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EXECUTIVE SUMMARY: THE POTENTIAL
OF UTILIZATION OF GEOTHERMAL
ENERGY IN ARIZONA

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ABSTRACT

Arizona is one of the fastest growing states in the United States. It is in the midst of the movement of the population of the United States from its cold regions to the warm southwest. Being a hot, arid region, its electrical demand is nearly 50 percent higher in the peak hot summer months than that of the other seven months.

The major uncertainty of utilizing geothermal energy in Arizona is that very little exploration and development have occurred to date. The potential is good, based on (a) the fact that there are over 3,000 thermal wells in Arizona out of a total of about 30,000 shallow (less than 1,000 ft) irrigation wells. In addition, there is much young volcanic rock in the State of Arizona. The combination of data from thermal wells, young volcanic rock, water geochemistry and other geological tools, indicate that there is a large geothermal resource throughout the southern half of the state. It is believed that most of this resource is in the range of 50°C (122°F) to 150°C (302°F), limiting its uses to direct heat utilization rather than for electric power generation.

The utilization of geothermal energy for cooling systems is of vital interest, because Arizona consumes nearly 50 percent more electricity during the peak summer season due to electrical-driven air conditioning units. Geothermal-assisted heat pumps were shown to be economical for nearly all areas of Arizona. Further, the necessary low-temperature geothermal resource is widely available, based on the known 3,000 thermal wells. Geothermal-driven absorption systems (with a resource above 105°C) is a second way to reduce electrical energy, and some areas of Arizona are believed to have such geothermal resources at economical depths.

The results of this project, over four years, as reported in 15 specific-final reports, indicate that geothermal resources in Arizona can be utilized as follows:

1. Replace a portion of the electrical load currently used for space cooling, using geothermal-driven absorption cooling systems.
2. Utilize low-temperature geothermal resources for heat pump systems to reduce electrical power loads.
3. Utilize geothermal resources for irrigation pumping, and in many cases blend the geothermal brine effluents with the irrigation waters, to back out the more valuable potable groundwaters of Arizona.
4. An exciting potential of geothermal resources is its utilization in hybrid geothermal/coal fired power plants where (a) the geothermal resource could back out 12 to 17% of coal requirements and (b) the geothermal brines could be employed for cooling water and other uses to replace the more valuable Arizona potable groundwater.
5. An equally exciting potential of geothermal resources in Arizona is in its utilization by the large copper industry, of which over 60 percent of the United States production is in Arizona. Geothermal resources can produce (a) energy for direct heating of copper flotation processes, (b) energy for direct heating of dump leaching processes, and (c) the direct utilization of geothermal brines in the above systems to replace the more valuable potable underground waters of Arizona. Currently, underground waters in Arizona are being depleted at an alarming rate.

There are many other potential applications of geothermal energy in Arizona. These include utilization as direct heat in agricultural processes, food processing, specific space heating applications, specific space cooling applications, the replacement of potable water now being used for cooling, and many other applications. These geothermal uses will not be achieved until much more data are available about the geothermal resource per se, including locations, depth of resource, size of reservoirs, flow rates of brine and possible geological subsidence. Some work is in progress to provide this information, but it is small compared to the corresponding efforts occurring in the states neighboring Arizona.

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INTRODUCTION

Alternative sources of energy will have to be developed as the availability of traditional energy resources continues to diminish. Arizona is believed to have geothermal resources which potentially could supplement the existing energy supplies. Consequently, planning efforts have concentrated on estimating the potential of geothermal energy utilization in Arizona.

The State of Arizona was divided into local areas, in order to prepare "geothermal development plans" for each area. It was logical and convenient to follow county lines, such that four geothermal development plans were proposed for one county each, namely, Maricopa, Pima, Pinal and Yuma counties. The other three geothermal development plans consist of one or more counties on a regional basis. Although most of the work herein is based on 1979 data, certain items have been updated to 1981. This is especially true for the geothermal resource information, although it must be noted that there are few proven geothermal resources -- there are no commercial wells and only four developmental wells in the State of Arizona.

Geothermal development plans were prepared for seven distinct intrastate subdivisions. Geothermal resource prospects and the potential geothermal uses for each area are discussed in separate Geothermal Development Plans (GDPs). The major objective of the GDP is to provide information relevant to the prospective development and commercialization of geothermal energy for the specified areas. Attempts are made to match the available geothermal resources to potential residential, commercial, industrial and agricultural users.

SCOPE OF WORK

The seven GDP's for the State of Arizona provided basic data on geothermal resource areas, land use, population and economy growth factors, energy use, the water situation, and potential users of geothermal energy resources. Current data for each of these subjects were projected through the year 2020, so that alternative energy uses could be assessed in a logical manner.

