,467,472	4,906,256
4	1,467,472	6,373,728
5 (4.491)	720,272	7,094,000

Note that in Year 5, \$1,467,472 is the amount of savings available to pay off the difference between the Year 4 cumulative total (\$6,373,728) and the full investment in the geothermal drill (\$7,094,000). The \$720,272 needed to make up that difference and pay off the drill is 0.491 of 1 year's savings. Thus, **4.491 years** of work (~18 wells) will pay off the geothermal drill investment cost.

Using these figures, the savings attributable to the use of a compact geothermal production well drilling rig create an ROI of 22.27%.

ROI Penalty for Using a Doubles Drill versus a Triples Drill - Consideration has been given to the fact that a "conventional" drill pulling three drill pipes at a time might drill a 10,000 foot deep well faster than the compact geothermal drill that is designed to pull only two drill pipes at a time.

Rate of Return calculations made using 3 days "tripping penalty" (to allow for trips made for reasons other than bit changes) on 4 wells per year show that the **22.78%** ROI without the penalty is reduced to **22.14%** with it. This minimal ROI decrease of 0.64% confirms that the bottom line advantage of using a triples drill is small.

Recommendations

1. A Business Scenario to Benefit Drilling Contractors and Geothermal Developers

The impressive savings identified above will be realized if they can be utilized by both the drilling contractors serving the geothermal industry and the geothermal developers working on foreign projects. The business scenario proposed below facilitates this.

- One or more geothermal developers contract agree to employ a drilling contractor to drill no less than four, 10,000 foot deep (~60 day) geothermal wells per year at a foreign site until at least 18 wells have been drilled. This agreement is conditioned on the contractor's funding of the construction, shipment and use of a compact geothermal drill.
- The drilling contractor has the compact drill built and shipped overseas and uses it to drill at least eighteen 10,000 foot deep (or 60 day) wells.

- The contractor gets paid enough during this contract to pay off the drill, so that the drilling company now owns it free and clear.
- The drilling contractor's future profits will greatly increase because he will have no more long term debt to pay on this drill and he can improve his economics still further by saving about \$500,000 (over the cost of returning a conventional drill to the US) when his compact geothermal drill is moved back to the US.
- Last but not least, the geothermal developers have reduced the cost of their geothermal well drilling by **22.78%**, improved their project economics and in this way gained the ability to price their generated electric power or their sales of steam more competitively with respect to fossil fuel-generated power.

2. Marketing of the Compact Geothermal Drill Concept

It is acknowledged that there may well be considerable resistance to the concept of a compact geothermal drill both from the drilling contractors and the geothermal developers. There has always been a certain amount of "inertia" in the drilling industry that promotes a philosophy of "if it ain't broke, don't fix it". The conventional drills now in use do work and the industry veterans are quite comfortable with their capabilities.

The geothermal developers may resist because of the glut of relatively inexpensive conventional drills presently available. However, this glut will not last forever and they should anticipate the demise of the "dinosaurs" by accepting the compact drills.

In order to begin marketing the compact geothermal drill, it is recommended that meetings be scheduled with the major geothermal developers and with several drilling contractors currently building drills. The compact drill would be described, pictures of the PetroBras drills would be shown, the business scenario would be presented and questions would be answered. Hopefully, in this way, initial interest could be generated and just maybe, one or more developers and contractors would be impressed enough to build and use the first drill.

APPENDIX A

COMPACT DRILL RIG CONCEPT AND RECOMMENDED DESIGN

See especially "Recommended Compact Drill Rig Design" , page A-12

1.0 Drill Rig Concept: This drill should be a predominantly automated doubles rig with a top head drive, a mast ~ 100 feet high and a self-erecting, ~ 20 foot high substructure. It should have a small footprint and be transportable in about 10 truck or trailer loads including engines, generators, pumps, the mud system and tubulars for a 10,000 foot well.

The drill should utilize state-of-the-art hard and software that is (or will soon be) accepted by the drilling industry as having economic efficiency and safety advantages over "traditional" hardware. Use of this drill is intended to save money, time and environmental degradation when compared to use of the "conventional" large, triples drills currently used by geothermal developers.

Note: The previous requirement recognizes the current availability of older, large drills at very low cost due to relatively low demand for them in the petroleum industry. It is anticipated that this "oversupply" will end soon. The introduction of the cost-effective compact geothermal production well drill is scheduled for that time.

2.0 Specifications of the Compact Geothermal Drill

2.1 Crew size - Drilling and tripping should be possible with two men. A third, and if absolutely necessary, a fourth will be on site for performance of miscellaneous plumbing, electrical, hydraulic and mechanical operation/maintenance functions.

2.2 Drill pipe stand size - The drill should be designed to allow the make-up of doubles (~60 feet) in the mousehole while drilling and the racking of doubles while drilling or tripping.

2.3 Pipe handling

2.3.1 - Pipe handling should be fully automated. An arm should be designed to be able to pick up singles from the off-rig pipe rack, pipe bin or truck, swing them into vertical position and place them either into the mousehole for make-up into doubles while drilling or over the hole for stabbing into the drill string. The arm should also be able to move doubles from the well while tripping out and either rack them using polar or rectangular coordinates, move them to the mousehole for break-down or lay them down (as doubles) off-rig if necessary.

2.3.2 - A break-out wrench should be attached to the top head drive assembly to allow disconnection of the top head drive when it is positioned far above the rig floor.

2.3.3 - The mousehole should have a moveable, spring-loaded floor to assure minimum impact-related damage and a pipe gripper/spinner system to allow make-up of doubles while drilling or tripping.

2.3.4 - Automated, (hydraulic preferred) slips should be provided in sizes adequate to hold drill pipe and collars up to 9¹/₂ inch diameter.

2.3.5 - Automated tongs and supplementary catheads should be hung just above the rig floor.

2.4 Rig-up/rig-down - The substructure and mast should be designed to be raised and lowered easily without the use of cranes or gin-pole trucks. Sling-shot or wireline methods are preferable. The objective should be rig moves requiring hours (rather than days) for short (< 1 mile) distances.

3.0 Transportation

The drill should be mounted on a very few trucks or trailers so that assembly can be rapid and efficient. Possibly, the drawworks, power plant and the upper part of the mast could comprise one load, while the substructure, controls, the rest of the mast, pipe handling equipment, the floor and stairs might make-up a second load. A third load might include the mud system, a fourth load the mud pumps and engines and a fifth load could be tubulars. Probably one or two other loads would transport miscellaneous items (drilling supplies, bits, spare parts, sheds, fuel/lubricants etc.).

4.0 Primary Truck/Trailer Characteristics

4.1 Critical Features - Whether they are mounted on self-propelled or truck-and-trailer style beds, the "drawworks etc." load and the "substructure etc." load should be designed with the following in mind:

- 4.1.1 - Use of construction materials having maximum strength-to-weight ratios,
- 4.1.2 - Centers of gravity should be as low as possible while still allowing ground clearance adequate for travel on dirt roads (at least 1 foot).
- 4.1.3 - Loads should have a tolerance for road crowns of up to 5°.
- 4.1.4 - Loads should be narrower than 12 feet.
- 4.1.5 - All vehicles should have enough axles to permit the "weight per axle" to comply with bridge/road limits in developing countries (~20,000 pounds per axle).
- 4.1.6 - Vehicle heights should be as low as possible (preferably under 16 feet) to allow passage beneath most power/phone lines.
- 4.1.7 - Vehicle lengths should be as short as possible (preferably under 50 feet) to allow use of short radius switchbacks on mountain roads and
- 4.1.8 - Jacks should be provided for load stabilization or leveling during storage or rig-up.

5.0 Drawworks

Though the compact geothermal drill is being designed for nominal 10,000 foot capability, the severity of subsurface geothermal drilling conditions commonly encountered dictates that 1000 horsepower drawworks, either mechanical or electric be specified. Several adequate machines include:

Continental Emsco: Mechanical or Electric - Model D-3 (possibly D-2).

Dreco: DC Electric - Model D1000E

National Oilwell: Mechanical - 80-B or NE1000
Electric - 80 UE or NE 1000 UDB

IRI-IDECO: DC Electric - E-1200
AC Electric - Model 1000

5.1 Drawworks features - All of these drawworks operate at or close to 1000 horsepower and can hoist 4½ inch drill pipe out of 10,000 to 14,000 foot wells and lift 6,000 feet of 42 pound per foot 9⅝ inch casing using 8 to 10 line string-ups. Most units have at least 4 hoisting speeds. The AC electric units have infinitely variable speeds.

5.2 Technical descriptions - The parameters listed below must be optimized.

5.2.1 - Drum: Diameter and length; Lebus grooving desirable.

5.2.2 - Main Brake: Size and description.

5.2.3 - Drum Clutch: Drum or disk?, torque capacity?, oil states?, Eaton, Fawick?

5.2.4 - Drum Drive: Chain size and number, or direct drive.

5.2.5 - Drum Shaft: Steel type.

5.2.6 - Drum Shaft Bearings: Describe.

5.2.7 - Lubrication Method: Describe.

5.2.8 - Controls: Electric?, Pneumatic?, where located?

5.2.9 - Main Frame Construction: Describe steel thickness, skid weight.

5.2.10 - Hydromatic Brake: Describe chains and clutch (Eaton?).

5.2.11 - Brake Cooling System : Water or air?

5.2.12 - Primary Power Source (Main Engine): Caterpillar Model 3512AT (1020 HP at 1200 RPM or consider two 500 HP Caterpillar 3408AT or equivalent.

5.2.12.1 - Spark Arrestors: Needed?, on exhaust?

5.2.12.2 - Engine Kill Valve: Where located?, how many?

5.2.13 - Transmission: Describe; Allison?, with or without torque converter?, one or more output shafts?, how many speeds?

5.2.14 - Compound Transmission: To the hydraulic system?, describe.

5.2.15 - Drive Lines: Manufacturers and series numbers.

5.2.16 - Gear Box from Engine to Drawworks:.

6.0 Mast

The objective is a mast as short as possible (for transportation reasons) that can pull doubles, accommodate a top head drive, support an automatic side-arm pipe-racker and be wide enough at the base to allow setting of 30 inch surface casing through the floor.

6.1 Suitable Mast - Dreco Model M10012 Beam Leg Floor Mount Cantilever Style (or equivalent).

6.2 Specification

6.2.1 - Height: ~100 feet, base width: ~12 feet.

6.2.2 - Gross capacity: ~500,000 pounds; hook load capacity: ~333,000 pounds with 8 lines strung.

6.2.3 - Windload: Describe with and without setback (From manufacturers).

6.3 Certifications - API numbers should be listed for all parts (From Manufacturers).

6.4 Special Features

6.4.1 - Connections to substructure: One end of each member in the back face of the mast should be designed to stay pinned so as to facilitate reassembly.

6.4.2 - Space utilization: beam leg masts preferred in order to reduce the size of the package for moves.

6.5 Technical Aspects

6.5.1 - Mast Stem: Describe upper and lower parts, how they attach and how they travel.

6.5.2 - Crown: Describe steel type, sheaves and mounting style, sheave bearings, bearing lube access, platform, padeye for top head drive and traveling block, other padeyes and deadline location.

6.5.3 - Finger Board: Describe style (rectangular or radial), capacities (minimum 10,000 feet of doubles including drill pipe, collars of several sizes and stabilizer(s).

6.5.3.1 - Height should be between 50 and 60 feet above the rig floor

6.5.3.2 - Platform must have standard safety features including a winch, a safety belt tie off etc.

6.5.4 - Ladder(s): Describe lengths and locations; full mast height on driller's side.

6.5.5 - Wireline Sheaves: groove for 0.092 inch slickline.

6.5.6 - Other Sheaves: Describe grooves for tugger(s) and sandline.

6.5.7 - Tong Counterweights: Describe.

6.5.8 - Mast Raising System: Describe cylinder sets, their uses and control locations.

6.5.9 - Top Head Drive Package: Describe rails, dollies, torque resistors, tensioners, power outlets, etc.

6.5.10 - Clamps: 4 inch clamps required for mud standpipe; 2 inch for hydraulic line and 1½ inch for air line

6.5.11 - Mast Leveling Equipment: Appropriate shims and 25 ton jacks to be provided.

6.5.12 - Paint: Use of zinc-rich primer and two 3 mil thick coats of epoxy paint required.

7.0 Substructure

7.1 General Description - The substructure should be completely self-erecting, fit on a single truck or trailer load, have a small (<100' x 100') footprint and be high enough to accommodate BOPE including double pipe rams, double blind rams, a flow T or Banjo Box a 9⅝ inch annular and a 9⅝ inch rotating head (~20 feet). The rig floor should be strong enough to support the full setback load and spacious enough for all automated tools, the setback stands of drill pipe, the control console, etc.

7.2 Substructure Features

7.2.1 - Rig-up: Should be easy and rapid with enough guides, stops, rollers, etc. to expedite assembly. Specified materials must be easily welded and able to withstand erection stresses over the lifetime of the drill. Design should permit assembly of all equipment on the substructure prior to its raising and preclude the need for cranes or gin-pole trucks.

7.2.2 - Substructure raising: The assembled substructure and mast should be able to be raised hydraulically, with the wireline, or with the use of jacks. One central station should be designed from which all raising activities can be safely controlled.

7.2.3 - Safety: The substructure should be designed so that no personnel need to be on it during raising or lowering. Also, all stairs and handrails should be in place prior to raising so as to be immediately available when substructure erection is complete.

7.2.4 - Transport: The need to disassemble rig parts for moves should be minimized. Any such disassembly should be facilitated by the use of pins rather than bolts. The substructure should be designed to collapse into a shape that can fit on one truck or trailer load that will comply with applicable road and bridge regulations.

7.3 Substructure Specifications

7.3.1 - Floor Height: Should be adequate to accommodate the BOPE as listed in section 7.1 above. It is estimated at ~ 20 feet.

7.3.2 - Floor Dimensions: Should be approximately 30 feet long by 20 feet wide with fold-up side wings if necessary.

7.3.3 - Floor Capacities: Should support a hook load of 700,000 pounds on the mast and a setback weight of 260,000 pounds. This assumes the maximum weight to be 6000 feet of 9⁵/₈ inch, 42 pound per foot casing.

7.3.4 - Equipment to be accommodated on the rig floor:

Automated tongs/cathead	Driller's console
Auto-spin mousehole	Skid-mounted wireline unit
Mast such as Dreco M10012.	Setback stands

7.4 Technical Descriptions

7.4.1 - Base boxes: Prefer one set of girders ~ 25 feet long.

7.4.2 - Floor elevator: Design to allow flush floor with master bushing support frame installed. Include mast shoe mounts and pin pockets for vertical supports.

7.4.3 - Vertical supports: Provide one set to support the floor elevator above the base.

7.4.4 - Cylinders: Design for provision of multistage hydraulic cylinders used to raise/lower the floor elevator girders. Cylinders should retract for storage during drilling operations.

7.4.5 - Rotary beams: Design as required to support the master bushing support frame flush with the drill floor.

7.4.6 - Rotary/setback spreader: Design to accommodate 6 inch timber over ³/₈ inch plate steel. Should include framed mousehole opening and referenced timber installed.

7.4.7 - Flooring: ³/₈ inch steel plate should be provided around the master bushing; ³/₁₆ inch plate steel will suffice elsewhere. All plate should be reinforced with "stiffeners".

7.4.8 - Winch: One hydraulic winch on a pedestal should be included. Capacity should be equal to or better than that of a Braden model BG8A.

7.4.9 - Tong connections: Provision should be made for a set of two removable tong back-up connections in the mast legs.

7.4.10 - Stairs: Stairs to the ground must be provided on the driller's console side and, on the off-driller's side of the floor, stairs should lead to the shaker tank area. Handrails and skid resistant (serrated) treads should be included on all stairs.

- 7.4.11 - BOPE beams: Two 25 ton capacity beams should be designed to fit under the substructure so as to accommodate a trolley used to install and remove BOPE.
- 7.4.12 - Paint: The substructure should be blast-cleaned, covered with a 3 mil thick coat of a zinc-rich primer and painted with two 3 mil thick coats of epoxy paint.

8.0 Traveling and Rotating Equipment

8.1 Top Head Drive

8.1.1 - General description: The top head drive can be run on DC current, AC current or hydraulic pressure, but it should generate about 25,000 to 30,000 ft.-lb. of torque at variable or multiple speeds from 0 to ~ 350 RPM. It is likely that two 200 HP motors will be required.

8.1.2 - THD Specifications:

Horsepower: About 400.

Number of motors: 2

Type: Rexroth (hydraulic), Reliance (electric) or equivalent.

Load capacities: 350,000 pounds static; 260,000 pounds dynamic.

Pressure (if hydraulic): 4,000 to 5,000 psi.

8.1.3 - THD Performance:

0-350 RPM

1, 2 or 3 gears

Motor setting/Speeds: Electric - infinite; hydraulic - 1, 2 or 3

Torque capability: 25,000 ft.-lb. continuous, 30,000 ft.-lb. intermittent

8.1.4 - THD Technical Descriptions:

8.1.4.1 - Motors: Hydraulic motors should comprise two of 200 HP each, variable displacement, piston types made by Rexroth or the equivalent. Electric motors should comprise two of 200 HP with single speed, variable frequency (AC) made by Reliance or the equivalent.

8.1.4.2 - Gear Drive/Frequency Control: If hydraulic, should be a remote, multi-speed gear drive or, if AC electric, a square wave frequency control for infinite 0 to 350 RPM.

8.1.4.3 - Lubrication: Should be self contained with adequate pumps and filtration in the top head drive assembly.

8.1.4.4 - Top Head Drive Shaft: The design should incorporate a way to protect threads when making or breaking connections. ID and OD should be compatible with 3 1/2 and 4 1/2 inch drill pipe.

8.1.4.5 - Seals: Regardless whether the top head drive is electric or hydraulic, all connections and or hoses must be designed to: 1) prevent mud entry into the gear case, and 2) withstand envelopment in wet steam or water at 300°F for 2 hours. Seals and hoses rated at 210°F may be used if they are protected by steel deflection shrouds.

8.1.4.6 - Bail Hooks: The top head drive body should be equipped with bail hooks able to accommodate links having a 320,000 pound capacity.