The potential of high-temperature geothermal resources for the direct generation of electrical power in Arizona is low, so little effort was devoted to this possibility. However, the entire lower-half of the State of Arizona, coinciding with the major activities of population, industry and agriculture, appear to have many potential geothermal resource areas. Therefore, all possible direct energy uses of geothermal energy were evaluated with respect to Arizona conditions and needs. These included in some detail the following:

1. Space heating, both central and district.
2. Space cooling reducing electrical consumption.
3. Irrigation pumping by geothermal turbine-drive systems.
4. Increased copper recovery by direct heating of flotation waters and dump leaching acid solutions.
5. The replacement of 12 to 17 percent of the coal requirements of coal-fired power plants by means of hybrid geothermal/coal fired systems.
6. Utilization of geothermal brines for the replacement of potable waters, especially for power plant needs, copper flotation and leaching, certain irrigation waters and possibly in other heating and cooling applications.
7. Direct heating of greenhouses.

Many other direct use applications of geothermal energy were

investigated, but for various reasons did not result in sufficient significant findings to merit special reports. Many of these projects were reported in the annual and quarterly reports of this four-year project. These included the following:

1. Hybrid irrigation pumping/citrus processing.
2. Advanced geothermal-assisted processes for ethanol from cellulosic wastes.
3. Geothermal pumping of Central Arizona Project (CAP) waters from the Colorado River.
4. Advanced planning for geothermal utilization in Scottsdale, Arizona area.
5. Geothermal-heated industrial parks in satellite cities of metropolitan Phoenix.
6. Geothermal production of heavy water in a remote area of Arizona.
7. Geothermal-assisted desalinated water, as part of Bureau of Reclamation Project.
8. Geothermal district heating and cooling for Sun City, Arizona.
9. Geothermal energy in food processing.
10. Integrated cattle feedlot/ethanol/alfalfa in an advanced processing system.
11. Geothermal energy for Spreckel's Sugar Beet processing at Chandler, Arizona.
12. Geothermal energy for cottonseed processing in Phoenix and Casa Grande areas.
13. Geothermal energy for lettuce quick-cooling.
14. Various cascading systems for low-temperature geothermal energy.

The group involved in this project funded by the DOE for the evaluation of geothermal energy utilization performed many other functions, including the following:

1. Provided technical assistance to many groups and individuals in Arizona, that expressed an interest in geothermal energy.
2. Published a monthly newsletter to disseminate geothermal energy information.
3. Participated in public meetings, especially for municipal officials and civic groups.
4. Provided information to legislative personnel of the State of Arizona.
5. Provided the Arizona Solar Energy Commission and other state agencies with up-to-date information on the status of geothermal energy in Arizona.
6. Provided data in response to numerous DOE requests on various aspects of geothermal resources and utilization in Arizona, especially over the first two years.
7. Interacted with the New Mexico Energy Institute on the economic analysis of geothermal space heating.

BACKGROUND INFORMATION ON ARIZONA

Arizona is a hot, arid region with about 12 inches of water precipitation annually. It is the sixth largest state geographically.

It has about three million people, concentrated in the Phoenix and Tucson areas. Its initial economy was based largely on cattle and irrigated agriculture, which is now a billion dollar industry. Agriculture is a major economic factor in the state, along with the large copper industry, electronics industry and tourism.

Arizona is largely a state of public lands, illustrated by Figures 1 and 2. Geologically, its lowlands are in the southern half of the state and in the western areas along the Colorado River. These regions contain river valleys that constitute the irrigated areas of the state. The Mogollon Rim separates the Colorado Plateau of the north from the high pine tree country, which in turn separates the Plateau from the lowlands. Major dams are on the Colorado River, the rivers in the mountains to the northwest of Phoenix, and a in a few other regions, as shown in Figure 3. The lowlands contain basins filled with groundwater; these basins were filled to a depth of about 2740 m (9,000 feet) (before reaching volcanic rock) over the past two billion years.

Arizona is one of the fastest growing states in the USA, population wise, and thus has problems connected with energy and a steady economy. The population is concentrated in metropolitan Phoenix and Tucson, with the rest of the state being sparsely populated. Arizona has a severe peak electrical load in five summer months, due to the need for air conditioning, as shown in Figure 4. The required electricity is provided by natural gas and coal-fired power plants, hydroelectric power from the dams of the Salt River Project northeast of Phoenix, and imported power from the Hoover Dam, as shown in Figure 5. The important agriculture industry, based entirely on irrigation, occurs in the river valley of the southern half of the State, shown schematically in Figure 6. The copper industry of the United States is centered in Arizona, where 60 to 70 percent of the domestic production occurs, mostly in southern Arizona, shown in Figure 7. The fast-growing solid state, electronics, computers, missiles and other high-technology industries are concentrated in the metropolitan Phoenix and Tucson areas.