8.1.4.7 - Safety Valve: The top head drive must be equipped with a safety valve rated for at least 5,000 psi working pressure. Size and thread connections must be compatible with adjacent drill pipe and the top head drive shaft.

8.1.4.8 - Saver Sub: The top head drive should be equipped with a saver sub having connecting thread sizes and orifices compatible with the adjacent drill pipe and the top head drive shaft.

8.1.4.9 - Backup Wrench: The top head drive should be equipped with a hydraulic backup wrench sized to handle up to 5 inch drill pipe and with torque capability to 25,000 ft.-lb.

8.2 Master Bushing Support Frame - Note: The extra large opening is specified so that 30 inch surface casing can be set through the rig floor.

8.2.1 - Specifications:

Frame opening: 37 $\frac{1}{2}$ inches

Static Load rating: 600,000 pounds (to allow for jacking, if necessary)

Shape: Rectangular, with cover to create flush floor.

8.2.2 - Master Bushing: One Den-Con "37 $\frac{1}{2}$ - 49 $\frac{1}{2}$ inch HMB Hinged Pin" drive master bushing or equivalent. Should include lifting slings, be compatible with automatic slips and fit in the master bushing support frame.

8.3 Traveling Block - Should be a 300,000 pound capacity Dreco 436B-150 or equivalent designed to accommodate wireline and/or a coring arrangement, accept sheaves of various sizes and have an adequate, accessible lubricating system.

8.3.1 - Specifications:

Load Capacity: 300,000 pounds.

Number of Sheaves: 4 minimum (5 if possible).

Planned wireline size: 1 $\frac{1}{8}$ inch.

Shaft diameter: As required; 5 to 8 inch.

Sheave diameter: 36 to 42 inch.

8.4 Deadline Anchor - Design for mast-leg mounting on the off-driller's side. Should be a Dreco Model LOF-50-C or equivalent.

8.4.1 - Specifications:

Rated Capacity: 50,000 pounds.

Load Cell(s) Accommodated: weight, compression and tension; Martin Decker or Totco models as follows:

	<u>M-D</u>	<u>Totco</u>
Weight	Type D	WLA 50 }
Compression	E 543	213731 } or equivalent
Tension	E 80	212407 }

Anchor Test Load: 75,000 pounds.

Wireline Size: 1 $\frac{1}{8}$ inch.

Drum Diameter: 24 inches.

Weight: should be 1,000 to 1,400 pounds.

8.5 Links - Should be weldless, with 300,000 pound capacity.

8.6 Elevators

8.6.1 - Sizes: Must be suitable for 3 $\frac{1}{2}$, 4 $\frac{1}{2}$ and 5 inch drill pipe.

8.6.2 - Capacities: 300,000 pounds.

8.6.3 - Types: Bottleneck, center latch, 18° angle, with remote operation such as:

DEN-CON CL-150 #7450-119 (for 3 $\frac{1}{2}$ inch)

DEN-CON CL-150 #7450-121 (for 4 $\frac{1}{2}$ inch)

DEN-CON CL-150 #7450-123 (for 5 inch), or equivalent

9.0 Pipe Handling Equipment

9.1 Side-Arm Pipe-Racker

9.1.1 - Requirements:

- 9.1.1.1 - Pick up drill pipe, collars, casing or other tubulars from a truck, pipe rack or pipe bin. Move them to well center and stab into string for make-up.
- 9.1.1.2 - Reverse procedure when coming out of hole and laying down pipe.
- 9.1.1.3 - Place single drill pipes into mousehole for make-up into doubles.
- 9.1.1.4 - Rack and remove doubles from racking board during trips in and out.
- 9.1.1.5 - Pick up doubles made up in mousehole and move them to racking board during drilling operations.

9.1.2 - Basic Design: Should allow movement up and down side of mast, pivoting of arm from horizontal to vertical and from side to side. Pipe grippers should telescope and be useable in a "pick-up/lay-down" mode and in a racking mode. The racker should be able to lean drill pipe slightly out of vertical when in the racking mode.

9.1.3 - Capabilities:

- 9.1.3.1 - Handle singles or (60 foot) doubles.
- 9.1.3.2 - Handle 3¹/₂ inch drill pipe, 9¹/₂ inch collars, 13³/₈ inch casing and core barrels.
- 9.1.3.3 - Manual override should be possible.
- 9.1.3.4 - Optimum movement patterns so as to minimize impact loads.
- 9.1.3.5 - Rapid, accurate movements.
- 9.1.3.6 - Heavy-duty components in order to minimize maintenance costs.

9.2 Side-Arm Racker Controls

9.2.1 - General Description: The controls should be designed to allow gradual stops and starts and accurate positioning.

9.2.2 - The controls must be safe and easy to use. Arm motion limits and operational sequencing should also stress safety and efficient pipe movement.

9.2.3 - All controls should be designed to operate only when someone's hand is on them. Auto-movement should not be possible.

9.2.4 - The controls should be equipped with warning sounds or lights to indicate incipient interference or collisions between the racker arm, the top head drive, the power tongs and/or any other equipment.

9.3 Hydraulic Slips

DEN-CON "Flex-Grip", Power Slip System and DEN-CON Pipe C.A.T. (Centering and Alignment Tool) or equivalent are recommended.

9.3.1 - Requirements:

- 9.3.1.1 - Should be controllable from driller's console.
- 9.3.1.2 - Should be able to accommodate tubulars having 2³/₈ to 13³/₈ inch diameters.
- 9.3.1.3 - One slip should be able to handle multiple pipe sizes during any one trip.
- 9.3.1.4 - C.A.T. should be automatic, and controllable from driller's console.

9.3.1.5 - The C.A.T. should be able to move pipe anywhere within a circle, centered on the wellbore, to allow stab-in.

9.3.2 - To Be Provided:

9.3.2.1 - Slips for $2\frac{3}{8}$, $4\frac{1}{2}$ and 5 inch drill pipe.

9.3.2.2 - Slips for $6\frac{1}{2}$, 8 and $9\frac{1}{2}$ inch drill collars.

9.3.2.3 - Slips for 6, 7, $9\frac{5}{8}$ and $13\frac{3}{8}$ inch casings.

9.4 Hydraulic Power Tongs

9.4.1 - Requirements:

9.4.1.1 - Should be mounted on a powered, retractable carriage, controllable from the driller's console.

9.4.1.2 - Should be equipped with a back-up wrench.

9.4.1.3 - Should be able to handle $2\frac{3}{8}$ inch to $13\frac{3}{8}$ inch tubulars.

9.4.1.4 - Hydraulic catheads should be provided as backups for use when extra torque is required (for bits, large collars, etc.).

9.4.2 - Torque Ratings: Tongs - 75,000 ft.-lb. min.; Catheads - 150,000 ft.-lb. min.

9.5 Mousehole

9.5.1 - General description: Should be at least 15 feet long, contain a pipe clamp, an automatic spinner and a spring-loaded bottom. Possible types include: Foley Drilling Tools, Hitec "Traveling Mousehole System", International Tools Co. "Phantom Mouse"™ and Varco "Auxiliary Mousehole" or equivalent.

9.6 Pneumatic Fingerboard

9.6.1 - Requirements: Should be able to hold, at least:

160 double stands of 5 inch drill pipe.

3 double stands of $9\frac{1}{2}$ inch collars

3 double stands of 8 inch collars.

3 double stands of $6\frac{1}{2}$ inch collars.

3 double stands of $4\frac{3}{4}$ inch collars.

Manual racking should be possible at all times.

9.7 Auxiliary Handling Boom

Requirements:

9.7.1 - Hydraulic powered.

9.7.2 - Minimum 8,000 pound capacity.

9.7.3 - Minimum lift height of 45 feet.

9.7.4 - Hydraulic winch to be integrated into boom.

9.7.5 - Controls should be adjacent to the boom or at the driller's console.

10.0 Mud System Parts on the Drill Rig

10.1 - Standpipe Manifold: Should be floor mounted and designed for either mud or cement; The manifold should be equipped with a 4 inch outlet for mud, a 2 inch outlet for cement and appropriate valves and pressure gauges.

10.2 - Mud Standpipe: Standpipe should be 4 inch diameter and extend upward ~60 feet from the manifold. It should be equipped with an FMC Model 1003 misaligning union or equivalent at the manifold end and a 160°, gooseneck-type hammer-union at the top.

10.3 - Rotary Hose Requirements:

- 10.3.1 - 3 inch ID, 60 feet long, Goodall S-5000 (or Gates equivalent), API Grade D, 10,000 psi test pressure, 5,000 psi working pressure.
- 10.3.2 - Coupling must be full flow "Barney" type or equivalent.
- 10.3.3 - API nipples at each end.
- 10.3.4 - Safety clamps required.

11.0 Electrical System

All cabling must be compatible with 24 VAC power from diesel engine alternator or SCR.

12.0 Instrumentation

12.1 - Weight Indicator: Requirements:

- 12.1.1 - M/D Totco (or equivalent) 40,000 pound indicator system having one dial each for hook load and for weight on bit.
- 12.1.2 - Should have replaceable dial faces for use with different wireline reaving
- 12.1.3 - Should operate using a compression load cell located in the deadline anchor assembly (M/D Totco Model 16.1 or equivalent).

12.2 Torque Indicator: Should be M/D Totco (or equivalent) indicator that uses hydraulic pressure on the top head drive as a measure of torque in foot-pounds.

12.3 Revolutions Per Minute Indicator: One RPM gauge is required, registering top head drive rotation speed, from 0 to 500 RPM.

12.4 Mud System Gauges

- 12.4.1 - Pump Speed Indicator: Two M/D Totco (or equivalent), 0 to 200 strokes per minute counters should be provided.
- 12.4.2 - Pressure Gauge: Should be M/D Totco GM-14 Series (or equivalent) with 2 inch couplings and an "easy-fill" connection; 5,000 psi capacity with 6,000 psi sensor assembly. A hand pump and replacement gauge fluid should be included.
- 12.4.3 - Mud Tank Level Indicator: Should be designed for 8 foot fluctuations and come with 250 feet of cable. Possible sources include:
 - 12.4.3.1 - Houston Digital Instrument, Model 7,000.
 - 12.4.3.2 - M/D Totco "Mud Watch".
 - 12.4.3.3 - Petron "Mud Data".
 - 12.4.3.4 - Rigserve "Mud Function Instrument".

12.5 Air Pressure Gauge: One 0 to 300 psi gauge is required.

12.6 Power Tong Gauges

- 12.6.1 - Torque Gauge: Should use hydraulic pressure to measure torque during make-up and break-out on either the power tongs or the backup catheads. Range of 0 to 120,000 ft.-lb. M/D Totco H-29 Series (or equivalent).
- 12.6.2 - Clamping Pressure Gauge: Should use hydraulic pressure on clamps to measure gripping force. Units are made by M/D Totco, Bilco, Petron, and Weatherford Enterra.

12.7 Hydraulic System Gauges

Hydraulic Tank Level Indicator and Hydraulic Oil Thermometer by M/D Totco, Frank Murphy or equivalent

13.0 Miscellaneous Systems

13.1 - Hydraulic Systems Should comprise two separate systems; one driven off the main diesel power source(s) and the other by a smaller self-contained power unit.

13.1.1 - Main Diesel-Driven System: Should be connected and provide fluid to the top head drive (unless it is electrically driven) and to the wireline spooler.

13.1.1.1 - Specifications: Driven by main power source (Caterpillar 3508 or two Caterpillar 3412s) or equivalent, having 935 HP. Tank Capacity: 250 gallons.

13.1.1.2 - Pumps: two, valved Sundstrand (or equivalent) axial piston, variable displacement types.

13.1.1.3 - Tank: should be baffled, have a removable top, a drain, operation and maintenance shut-off valves, a filler/breather cap, an oil level gauge and a heat exchanger.

13.1.1.4 - Filtration: Should include wire mesh, a magnetic separator, a pump outlet pressure filter and a filter on the return line.

13.1.1.5 - Instruments: Should include a 5,000 psi gauge on each pressure line and an oil thermometer.

13.1.2 - Smaller, self-contained Hydraulic System: Should be connected to the mast and substructure raising cylinders, the side-arm pipe racker, hydraulic slips, the BOPE hoist, power tongs, the catheads and the auxiliary handling arm with its winch.

13.1.2.1 - Specifications: Driven by its own diesel (Caterpillar 3116 DIT or equivalent); ~115 HP; Tank capacity of 150 gallons; Skid mounted, with oil pan for spill control.

13.1.2.2 - Pumps: see 13.1.1.2

13.1.2.3 - Tank: see 13.1.1.3

13.1.2.4 - Filtration: see 13.1.1.4

13.1.2.5 - Instruments: see 13.1.1.5

13.1.3 - Smaller, Self-contained Unit Spooler: Should be Mathey/Leland "Retriever" or equivalent with the following characteristics:

13.1.3.1 - Capacity for 15,000 feet of 0.092 inch wireline.

13.1.3.2 - Line pull capability of 1,200 pounds.

13.1.3.3 - Line speed of at least 1,000 feet per minute.

13.1.3.4 - Inclusion of a hand crank.

13.1.3.5 - Should have mechanical brakes on each drum flange.

13.1.3.6 - There should be direct drive between the drum and the hydraulic motor. The clutch should be of the "sliding dog" type or equivalent.

13.1.3.7 - The power drive should be explosion proof and put out 15 HP at 1,800 RPM.

13.1.4 - Smaller, Self-contained Unit Hydraulic Assembly: Requirements:

13.1.4.1 - 2000 psi working pressure.

13.1.4.2 - Pump and motor as supplied by Mathey (or equivalent).

13.1.4.3 - Should have relief and governor valves.

13.1.4.4 - Should have adequate filtration system.

13.1.4.5 - A centerpoint lifting eye would facilitate movement of the unit.

13.1.4.6 - Should have sheet steel safety covers.

13.1.4.7 - Should be equipped with a Mathey Type O wireline measuring meter (or equivalent), with readout in feet and a 7 inch register wheel.

13.1.4.8 - Should be equipped with a 7 inch hay pulley.

13.1.4.9 - Should be equipped with a line wiper, a line clamp and an oiler.

13.2 BOPE Hoist: Should be designed to run on beams provided, be hydraulically powered and have a 50,000 pound capacity.

13.3 Air System: Main diesel engine(s) should have air compressors large enough to supply drawworks brakes, one or more air tuggers and other miscellaneous tools.

13.4 Hydraulic Catheads

13.4.1 - Specifications: two Drecto 9015-D5 catheads (1 for make-up, 1 for break-out); should be mounted in mast legs; should have an approximate stroke length of 29 inches so that the wireline can move 58 inches. The catheads should have a line pull capacity of about 33,000 pounds at 2,500 psi hydraulic pressure for break-outs.

13.4.2 - Controls: Should have manual control valve and a pressure gauge calibrated to the tong length.

13.5 Wireline Spoolers

Operate using the main diesel-driven hydraulic system: Should have a spooler with a capacity for 3300 feet of 1 inch wireline (6 x 19 EWRC XIPS or equivalent).

Recommended Compact Drill Rig Design

A detailed description of the compact drill design is given below. This description is excerpted from DRECO Proposal Number DH/9961, Revision 1, dated 8 May 1997, for their "**Model 700/400 Three-Trailer, Semi-Automated Mobile Drilling Rig**".

The drill rig is designed to fit on three trailers and to require just two men to perform most normal drilling and tripping operations. The drill will pull doubles and has the equipment needed to make up doubles while drilling. Pipe handling is automated, with inclusion of a Pipe Handling Arm, a hydraulic Top Head Drive (THD), a mechanized mousehole, hydraulic slips, and an "iron roughneck". The 100 foot high mast and 22 foot high "slingshot" style substructure can be hydraulically raised without the need for a crane.

1.0 Trailers - The equipment needed to drill a well includes the mast and substructure, the power generation equipment, the drawworks, mud pumps and high pressure equipment, mud conditioning equipment, BOPE, rotating equipment, traveling gear and pipe handling equipment, instrumentation, the drill string and bottom-hole-assemblies and miscellaneous equipment. Some of these components are attached to one another during travel, but others require their own trailers. It is estimated that moving the drill herein described will require a total of 10-15 trailer loads in addition to the three discussed below.

The three trailers on which the drill is transported are the Drawworks Trailer and the Primary and Secondary Substructure Trailers.

1.1 The Drawworks Trailer - This trailer carries the drawworks, the main engine, the hydraulic power unit, the wireline spool, the air compressor and, during rig moves, the top mast section, the top head drive and the traveling block and hook (already strung up).

The all-steel trailer is designed to minimize weight. It is about 55 feet long, 12 feet wide and 15 feet high (loaded for rig moves). It uses triple axle suspension with twelve 10:00x20R radial tires, is equipped with air brakes and can be leveled on location with hydraulic jacks. Its estimated weight is 115,000 pounds.

1.2 The Primary Substructure Trailer - This trailer is really about 66% of a slingshot substructure on wheels but during rig moves, it also carries the lower mast section complete with the jib boom and the automatic pipe racking arm. The trailer is about 54 feet long, 12 feet wide and slightly less than 15 feet high. It too has three axles, twelve 10:00x20R radial tires, air brakes and hydraulic leveling jacks. It will weigh about 100,000 pounds.

1.3 The Secondary Substructure Trailer - The third trailer needed to move the drill rig carries the middle part of the mast and the off-driller's side (~34%) part of the substructure. The dimensions and appurtenances of this trailer are the same as the other two and its weight should approximate 100,000 pounds.

1.4 Basic Rig-Up Procedure - First, the Primary Substructure Trailer is positioned over the planned well site. Then, the substructure base boxes are hydraulically lowered to the ground and the substructure and lower mast are raised off the trailer, which is driven away.

Next, the Secondary Substructure Trailer is backed into place and the middle section of the mast is pinned to the lower mast section. The trailer is turned 180° and positioned next to and parallel with the primary part of the substructure, on the off-driller's side.

The Drawworks Trailer is then backed into place so that the top mast section can be pinned to the middle mast section, the Drawworks Trailer can be pinned to the main part of the substructure and the Drawworks Trailer jacks can be set.

Finally, the mast is raised using the hydraulic Mast Raising Cylinders and the main part of the substructure is raised by opening its hydraulic raising valve. After this, the off-driller's side portion of the substructure is hydraulically raised, its tractor is driven away, the substructure stabilizer wings are folded out and, using the Jib Boom, the several floor extensions are set. The rig is ready to drill.