Figure 1. Location of Public Lands in Arizona

Figure 2. Location of Military Areas, National Forests, Wilderness Areas and Indian Reservations in Arizona

Figure 3. Location of Dams in Arizona

Figure 4. Seasonal Peak Electric Loads in Arizona

Figure 5: Electric Power Plants and Transmission Lines in Arizona

Figure 6. Schematic of Major Irrigation Areas of Arizona

Figure 7. Copper Mining Locations and Potential Geothermal Locations in Southern Arizona

POTENTIAL GEOTHERMAL RESOURCES

Arizona appears to have a large potential in low to medium-temperature geothermal resources, scattered throughout the southern half of the State. However, it is relatively unexplored except on a preliminary geological basis. A geothermal resource group in the Arizona Bureau of Geology and Mineral Technology has paralleled the work of this project, also sponsored by the DOE. Its detailed reports are referenced in the seven reports on GDP's, issued by this group (1-7).

The State of Arizona has about 30,000 irrigation wells, which have provided considerable temperature gradient data but at depths of only up to 305 to 457 m (1,000 to 1,500 ft). The State also has about 3,000 so-called thermal wells, with some of the major ones shown on Figure 8. The state has only two Known Geothermal Resource Areas (KGRA's), as shown on Figure 9. These are located in the Clifton/Morenci area, on the eastern border of the state. The detailed areas that show promise of geothermal resources are given in subsequent sections, where the geothermal utilization of each GDP is outlined.

Geothermal exploration and drilling in Arizona is active, but on a much lower level than in neighboring states of California, Nevada, Utah, Colorado and New Mexico. Exploration studies and/or shallow 100 m (300 ft) temperature gradient holes have been drilled in recent years in the Clifton/Morenci, Hyder, San Bernadino Valley, Springerville, Aquarius Mountains, Wikiup, Flagstaff, Hassayampa Plain and Chandler areas.

A report on geothermal leasing in the State of Arizona as of January 1, 1981 was as follows:

Figure 8. Major Thermal Wells in Arizona

Figure 9. Location of Potential Geothermal Resource Area in Lower San Francisco Area

<u>Area</u>	<u>Total Acreage Leasing for Geothermal Resource</u>			
	<u>Federal Lands</u>		<u>State Lands</u>	
	<u>Approved</u>	<u>Pending</u>	<u>Approved</u>	<u>Pending</u>
Flagstaff	0	118,000	0	0
Aquarius Mountains	0	30,638	0	0
San Bernadino Valley	0	16,591	30,596	0
Clifton/Morenci	6,304	11,864	0	0
Hassayampa Plain	15,000	564	0	0
Wikiup	0	12,360	0	0
Other Areas	237	0	3,760	0
TOTAL ACREAGE	21,541	190,017	34,356	0

Many of the requested leases on federal land have been pending for as long as 1974. Some industrial companies believe that Arizona doesn't have attractive enough geothermal resources compared to surrounding states — it simply doesn't have large enough blocks of state geothermal land to warrant leasing. Competitive bidding on state land is also seen as a deterrent in Arizona. Some industrial companies believe that the major geothermal resource developments in Arizona will occur on federal land.

The recent interest in the potential of oil and gas in the "overthrust" of Arizona may provide geothermal resource data. A report as of January 1, 1981 reported that oil and gas leasing activity in Arizona continued at a torrid pace. Of the some 10,000,000 acres of state-owned lands, 7,790,029 were under lease for oil and gas exploration. Legislation was passed in 1980 that increased the yearly rentals from 25 cents per acre to \$1.00. The legislation also provided for the formation of exploratory drilling units which will permit the combining of state, federal, and fee lands to make up the proposed unit.

The Bureau of Land Management (BLM) issues oil, gas, mineral, and geothermal leases on federal lands within the state. Of the 31,595,388 acres available for leasing under their jurisdiction, 2308 leases have been issued covering 4,425,286 acres. They had 200 applications on hand waiting to be

processed for a total of 7,861,441 acres. The ratio of leases versus acreage variance on lands leased and applications on file was due to the revision in 1980, whereas one lease can now include 10,240 acres where previously it was limited to 2560 acres per lease. Throughout the year there were from five to eight geophysical crews working in the state.