The five preliminary DRECO drawings attached to this report show the proposed drill rig truck loads, the procedure followed to erect the drill and the appearance of the drill from the front, rear and above.

2.0 The Drawworks - The proposed unit is DRECO's Model K 180 AH diesel-mechanical. It requires 700 horsepower maximum input, has six forward hoisting speeds, a Fawick pneumatic clutch and uses multi-plate disc, water cooled, pneumatically actuated dynamic brakes.

The drum is a diameter of 16 inches, is 37 inches long and has $1\frac{1}{8}$ inch Lebus grooving. It is designed to pull doubles with an 8-line string-up. The drum drive is an oil sprayed roller chain driven by the input shaft. The 4140 chrome moly-manganese steel, heat treated and stress-relieved shaft runs on a double row of self-aligning roller bearings that are lubricated by a pressure spray and an oil bath.

The drawworks performance data is as follows:

<u>Speed</u>	<u>1st</u>	<u>2nd</u>	<u>3rd</u>	<u>4th</u>	<u>5th</u>	<u>6th</u>
Maximum one line pull, lb	55,000	37,000	27,600	18,500	13,700	9,200
Line speed (ft./min.)	414	618	824	1227	1655	2474

3.0 The Engine - The main engine for this drill is a Caterpillar 3412 DI-TA diesel rated for 700 HP at 2,100 RPM. The engine comes complete with fuel and oil filters, radiator, coolers for the transmission and engine oil, standard engine instruments, an electric starting system, a fan, spark arresting exhaust mufflers and two 24 volt batteries installed with cables and connections all enclosed in a box. Note: This engine is supplemented by a 300 HP hydraulic power unit engine. See section 12.1.

4.0 The Transmission - The transmission, manufactured by Allison has a built-in torque converter, a single output shaft, six forward and one reverse speed and full torque shifting ability. The transmission is operated by a Wabco cylinder and Rotair valves.

4.1 The Compound - This unit comprises a single engine, two output chain drive with force-fed lubrication.

4.2 The Right Angle Gear Box - This item, made by DRECO of heavy tubular steel to minimize distortion in service, has an output shaft extension to drive the drawworks on the off-driller's side. The right angle is driven by hardened spiral bevel gears with oil-bath lubrication. The input shaft has double taper roller bearings with straight roller bearings on the pinion end. The output shaft runs on spherical bearings.

5.0 The Mast - The mast of choice is DRECO's model M10010-600. It is hydraulically raised, has a clear working height of 100 feet a base width of 10 feet, a gross nominal capacity of 600,000 pounds and a static hook capacity, with 8 lines strung to the traveling block, of 400,000 pounds. The mast carries API #4F and #8C certifications with respect to its structural adequacy and its ability to resist windloads of 115 MPH with the setback empty and 85 MPH with the rated setback.

The mast is manufactured in three sections all of which have funnel alignments to facilitate single-pin connections during rig-up. There are no bolted connections nor is there any plan bracing in the mast (to reduce the fouling of lines). The mast is designed to accommodate a DRECO leg-mounted deadline anchor so as to reduce floor clutter and the need for substructure bracing.

5.1 The Mast Crown - Rated for the specified gross and static hook loads, it has four 36 inch working line sheaves and one offset 0.092 inch wireline sheave all mounted on heavy duty double row tapered roller bearings drilled for individual bearing lubrication. The crown safety platform has expanded metal flooring, square tubing handrails and toe boards, air tugger padeyes, wooden bumper blocks and a ladder opening. The traveling block has a top drive hanging padeye. The deadline is located on the off-driller's side.

5.2 The Racking Board - At the 56 foot level is a racking board frame sized to accommodate a fingerboard holding the following tubulars simultaneously:

- 160 stands of 5" pipe
- 3 stands of 9 $\frac{1}{2}$ " drill collars
- 3 stands of 8" drill collars
- 3 stands of 6 $\frac{1}{2}$ " drill collars and
- 3 stands of 4 $\frac{3}{4}$ " drill collars

The platform includes an access landing from the driller's side full height ladder, a walkway around three sides that is covered with expanded-metal grating, 7 foot high handrails, supports for a pull-back winch and lugs for tying off safety belts.

5.3 Other Mast-Related Equipment - The mast also comes with: a wireline sheave unit grooved for 0.092" slick line, two 14 inch tugger sheave units having tapered roller bearings, two complete sets of tong counterweights, a two-cylinder hydraulic system for raising the mast (with required controls), all items needed to install, support and service the DRECO top head drive, a traveling-block dolly, clamps for a 4" mud standpipe, two 1 $\frac{1}{2}$ " hydraulic lines and one 1 $\frac{1}{2}$ " air line, mast-leveling equipment comprising shim packs for each mast shoe plus a 25 ton hand-operated hydraulic jack and DRECO's standard three-coat epoxy paint job.

6.0 The Substructure - The substructure selected for this drill is DRECO's patented cylinder-raised "Slingshot" model with integral trailerization. The slingshot substructure, including all beams, supports, flooring and the doghouse, is raised hydraulically using a single station control. Safety is paramount. No personnel ride the drill floor elevator during the raising operation. All handrails and stairs are installed at ground level after the mast has been erected but before the substructure is raised. During transport, all floor elevator linkages, supports, cylinders and girders are left connected though protected. All move-related connections are pinned and no field-bolting of connections is required.

6.1 Substructure Specifications and Approximate Site Dimensions - The height of the substructure is 22 feet to accommodate a full geothermal BOP stack. The substructure is designed to support an API static hook load of 400,000 pounds and a setback load of 250,000 pounds. The floor accommodates a floor-mounted hydraulic wrench, an automatic mousehole and the DRECO M10010-600 mast.

The floor is 35 feet long and 20 feet wide (with side panels and the control station in place) so that the total footprint of the drill, with the mast up, is 98 feet long by 28 feet wide. Three 400 barrel mud pits (40 ft x 8 ft.) would add about 16 feet in width and the pipe rack would add about 30 feet in length. The mud pit would be less than 100 feet long and 30-50 feet wide. With space allowed for mud pumps, mud pump engines, miscellaneous equipment and storage sheds the dimensions of a typical drill site would be 200 feet by 200 feet or slightly less than 1 acre. DRECO has not suggested a preferred configuration for pumps, pits etc.. Accordingly there is flexibility to design the site plan to meet topographic constraints.

6.2 Substructure Technical Description - The substructure includes base boxes specially designed for lightness combined with enough strength to accommodate the stresses involved in slingshot style erection of the rig, a floor elevator, one set of vertical supports, two double acting, multi-stage hydraulic raising cylinders with counterbalance valves (to prevent collapse in case of hydraulic pressure loss), a set of rotary beams, rotary/setback flooring framed to accommodate the mousehole and a set of two 12.5 ton capacity BOP trolley beams. The substructure is floored with $\frac{3}{16}$ " and $\frac{3}{8}$ " checkered-plate, reinforced steel.

Mounted on the substructure are a 6,000 pound-capacity hydraulic winch, a set of two removable back-up tong connections (for occasional use only) and two sets of stairs: one from the floor to the shale shaker/mud tank area and one from the drill floor to the ground with an intermediate landing. Both stair sets have handrails and serrated grating treads. The whole substructure is protected by DRECO's standard three-coat epoxy paint job.

7.0 Traveling and Rotating Equipment - This includes the Top Head Drive (THD), the master bushing frame, the traveling block, the deadline anchor, the links and the elevators.

7.1 Top Head Drive - The model selected is DRECO's DTD-H-200-25-350-G, hydraulic unit. It puts out 400 horsepower using two, 200 horsepower variable displacement bent axis hydraulic piston motors with a pressure rating of 5,000 psi. Their performance is as follows:

<u>Motor Setting</u>	<u>Max. Torque (ft.-lb.)</u>	<u>Speed (RPM)</u>
Torque	25,000	0-80
Low	16,777	0-126
Medium	11,400	0-185
High	6,000	0-350

The THD gear drive has two speeds, is heavy duty and has a remote hydraulic shift capability. It is lubricated with a built-in circulating pump and filter. The THD shaft is of the floating output type with a 3.06" ID and with 4¹/₂" I.F. threads. The top seal is covered to protect against mud entry and the swivel packing is rated for 4,000 psi. The THD is equipped with bail hooks sized to accommodate 200 ton links and a Griffith 18" saver sub with 4¹/₂" IF x 4¹/₂" IF connections is provided.

The purchase of a hydraulic backup wrench (for \$123,000) is recommended as it will allow breaking the THD out of the drill pipe at any elevation above the floor.

7.2 The Master Bushing Support Frame and the Master Bushing - A fabricated high strength steel frame will be mounted in the floor to support the master bushing. This frame has a 37¹/₂" opening, a static load rating of 200 tons. It is made of heavy duty stress-relieved steel, is rectangular and has a cover. The master bushing provided is a Den-Con 37¹/₂ inch SSB split square drive type complete with lifting slings. This bushing is compatible with the Den-Con hydraulic slip system and fits in the support frame described above.

7.3 Traveling Block - The DRECO Model 436B-200 traveling block main frame is made of heavy steel. It has heavy wireline guards, DRECO sheaves, heavy duty double-row tapered roller bearings, a high strength steel dividing becket and is of a "split design" that saves height and permits both wireline and coring operations. The traveling block has four 36 inch sheaves, a load capacity of 200 tons and can accommodate 1 inch and 1¹/₈ inch wirelines.

7.4 The Deadline Anchor - The deadline anchor provided is DRECO's model LOF-50-C. It is mounted on the off-driller's side mast leg, is rated for 50,000 maximum deadline load and accommodates a compression type load cell (not included).

7.5 The Links - One set of 200 ton weldless links is provided.

7.6 Elevators - The drill includes one DRECO hydraulically operated clamshell elevator with inserts for 5 inch drill pipe and for 8 inch drill collars.

8.0 Pipe Handling Equipment - Tubulars are handled by the side-arm racker, the hydraulic slips, hydraulic power tongs, the mousehole, the fingerboard and an auxiliary handling boom. Particulars are presented below.

8.1 DRECO's Dual Function Side-Arm Racker - This machine actually performs three operations: 1) it can pick up tubulars from a pipe rack, pipe bin or a truck to stab them directly into the tubular in the slips or reverse this procedure, 2) it can move tubulars from storage into the automatic mousehole for makeup into doubles or reverse this procedure and 3) it can remove doubles from the mousehole and stab them into the tubulars in the slips or place them in the rack. This flexibility allows makeup and breakdown of doubles while drilling or tripping and minimizes tubular wear and tear due to frequent lay-downs.

8.1.1 Racker Description - The racker comprises a hinged arm mounted on a dolly that can move up and down along the driller's side of the mast. The arm, which can pivot from horizontal to vertical and hinge from side to side, has two telescoping pipe grippers for holding and moving the tubulars. When racking tubulars, the grippers are designed to lean the pipe slightly into the racking board for added stability.

8.1.2 Selected Racker Arm Features - The racker can handle tubulars from 3¹/₂ inch to 9¹/₂ inch, collars to 13³/₈ inch and core barrels. In case of a malfunction, the arm can be manually manipulated. The racker dolly locks tightly to the mast during tripping operations so as to provide speed with optimal accuracy. The geometry of the arm results in the minimum radius for all swinging motions in order to minimize inertia impact loads and allow faster motions and heavier lifts. Finally, the arm is designed with heavy duty construction and bearings for minimum maintenance, accurate movements and long service life.

8.1.3 Racker Arm Controls - Racker arm controls are designed to maintain proper sequencing, soft starts, accurate positioning and to prevent motions without an operator's hand on the controls. Warnings are provided to indicate possible interference between the arm, the THD and the power tongs.

8.2 Hydraulic Slips - This drill will be equipped with a "Flex-Grip" power slip system that includes the base and arm mechanism, a slip canister rack, insert bowls together with slips for 5 inch drill pipe and 8 inch drill collars.

8.3 Hydraulic Power Tong - The power tong to be provided is heavy duty, can handle tubulars from 3 inches to 14¹/₂ inches and can be operated remotely. It is mounted on a hydraulically powered retracting carriage and has a built-in back-up wrench. Hydraulic catheads are also provided for use with conventional tongs as a back up or when very high torques are required. The power tong can exert 75,000 ft.-lb. of torque while the cathead system can rotate with up to 150,000 ft.-lb. of torque.

8.4 The Mousehole - A "Phantom Mouse" rotating mousehole about 15 feet long is provided. It comes with a pipe clamp and spinner for making up doubles and it has a spring in the bottom to protect pipe ends. It is Manufactured by International Tool Co. Inc. and is shown and summarily described on the figure attached to the end of this report.

8.5 The Auxiliary Handling Boom - A 4 ton hydraulically powered jib boom is attached to the off-driller's side of the mast. It can be used for moving small equipment from off the rig to the floor. It has a 40 foot lift, an integral hydraulic winch and it is run from floor-mounted controls.

9.0 Mud System Parts - Included are a mud/cement manifold, a mud standpipe and a rotary hose.

9.1 Mud/Cement Manifold - This unit is floor mounted and comprises one outlet for a 4 inch mud standpipe one 2 inch outlet for a cement line, appropriate valves and a mud standpipe 5,000 psi pressure gauge.

9.2 Mud Standpipe - This is a single 4 inch standpipe, rated to 5,000 psi, that extends from the floor-mounted manifold to the 55 foot level on the mast. It includes a misaligning union at the manifold and a 160° gooseneck fitted with a hammer-union coupling.

9.3 Rotary Hose - This hose, between the THD and the mud standpipe is 60 feet long, has a 3 inch ID and is Goodall's model S-5000. It meets API grade "D" specifications for 5,000 psi working pressure. At each end of the hose are "Barney" full flow couplings and an API nipple. Safety clamps are built in.

10.0 Electrical System - All interconnect control cabling between the systems supplied by DRECO is provided. The drill rig system will operate on 24 VAC power supplied by the diesel engine alternator. The proposal as submitted by DRECO does not include night lights or plug-ins for hand tools, computers, etc.

11.0 Instrumentation - Though there is considerably more instrumentation on the driller's control panel, the following is a list of some important instruments included with the drill:

- A 200 ton electric weight indicator
- A hydraulic pressure activated drilling torque indicator reading in ft.-lb.
- A THD RPM digital indicator.
- Two M/D Totco mud pump stroke counters with a range of 0-200 strokes per minute.
- A M/D Totco mud pressure gauge that receives its signal from a 2 inch 6,000 psi sensor on the mud standpipe manifold. The gauge is 6 inches in diameter, measures to 5,000 psi and comes with a hand pump and filling fluid.
- Two 10 foot mud tank level indicators with 250 feet of cable.
- An air receiver tank, 0-300 psi pressure gauge.
- A make-up/break-out, hydraulic pressure activated, 0-110,000 ft.-lb. torque gauge for use with either the hydraulic power tongs or the back-up hydraulic cathead tongs.
- A power tong, hydraulic pressure activated clamping pressure gauge.
- A hydraulic system tank level indicator and
- A hydraulic system oil temperature gauge.

Neither BOPE nor controls are included in the proposal as submitted.

12.0 Miscellaneous Systems - These include the hydraulic and air systems, the hydraulic cathead package, a wireline spooler and the operator's cabin and controls.

12.1 Hydraulic Power Systems - There are 2 diesel driven HPUs: one driven by the 700 HP Caterpillar 3412 main engine mounted on the drawworks trailer and the other driven by a skid-mounted Caterpillar 3306 300 HP engine carried on the substructure trailer.

12.1.1 Hydraulic Pumps - Multiple hydraulic pumps with axial pistons and variable displacement are used for high horsepower drivers. Gear driven pumps are used for the lower horsepower drives.

12.1.2 Hydraulic Fluid Tanks - The main hydraulic fluid tank is baffled, has a removable top, a low-point drain, maintenance shut-off valves, a filler/breather cap and an oil-level sight gauge.

12.1.3 Hydraulic Fluid Filtration - Four levels of fluid filtration are provided.

1. The filler opening is crossed by wire mesh to catch large particles.
2. A magnetic suction separator is located between the tank and the pumps to further protect the pumps.
3. A high performance pressure filter is located at the pump outlets to protect the equipment, and
4. A high volume return-line filter is positioned at the tank to capture any wear particles from the equipment.

12.1.4 Instrumentation - The standard package includes a glycerin-filled pressure gauge on each pressure line and one oil temperature gauge.

12.2 Air System - Air compressors sized to meet rig requirements are connected to the main diesel engine so as to provide air for drawworks brakes and other miscellaneous purposes.

12.3 Hydraulic Cathead Package - Two DRECO 9015-D5 hydraulic catheads are mounted on the mast legs for breakout duty or for other stand-by service. A make-up and a break-out cathead are included. They are complete with a hydraulic cathead cylinder mounted vertically on the rear rotary spreader of the substructure. The cylinder has a swivel sheave, a travel sheave, wireline, an anchor and a retract spring. A 29 inch stroke on the cylinder moves the wireline 58 inches. The line pull is 32,900 pounds at 2,500 psi for break-out purposes.

12.4 Wireline Spooler - A hydraulic-powered wireline spooler is provided. Its reel is loaded to capacity with 11,500 feet of 1¹/₈ inch 6 x 19 EWRC XIPS wireline.

12.5 Operator's Cabin and Controls - An operator's cabin, approximately 5 feet wide and 6 feet high is provided. The cabin and the contained ergonomically designed console are located so that all rig activities can be seen. The controls are computer interfaced and each function can be customized to varying degrees.

13.0 Price and an Option - The total price of the Drilling Rig as described, tested, F.O.T. at the DRECO plant is **\$3,496,617.00**. A hydraulic back-up wrench to be mounted below the THD is an option that will cost **\$123,000 F.O.T** at the DRECO plant. DRECO can furnish virtually any option desired by a buyer.