POTENTIAL UTILIZATION OF GEOTHERMAL ENERGY IN MARICOPA COUNTY

Six potential geothermal resource areas with temperatures less than 100°C (212°F) and in addition, four suspected intermediate temperature areas (90° - 150°C, 194° - 300°F) were identified, as shown in Figure 10. Geothermal resources are found to occur in and near the metropolitan Phoenix areas where average population growth rates of two to three percent per year are expected over the next 40 years. Rapid growth in the manufacturing, trade and service sectors of the regional economy provide opportunities for the direct utilization of geothermal energy. A regional energy use analysis was made, containing energy use and price projections (1). Water supplies are found to be adequate to support this growth, though agricultural water use is expected to diminish.

The study also contains a detailed section matching geothermal resources to potential users (1). Two comparative analyses providing economic details for space heating projects are incorporated. The first analysis compares the effect of building sizes on geothermal competitiveness, and finds that potential wells in the western Phoenix area could currently compete with natural gas in the space heating market given that the size of the building were large enough to utilize the available geothermal heat. In the second case, apartment heating was compared with home heating. Because of the increased density of apartment dwellings, geothermal heat should be competitive with natural gas in 1984 as compared to 1989 for a mixed home and

Figure 10: Locations of Potential Geothermal Resource Areas in Maricopa County

apartment development. In addition, the study identifies 430 firms in 60 industrial classes that have some potential for geothermal energy use. Further, 191 agribusiness firms were found in the County. Geothermal energy utilization projections suggest that by the year 2000, geothermal energy may economically provide the energy equivalent of 5,600,000 barrels of oil per year for industry if developed by the private sector. Geothermal utilization projections increase to 6,000,000 barrels of oil per year by 2000 if a municipal utilities developed the resources. Several specific industrial processes are described to highlight the incorporation of geothermal energy into relatively large energy use industries found in Maricopa County.

Water depletion in Maricopa County is serious, because it is utilizing groundwater faster than its sources are replenished. This is especially true in the metropolitan Phoenix area, and southwest of Phoenix where large nuclear power plants will become operative over the next six years. The total water consumption in Maricopa County is about 2.5 million acre feet per year, over 70 percent of which is used for irrigated agriculture. It is believed that geothermal brines can help alleviate this situation -- they can be used for power plant needs, copper flotation and leaching, certain irrigation waters and possibly in other heating and cooling applications in Maricopa County.

The principal contributor to Maricopa County's economy is manufacturing, specifically the manufacture of high technology products. Manufacturing accounted for an estimated 91,000 jobs in the county in 1979 or about 17 percent of the labor force. Value added by manufacturing was estimated at just over \$3 billion for 1979.

The second largest contributor to the economy of Maricopa County is tourism and travel. Tourism showed a 22-percent gain in 1978 over 1977. Reports showed that the tourism industry realized \$1.68 billion in revenue in

1978 and provided about 180,000 jobs for Maricopa County residents.

In dollar figures, agriculture is the third largest industry in Maricopa County. Approximately 510,000 acres of the county are used for agriculture, 50 percent of which was planted in cotton and the rest divided between wheat, hay, vegetables and fruits (mostly citrus). The total value of crops and livestock exceeds \$1 billion annually.

The Department of Economic Security estimates that employment in agriculture will decline over the next 20 years at an average rate of 1.7 percent per year. This reflects the problems of water availability, since agriculture uses 70 percent of the county's water. Also, the high value of land for non-agricultural purposes will force the amount of agricultural acreage downward in the future.

The possibility of providing either heating or cooling by means of geothermal energy is of prime interest to Maricopa County. A preliminary study of the technical and economic feasibility of installing a geothermal district heating and cooling system was analysed for the Maryvale Terrace residential subdivision in Phoenix, Arizona (8). The development consisted of 557 residential houses constructed by the John F. Long Realty Company. The study was undertaken as a model for analysing district heating and cooling systems for new residential developments. The design heating load was estimated to be 16.77 million Btu/hr and the design cooling load was estimated to be 14.65 million Btu/hr. Average annual energy use for the development were estimated to be 5,870 million Btu/yr and 14,650 million Btu/yr for heating and cooling, respectively. Geothermal energy must compete with natural gas for heating and electricity for cooling.

A geothermal resource was assumed to exist beneath the site at a depth of 1829 m (6000 ft). Five production wells producing 1000 gpm each of 105°C

(220°F) geothermal fluid would be required. Total estimated cost for installing the system would be \$5,079,300. First year system operations cost (including debt service) were estimated at \$974,361. The average annual geothermal heating and cooling cost per home is then estimated \$1,750 as compared to a conventional system annual cost of \$1,145. Further, the cost of geothermal heating and cooling including the capital cost is estimated to be \$47.50 per million Btu. All calculations are based on 1980 dollars. Thus, district heating by geothermal energy in Arizona does not appear economical for some years to come.

On the other hand, the use of geothermal energy for cooling in Maricopa County could be economical under certain circumstances. The cooling methods of (a) absorption coolers and (b) heat pumps, both using geothermal energy, were evaluated and found economic in some cases (9).

POTENTIAL UTILIZATION OF GEOTHERMAL ENERGY IN PIMA COUNTY

The study identified four potential geothermal resource areas with temperatures less than 100°C (212°F), and in addition, one area is identified as having a temperature of 147°C (297°F), as shown in Figure 11. Geothermal resources are found to occur in Tucson where average population growth rates of two to three percent per year are expected over the next 40 years (2). Rapid growth in the manufacturing sector and the existence of major copper mines provide opportunities for the direct utilization of geothermal energy. However, available water supplies are identified as a major constraint to projected growth.

The study identified 115 firms in 32 industrial classes that have some potential for geothermal use (2). In addition, 26 agribusiness firms were found in the county. Geothermal energy utilization projections suggest that by the year 2000, geothermal energy may economically provide the energy

Figure 11: Locations of Potential Geothermal Resources in Pima County

equivalent of 87,000 barrels of oil per year for industry if developed by the private sector. Geothermal utilization projections increase to 180,000 barrels of oil per year by 2000 if a municipal utility developed the resources.

Water depletion in Pima County is serious, because (a) fast-growing Tucson depends entirely upon pumping groundwater (compared with Phoenix that obtains part of its water from the mountains, lakes and dams serving the Salt River Project system) and (b) the water demands of Indian nations in the county and (c) the relatively large water demand of the copper industry south of Tucson. Projections indicate that Pima County will continue to have a water depletion through the year 2000 of approximately 200,000 acre-feet per year. It is believed that geothermal brines can help alleviate this situation -- it can be used for power plant needs, copper flotation and leaching, some irrigation waters and possibly in other heating and cooling applications in Pima County.

Pima County contains the state's second largest population center, namely Tucson. With a 1980 population of 531,263 and an area of 9,240 square miles, Pima County has population density of 57.5 persons per square mile. Further projections place population growth at 2.3 percent per year until the year 2000. However, many persons within Tucson believe these projections underestimate population growth, and express the opinion that the population of Tucson alone will exceed 1,000,000 people before 2000.

The principal contributor to Pima County's income is tourism, accounting for \$900 million in fiscal 1978 - 1979. This figure represents a 25-percent increase from the previous year. The second largest contributor to the county's economy is manufacturing, especially solid state, computers and missiles. Manufacturing accounted for an estimated 17,000 jobs in 1979 and

contributed over \$300 million to the Pima County economy in 1977. The third largest contributor to the Gross County Product of Pima County is mining, specially copper mining. Copper mining in Pima County accounted for about 40 percent of total production in U.S.A. in 1970. However, the copper industry fluctuates wildly depending upon the market price of copper and is currently in a slump.

Agriculture is also an important segment of the Pima County economy, accounting for over \$44 million in income in 1977. In 1978, a total of 46,000 acres was planted in Pima County, the majority of which were planted in cotton followed by grains, vegetables and alfalfa. The Department of Economic Security estimates that approximately 1500 persons were employed in agriculture in 1979. However, due to critical water problems, employment in agriculture is expected to decline 2.2 percent per year through the year 2000.

The large copper industry is centered in areas to the south, northwest, east and northeast of Tucson. The copper industry was identified as (a) not only a potential user of large quantities of geothermal energy, but also (b) an industry that could use geothermal brines to replace potable waters (10,11). The possible use of geothermal energy (a) to speed the recovery of copper from ore flotation and/or leaching of flotation tailing and (b) to utilize geothermal brines to replace valuable fresh water in copper flotation operations were evaluated (10). Geothermal energy could be used to enhance copper and molybdenum recovery in mineral flotation by increasing the kinetics of the flotation process. In another approach, geothermal energy could be used to heat the leaching solution which might permit greater copper recovery using the same residence time in a tailings leach facility. Since there is no restriction on the temperature of the leaching fluid, revenues generated from the additional copper recovered would be greater for tailing leach operations

than for other types of leach operations (for example, dump leaching operation) for which temperature restrictions exist.

The estimated increase in total revenues resulting from a two percent increase copper recovery in a 50,000 tons ore/day plant was estimated to be over \$2,000,000 annually. It would require an estimated geothermal investment of about \$2,130,000 for a geothermal well and pumping system. Thus, the capital investment would be paid out in about one year. Furthermore, considerable savings of fresh waters and process equipment are possible if the geothermal waters are used directly in the mine-mill operations.