APPENDIX B -- DETAILS OF COST ESTIMATES

Basic Procedures and Assumptions

- A quotation was obtained from DRECO, Inc. for construction and testing of a compact geothermal drill closely following specifications in Appendix A.
- Prices were obtained and carefully estimated, for all additional equipment not provided by DRECO, needed to make the compact geothermal drill operational.
- Daily rental rates for the geothermal drill were calculated, using as a base and appropriately modifying, selected figures and rationales contained in Pierce, Finger and Livesay, May 1996 concerning a hypothetical 18,000 foot capacity drill.
- The number of Revenue Tons and the estimated daily rental rate for a new 1000-1500 horsepower "conventional" triples drill with capabilities similar to those of the compact geothermal drill were obtained from a reputable drill manufacturer. These figures were then compared with those for the compact geothermal drill in order to calculate savings in the daily rate and in shipping costs from Houston to Jakarta, Indonesia.
- Information concerning the typical size of geothermal well sites and the cost incurred to construct them was obtained from knowledgeable geothermal industry sources. Knowing the difference between the well site needs for the compact geothermal drill and those of "conventional" drills enabled estimates of possible well site construction savings.
- Savings, attributable to the efficiency with which the compact geothermal drill can be moved in and out of well sites and be rigged up and down, were calculated.
- Annual savings were calculated for the compact geothermal drill assuming that four 10,000 foot deep wells would be drilled, in 60 days each (not including MIRU/RDMO) in a foreign country, with the drill working only 75% of the time (9 months of the year).
- A return on investment was calculated by determining the number of years required to pay off the initial investment in the compact geothermal drill.
- Finally, a business scenario was described through which a drilling contractor and one or more geothermal project developers could take advantage of the savings due to use of a compact geothermal drill to improve their bottom line profits and their competitiveness in electricity (or steam) sales markets.

Compact Geothermal Drill Rig Costs

The specifications and cost estimates for the basic compact geothermal drill rig are in Appendix A. The compact drill design that has resulted is very similar to that of two drills built by DRECO for Petrobras of Brazil.

The DRECO quotation of \$3,620,000 included the substructure, the mast and pipe handling arm, the primary and secondary power generation equipment, the drawworks, the rotating and traveling equipment, controls/instrumentation and assembly.

Cost of Additional Equipment

In order to compare similar, operational drills, prices were obtained for the following "add-on" (but standard) equipment needed to make the compact geothermal drill operational:

- Mud pumps and high pressure equipment.
- Mud conditioning equipment (tanks, guns, cleaners, etc.).
- BOPE and controls.
- Miscellaneous equipment (various tanks, sheds, pumps, tools etc.).
- A 4¹/₂ inch drill string and a full bottom hole assembly.

Discussions follow regarding the ways in which price estimates have been made for each of the items listed above.

Mud Pumps and High Pressure Equipment - The estimated cost for this equipment to service a "conventional" drill rig capable of drilling an 18,000 foot deep geothermal well is **\$1,008,000** (Pierce, Finger and Livesay; May 1996; Pages IX-12 and IX-13). In personal conversations, Pierce and Livesay agreed that the same equipment, down-sized to provide the lower pressures and smaller mud volumes needed to drill 10,000 foot deep wells with the compact geothermal drill, would cost approximately **\$750,000**.

Mud Conditioning Equipment - The compact geothermal drill will require three 400 barrel mud tanks as compared to three 500 barrel tanks needed by the above-referenced 18,000 foot drill. The cost of the mud conditioning equipment for the latter drill was quoted at **\$349,000** (ibid.). An estimated cost of **\$300,000** for this equipment on the compact drill reflects the lower cost of the smaller tanks.

BOPE and Controls - The diameters of the casing strings to be set in an 18,000 foot deep geothermal production well and those emplaced in a 10,000 foot deep well are basically the same (20", 13³/₈", 9⁵/₈" and 7"). The cost of the blowout prevention equipment and controls (BOPE) on an 18,000 foot drill was estimated at **\$875,000** (Ibid.). Accordingly, **the same figure** was used for the BOPE on the compact geothermal drill.

Miscellaneous Equipment - On any drill site, in addition to the basic machinery needed to drill, miscellaneous equipment including fuel tank(s), water tank(s), a utility room, a tool room, various pumps, air tools and rig lighting is needed. The cost for this with regard to an 18,000 foot-capacity drill was quoted at **\$409,000**. (Ibid.). Because: a) smaller fuel and water tanks can be used to supply the 10,000 foot capacity compact geothermal drill, b) a smaller utility room will be needed in light of the decreased crew size, and c) rig lighting costs will be reduced on the smaller drill, a cost of **\$300,000** has been estimated for this miscellaneous equipment.

A 4¹/₂ inch Drill String and a Full Bottom Hole Assembly (BHA) - The cost of this equipment for the 18,000 foot capacity drill was quoted at **\$975,000** (Ibid.). In order to calculate the cost for the 10,000 foot capacity geothermal drill, ¹⁰/₁₈ of this amount was used (\$541,666) to account for the differences in the hole depths to be drilled and then a reduction of 20% was applied to account for the fact that 4¹/₂ inch diameter drill pipe will be used to by the compact geothermal drill instead of 5 inch diameter. Accordingly, **\$433,000** was allowed for the drill pipe and BHA on the compact drill.

Estimated Total Cost for Compact Geothermal Drill Hardware

DRECO quotation for the basic drill	\$ 3,620,000
Mud pumps and high pressure equipment	750,000
Mud conditioning equipment	300,000
BOPE and controls	875,000
Miscellaneous equipment	300,000
A 4 ¹ / ₂ inch drill string and a full bottom hole assembly	<u>433,000</u>
Subtotal	\$ 6,278,000
Contingency (5%)	314,000
Taxes (8%)	<u>502,000</u>
Total cost	\$ 7,094,000

Expendable/Short Term Debt - (Drill pipe and BHA)	\$ 433,000
Capital Costs/Long Term Debt - (\$6,278,000-\$433,000)	\$ 5,845,000

Daily Costs

In order to be consistent with daily rate calculations made for an 18,000 foot capacity drill (op.cit., pages IX-14 and IX-15) the following parameters were used in the calculation of the daily rig rate for the compact geothermal drill:

- Long Term Debt
- Short Term Debt
- Maintenance
- Labor
- Office Support
- Insurance
- Fuel

Long Term Debt

As in the above-referenced publication, Long Term Debt at an annual rate of 12% was calculated on the assumption that it was used to obtain money for the capital items, i.e. all rig components except for the drill string and the BHA. Accordingly, the capital expenses for the 18,000 foot capacity drill and for the compact geothermal drill were taken in the

same ratio. Then, the quotient was used to multiply the daily long term debt amount used for the larger drill.

Capital costs for the geothermal drill	\$5,845,000
Capital costs for the 18,000 foot capacity drill	6,423,000
Daily long term rate from Pierce et al.	\$3,400

$$\$5,845,000 / \$6,423,000 = 0.91$$

$$0.91 \times \$3400 = \$3100 \text{ geothermal drill daily long term rate}$$

Short Term Debt

Short Term Debt at an annual rate of 12% was calculated on the price of the drill string and the BHA (ibid.). The same procedure as above was used to calculate Short Term Debt for the geothermal drill:

Short Term Debt costs for the geothermal drill	\$433,000
Short Term Debt costs for the 18,000 foot capacity drill	975,000
Daily long term rate from Pierce et al.	\$ 2,700

$$\$433,000 \div \$975,000 = 0.444$$

$$0.444 \times \$2700 = \$1200 \text{ geothermal drill daily Short Term rate}$$

Maintenance

The compact geothermal drill will be smaller, simpler and will drill fewer "deep, difficult feet" than the 18,000 foot capacity drill described in Pierce et al. Accordingly, a factor of 80% of the daily maintenance rate for the large drill was used to estimate the daily maintenance rate for the geothermal drill.

Daily maintenance rate for the 18,000 foot capacity drill	\$1,700
$0.80 \times \$1,700 = \$1,360 \text{ geothermal drill daily maintenance rate}$	

Labor

The compact geothermal drill has been designed to be operated by only two men, however, to be conservative, this analysis is based on operation by two, four man crews plus one tool pusher working 12 hour shifts. The average hourly salary used for the driller and the hands is \$15.00, the tool pusher's wage is estimated at \$6,000/month or \$200/day and the multiplier used for G&A and overhead expenses is 1.37 (ibid.)

Under these conditions, **daily labor costs on the geothermal drill** are calculated as follows:

$$((8 \text{ persons} \times 12 \text{ hours/day} \times \$15/\text{hour}) + \$200) \times 1.37 = \$2250$$

Office Support

Office support including engineering and clerical functions was calculated to be \$500 per day for an 18,000 foot capacity drill with a staff of 10 men per shift, two relief crew and a tool pusher (Ibid.). Since the compact geothermal drill will operate with only 9 persons (~30% smaller staff), the \$500 daily cost was multiplied by 0.70 to yield a **daily office support cost for the geothermal drill of \$350.**

Insurance

Insurance coverage on drills is predominantly a function of the capital cost of the drill and the size of the crew operating it. The daily insurance cost for an 18,000 foot capacity drill has been estimated at \$300 (ibid.). Using the same basic assumptions, this daily cost was modified by: 1) the ratio of the capital costs of the geothermal drill to that of the 18,000 foot drill and 2) the ratio of the numbers of working crew on the two drills.