Likewise, the possibility of using geothermal energy to heat a sulfuric acid leaching solution for the purpose of faster and more efficient copper recovery from copper-containing minerals was evaluated (11). Experimental studies reported in the literature have shown that this technique can be economically feasible for the extraction of copper from low-grade dump ores. Its main advantage appears to be the considerable reduction in long-term leaching periods; it could also be less expensive than other conventional processing operations if an economical geothermal resource were provided. It would also utilize geothermal brines to replace valuable potable waters.

A preliminary study of the technical and economic feasibility of installing a retrofit geothermal heating system was analyzed for the Environmental Research Laboratory Farms greenhouse facility located in Tucson, Arizona (12). The facility consists of 10.6 acres of greenhouse area, of which 7.4 acres are currently operational. Natural gas or diesel fuel are presently used for heating. The maximum heating load is estimated to be 28,620,000 Btu/hr. Average annual heating energy consumption between 1974 and 1979 was 35,684 million Btu/year for 7.4 acres of greenhouse, costing an estimated \$96,703 at 1981 natural gas prices.

Two 2,500 foot geothermal production wells are required, each capable to producing 1,500 gpm of 54°C (30°F) water. The geothermal water is expected to contain 500 ppm total dissolved solids. Total estimated capital cost for installing the system is \$902,946. The expected first year geothermal energy cost savings are estimated to be \$58,920. A simple payback of 9.1 years is calculated and the project has a net present value of \$961,751. Geothermal heat could be supplied at a cost of \$5.39 per million Btu in the first year of operation. Thus, the continuous use of geothermal energy for heating these greenhouses appear economically marginal, based upon the assumption made in the study.

POTENTIAL UTILIZATION OF GEOTHERMAL ENERGY IN PINAL COUNTY

Three geothermal resource areas with potential 70°C (158°F) temperatures, and one geothermal test well near Coolidge encountered bottom hole temperatures of 120°C (248°F) at a depth of 2,440 m (8,005 ft), and producing 18.3 l/sec (290 gpm) were identified (3). Geothermal resources are found to occur near population centers where average growth rates of 1.5 percent to two percent per year are expected over the next 40 years, as shown in Figure 12. Mining, agriculture and manufacturing are all important sectors of the regional economy and provide opportunities for the direct utilization of geothermal energy. The Casa Grande area and surrounding communities form a corridor that may eventually merge into metropolitan Phoenix and metropolitan Tucson.

The analysis contains a detailed section matching geothermal resources to potential industrial users. Fourteen firms in 10 industrial classes were identified as having some potential for geothermal energy use. In addition, 25 agricultural firms were identified as having some potential for geothermal use, including the mixed feed industry. Geothermal energy utilization

AREAS FAVORABLE FOR DISCOVERY OF GEOTHERMAL RESOURCES

AMAX GEOTHERMAL TEST WELL

0 16
miles

Figure 12: Locations of Potential Geothermal Resource Areas in Pinal County

projections suggest that by the year 2000, the energy equivalent of 1,700,000 barrels of oil per year could be economically provided to the industrial sector. In addition, future new growth areas might also benefit from geothermal space heating and possibly space cooling projects.

Pinal County has large acreage of irrigated agriculture. Its water depletion is even more serious than that of Maricopa and Pima counties -- in fact, a large area has subsided some six feet, leaving wide cracks in the earth and causing periodic repairs of the Interstate Highway 10. It is believed that geothermal energy can be used economically to pump irrigation waters and simultaneously, the geothermal brines can be blended with these irrigation water to back out potable water.

The potential of using geothermal energy in an isobutane binary system to drive directly a cluster of irrigation pumps was evaluated (13). This 3-well geothermal system, based on a 150°C (302°F) resource at 2,000 m (6,560 ft), would cost an estimated \$7,800,00 in capital investment to provide 6,000 gpm of irrigation water from 12 water wells. It would serve approximately 4.5 square miles of irrigated agricultural land, with the delivered water costing \$106.76 per acre-foot. This compares with an estimated cost of \$60.78 per acre-foot for a conventional irrigation system driven by natural gas at the current price (1980 dollars) of \$2.72/mm Btu. It is obvious that if natural gas prices continue to rise, or if geothermal resources can be found at depths less than 2,000 meters, then the geothermal irrigation pumping system would become economically attractive.

The results of the geothermal irrigation pumping system point out the importance of designing geothermal energy systems in a cascade mode (13). The system herein evaluated, used only 10-12 percent of the energy in the 150°C (302°F) geothermal resource. The economics would be improved considerably by

using the effluent geothermal brine and the turbine condenser waters in a cascade system of first supplying heat to greenhouses or fish farming and secondly blending directly with irrigation waters.

The importance of water to the economy and growth of Arizona was summarized (13). Total water consumption in Arizona is about 7,600,000 acre-feet annually of which about 87 percent is used for agriculture. Total supply from the Colorado River and water runoff is only 2,600,000 acre-feet per year, resulting in a net potable groundwater depletion of about 4,000,000 acre-feet per year assuming a recharge rate of about 1,000,000 acre-feet per year.

The Central Arizona Project will bring Arizona's share of Colorado River water to the Phoenix and Tucson areas by 1985 - 1990. Arizona is now taking about 1,600,000 acre-feet of water per year from the river, and when the canal is completed, this will be increased to a total of 2,800,000 acre-feet annually. Despite this additional supply of water, a major depletion of groundwater will occur through the years of the foreseeable future (to years 2000 - 2020).

The estimated annual groundwater pumpage in Arizona for the period 1966-73 is shown below. Today its pumping is roughly the same, probably somewhat larger due to increased population and industry, and this depletion will not be replenished in the foreseeable future:

<u>Irrigated Area</u>	<u>Pumpage, Acre-Feet</u>
Duncan basin	25,000
Safford basin	140,000
San Simon basin	100,000
Willcox basin	300,000
Douglas basin	100,000

Upper & Lower San Pedro basins	92,000
Upper Santa Cruz	250,00
Avra Valley	150,000
Lower Santa Cruz	950,000
Salt River Valley	1,700,000
Waterman Wash	55,000
Gila Bend area	180,000
Harquahala Plains area	110,000
McMullen Valley	100,000
Gila river drainage	120,000
Ranegras plain area	16,000
Gila River - Texas Hill/Dome	220,000
Yuma area	260,000
Sacramento Valley	5,000
Hualapai Valley	4,000
Big Chino Valley	8,000
Little Chino Valley	12,000
Williamson Valley	2,000
Colorado River Flood Plain	17,00
Other areas	<u>100,000</u>
TOTAL	5,016,000

FUTURE WATER SUPPLIES IN ARIZONA

Dependable water supplies in Arizona are expected to increase until the Central Arizona Project is completed and in full operation in 1987. After that year they will slowly decline as the states of the Upper Colorado River Basin develop and put to use their entitlements to waters of the Colorado River, thereby reducing water available to Arizona. In addition to Central

Arizona Project waters withdrawn from the Colorado River, it is anticipated that dependable water supplies will be increased by 91,000 acre-feet per year as a direct result of the construction of three new Central Arizona project reservoirs on the Gila, Salt and San Pedro Rivers. It is also anticipated that additional surface water supplies will be developed from the Little Colorado River and its tributaries to satisfy new development in the area.

Comparison of total projected water depletions with projected water supplies shows that substantial overdrafting of groundwater will continue unless uses are severely reduced or the supplies available to the state are augmented by large importations. With no new agricultural development, except on Indian reservations, and medium projections of nonagricultural use, the current annual overdraft of about 4,000,000 acre-feet will persist to a large extent in 1990, and may still be in excess of 2,000,000 acre-feet in 2020.

Projections of future water supply and use were developed for each of the state's fourteen counties and then aggregated to describe the situation in the planning districts and the state as a whole. These projections indicate that each of the counties in Arizona will be faced with its own unique problems. Some are not expected to have water supply problems in the 50-year period of evaluation, although localized deficiencies may exist or develop. Other counties will continue to experience deficiency of supplies and, depending on the level of development, may experience more aggravated imbalances of supply and use, even with sharp reduction in agricultural water demands.

Maricopa County will continue in the future to use more water than any other county. Large increases are forecast to meet urban and steam electric power generation needs. The lowest projection show increased depletions of over 200,000 acre-feet per year by year 2020 for these two uses alone. Conversely, agricultural water use will decrease, even under the highest

projections of agricultural development, because of urbanization of irrigated lands in the Phoenix metropolitan area. A balance of supply and demand can be maintained through the importation of Central Arizona Project supplies and a reduction in harvested acreage in the county of approximately 300,000 acres by year 2020. Without the retirement of agricultural lands sizeable overdrafts would continue under all alternatives investigated.

In Pima County, the importation of water via the Central Arizona project will make a significant contribution toward bringing depletion into balance with dependable supply. Nevertheless, groundwater overdrafting is projected to continue at high levels unless all agriculture is also retired, in which case a balance between supply and demand can exist until after the year 2000. Significant increases are expected in uses by the cities and the mineral industry.

Future water supply conditions in Pinal County are unique; the current excess of use over dependable supply reverses during the early years of Central Arizona Project operation so that a water supply surplus will exist for a few years before deficiencies return, although to a lesser degree, as uses increase and water supplies reduce. Water use by the mineral industry is forecast to increase substantially. Even the lowest projection forecasts a 100 percent increase in water use for mineral production by year 2020. Although agriculture will remain the principal water user in Pinal County, a reduction of use by this sector of almost 40 percent will be necessary by 2020 if a balance of supply and demand is to be realized for the county.