$\$5,845,000$ (Cap. cost of geothermal drill) / $\$6,423,000$ (Cap. cost of 18,000' drill) = **0.91**
9 person geothermal crew / 13 person 18,000 foot drill crew = **0.70**

$\$300 \times 0.91 \times 0.70 =$ **\$190 daily geothermal insurance cost.**

Fuel

The compact geothermal drill will have two diesel engines: a 700 horsepower Caterpillar Model 3412 and a 300 horsepower Caterpillar Model 3306. The former uses 35 gallons per hour of fuel and the latter uses 15 gallons per hour. It has been assumed that the large engine will run 24 hours per day, the small engine will run about 8 hours per day and the cost of diesel fuel is \$1.10 per gallon. There will also be four 400 horsepower mud pumps using 20 gallons per hour each and running (over the 60 day drilling time of a well) an average of 15 hours per day. **Daily fuel costs for the geothermal drill** were therefore calculated as follows:

$((35 \text{ GPH} \times 24 \text{ hr.}) + (15 \text{ GPH} \times 8 \text{ hr.}) + (4 \text{ pumps} \times 20 \text{ GPH} \times 15 \text{ hr.})) \times \$1.10 =$ **\$2,375**

Geothermal Drill Daily Cost Summary

Long Term Debt	\$3,100
Short Term Debt	1,200
Maintenance	1,360
Labor	2,250
Office Support	350
Insurance	190
Fuel	<u>2,375</u>

Total geothermal drill daily costs \$10,825

The daily rental rate for a new conventional drill having the same or similar capabilities as the compact geothermal drill has been informally quoted at \$14,000 to \$15,000 (M. Melnachuk, Parker Drilling Company, personal communication). Accordingly, the savings in the daily rate possible via use of the compact geothermal drill would be at least \$3,175. For a 60 day, 10,000 foot well this would aggregate \$190,500 and by drilling 4 wells per year, \$762,000 could be saved annually.

Shipping Cost Comparison

In order to obtain shipping cost information regarding "conventional" drills, a representative of Parker Drilling Company, one of the only companies now actively building small and medium sized drill rigs, was called. He was asked to estimate the size, in Revenue Tons (RT) and the cost to ship a "conventional" triples drill capable of penetrating 10,000 feet from Houston, TX to Jakarta, Indonesia. Similar information regarding the compact geothermal drill was obtained from DRECO.

An informal quotation obtained from Parker Drilling Company's Operations Manager for Asia and the Pacific was that a new "conventional drill" designed to penetrate 10,000 to 12,000 feet, able to pull triple stands, with about 1000-1200 horsepower and all of the standard equipment would require 48 truckloads and "weigh" about **4,500 Revenue Tons**.

The compact geothermal drill rig will require only 16 total truck loads to carry all equipment needed to drill a 10,000 foot deep production well. At 330,000 pounds for the three trailers carrying the main drill rig and 13 more truck loads each carrying 40,000 pounds, the total weight of the geothermal drill and equipment should be about 850,000 pounds. Using a generally accepted formula of 3.5 Revenue Tons (RT) per metric ton, the geothermal drill and all equipment should total about **1351 Revenue Tons**.

Using the \$160 per Revenue Ton (or cubic meter ["cube"]) price for shipping stated by the Parker representative, the following shipping costs (including packing, shipping, receiving, etc.) have been calculated for the geothermal drill and for a new "conventional drill":

Conventional Drill: 4,500 RT x \$160	\$720,000
Geothermal Drill: 1,351 RT x \$160	<u>\$216,160</u>

Year 1 Shipping Savings Possible by Using the Geothermal Drill \$503,840

Note that the calculation of shipping savings possible with use of a new compact geothermal drill is based on the assumption that a new drill will have to be shipped from the US at the beginning of a drilling project. Though this may not be true for projects in such geothermally active nations such as Indonesia or the Philippines, it may indeed be the rule in relatively new geothermal development areas such as Central and South America, Southeastern/Mediterranean Europe or Southeastern Africa.

Intra-Field Drill Rig Moves

Consideration has been given to the possibility that intra-field moves from site to site would also be less expensive for the 16 truck load compact geothermal drill than for a 48 truck load conventional drill. In reality, the custom established to date in Indonesia is that skidded moves (very short) cost a flat fee of \$30,000 and that longer moves (.5 to 2 miles or more) cost \$60,000 (including rig-down, move and rig-up). These fees apply regardless of how many truck loads are required or how long the move takes (L. Capuano, ThermaSource, personal communication). Therefore, under this payment system, there are **no savings** attributable in this category to use of the compact geothermal drill.

Shipping Savings Possible in the Last Contract Year

These savings due to use of the compact geothermal drill have been included in the analysis under the assumption that the drill will be moved some significant distance, perhaps to another country or back to the US after the initial contract has been completed. Even if it does stay "on site" for some time, eventually, it will be have to be exported in order to avoid payment of import duties that can be onerously high.

Five or more years in the future, when this "return move" will take place, shipping costs will probably have increased due to normal inflation. For the sake of conservatism, **no price increases have been assumed**, and the savings in the last contract year are estimated to be at least \$500,000.

It is unlikely that this savings will be utilized on the first contract. It is more likely that it will become a savings to the drilling contractor that will not be shared with a geothermal developer. It has been viewed therefore as being akin to salvage and **has not been used to calculate the ROI in this analysis**.

Site Preparation

One of the chief benefits of the compact geothermal drill is that the size of the well site required is 70% smaller than that needed for a conventional drill. The average area of well sites for conventional drills, in the US and in most foreign countries, is about 400 feet by 400 feet or 3.67 acres (R. Benoit, Oxbow Operating Company, personal communication). The compact geothermal drill can easily be rigged up on a site of **1.0 acre** or less (B. Zahn, DRECO, personal communication).

Experience in the US has shown that the costs to prepare an average well site for a conventional drill is \$50,000 to \$150,000, depending primarily on the type of terrain and the environmental constraints to be mitigated (R. Benoit, Oxbow Operating Company, personal communication). In foreign countries, rugged volcanic terrain, heavy rainfall, relatively poor access and increasingly significant environmental constraints together with

older machinery, less than optimum maintenance and relatively inexperienced crews mean that site construction costs can be \$300,000.

Though a compact geothermal drill will require only about 1 acre per well site, the costs to build it will not be 70% less than those required to build a 3.67 acre site. It is estimated that the 1 acre well site will still cost about \$200,000 so that savings of \$100,000 per site can be realized. If four well sites are built per year, **annual savings accruing to the compact geothermal drill will total \$400,000.**

Move-In/Rig-Up and Rig-Down/Move-Out (MIRU/RDMO) Efficiency

One of the greatest advantages in the use of a compact geothermal drill is the speed with which it can be moved in and rigged up at the start of a well and then rigged down and moved out to the next location upon well completion. L. Capuano (personal communication) has said that the time needed to MIRU/RDMO the conventional drills now being used in foreign geothermal fields averages 8 to 10 days. B. Zahn (personal communication) has stated that MIRU/RDMO time for the DRECO compact geothermal drill can be 2 to 3 days.

The standby rate (commonly charged during MIRU/RDMO) for a conventional drill averages about 75% of the operating day rate. In the case of a new conventional drill having the same capabilities as the compact geothermal drill whose daily operating rental rate is \$14,000 (M. Melnachuk; Parker Drilling Co.; personal communication), the standby rate charged during MIRU/RDMO would be \$9,546.

If use of the compact geothermal drill will save only 4 days each way on MIRU/RDMO, then $8 \times \$9,546 = \$76,368$ could be saved on each well and for 4 wells per year, **\$305,472 could be saved by drill rig assembly/disassembly efficiency.**

Summary of Cost Savings Possible via Use of a Compact Geothermal Drill

In the preceding report sections, calculations have been made of cost savings that may be possible by drilling 4 wells per year using a compact geothermal drill instead of a conventional drill having the same capabilities. Savings in the daily rental rate, shipping costs, operational efficiency and well site construction are summarized below:

Annual Daily Rate Savings	\$762,000
Annual Well Site Construction Savings	400,000
Annual MIRU/RDMO Efficiency Savings	305,472
Year 1 Shipping Savings	503,840

A Business Scenario to Benefit Drilling Contractors and Geothermal Developers

The impressive savings identified above will be realized if they can be utilized by both the drilling contractors serving the geothermal industry and the geothermal developers working on foreign projects. The business scenario proposed below facilitates this.

1. One or more geothermal developers contract with a drilling contractor to employ the contractor's services for the drilling of no less than four, 10,000 foot deep (~60 day) geothermal wells per year until at least 18 wells have been drilled. This contract is conditioned on the contractor's funding of the construction, shipment and use of a compact geothermal drill as previously described in Tasks 2 and 3 reports submitted as part of Sandia Contract Number AU-0076.
2. The drilling contractor has the compact drill built and shipped and uses it to drill at least eighteen 10,000 foot deep (or 60 day) wells.
3. The contractor gets paid enough during this contract to pay off the drill, which the drilling company now owns 100%. He can also improve his economics by claiming "salvage-like" savings of about \$500,000 when the compact geothermal drill is moved back to the US.
4. The drilling contractor's future profits will greatly increase because he will have no more long term debt to pay on this drill.
5. Finally, the geothermal developers have reduced the cost of their geothermal well drilling by **22.78%**, improved their project economics and gained the ability to price their generated electric power or their sales of steam more competitively.

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