In Mohave and Yuma Counties most future development and associated water use will occur along the Colorado River where no deficiency is anticipated. Groundwater overdrafting is expected to occur only in basins away from the River where its supply is not available. All projections of future water uses

show agriculture remaining as the largest water user in both Mohave and Yuma Counties.

The widest difference between the projected levels of water use occurs in Cochise County. This situation results because new agricultural development is most likely to occur in Cochise County under existing water supply conditions and institutional restrictions that prevent development in many other areas of the state. Paradoxically, it is the county with the greatest percentage of agricultural use in 1970 supplied from groundwater overdrafting. Although agriculture may experience large increases or may in the case of the low projection suffer a marked decrease, all other uses in Cochise County are projected to increase substantially. By the year 2020, total water depletions would range from a low forecast of 97,000 acre-feet per year to a high of 616,000 acre-feet per year. Zero overdraft is achievable under medium growth assumptions through the retirement of about 100,000 acres of agricultural lands. Medium projections result in an average annual groundwater overdraft of about 263,000 acre-feet per year in 2020, approximately the same as 1970.

Graham County is similar to Cochise County, agriculture may increase substantially to satisfy the criteria of the alternative projections utilized in this report. However, because of the availability of a dependable surface water supply from the Gila River, the reduction in agricultural uses to achieve zero overdraft will not be as significant as may be experienced in other areas of the state. The largest expected demand in water use will be for mineral production which may increase to as much as 50,000 acre-feet per year in 2020 compared to zero in 1970. Under high rate of growth assumptions, depletions would equal almost twice the dependable supply by year 2020. Zero overdraft is achievable in 2020 under medium growth assumptions with

retirement of about 20,000 harvested acres of agricultural land.

Water supplies in the three Northern Arizona Counties (Apache, Coconino and Navajo) are believed to be generally adequate to meet future needs. Total water depletion in the three counties may increase as much as 130,000 acre-feet by 2020. However, the availability of dependable groundwater and unappropriate surface water should permit these increased demands to be satisfied without overdraft. The most significant increase in water use will be for steam electric generating plants.

Future conditions in Yavapai County are difficult to assess. Nonagricultural water uses alone are expected to increase from two to three times 1970 levels. Because geographic conditions would appear to preclude economical transfers of water between basins, some areas will be faced with imbalance of supply and demand even with total retirement of agriculture. Other parts of the county can continue to support agriculture even under the highest projections of agricultural growth. Nevertheless, on a county-wide basis water supply deficiency will continue even if all agricultural acreage is retired.

Projected water use and supply conditions in Greenlee and Gila Counties are similar. Anticipated development of copper mining activity in these counties forecasts water deficiencies under all alternative future conditions. Water use by the mineral industry in the year 2020 is projected to comprise over 70 percent of total use in Gila County and over 80 percent in Greenlee County. Total water required in 2020 will be almost twice the dependable supply even under the lowest projection.

The overall picture of water supply and use in Santa Cruz County is not expected to change significantly unless agriculture is reduced to achieve a balance between supply and demand. Water for urban purposes is the only

demand that might increase substantially. Groundwater overdrafting is not expected to increase by a significant amount.

POTENTIAL UTILIZATION OF GEOTHERMAL ENERGY IN YUMA COUNTY

The major geothermal resource area receiving attention in Yuma County is in the Hyder area. There is also a growing belief that the large geothermal resource of the Imperial Valley extends to the city of Yuma area, and is masked by groundwater interaction; however, this as yet is unproven.

The Hyder study area consists of the Palomas Plain, Hyder Valley and the northern portion of the Sentinel Plain. Out of 250 wells known to exist in this area, 88 have reported temperatures in excess of 30°C (86°F). Of these warm wells, 28 are less than 100 meters (328 ft) deep and 81 are less than 400 meters (1,312 ft) deep. Temperature measurements and chemical geothermometry suggest that 40°C to 100°C (104° to 212°F) waters may be found at depths of 500 to 1000 meters (1,640 to 3,281 ft). The total volume of water below 300 meters (984 ft) was estimated at $60,000 \text{ km}^3$. Recoverable water below 300 meters (984 ft) was estimated at $23,500 \text{ km}^3$. Waters from existing wells contained less than 5,000 mg/l dissolved solids. Substantiation of projected temperatures should be undertaken as a first step in the geothermal development of this area.

Potential applications of geothermal energy in Yuma County include space heating, space cooling, irrigation pumping by geothermal-driven turbines and hybrid geothermal/coal fired power plants.

POTENTIAL UTILIZATION OF GEOTHERMAL ENERGY IN GRAHAM/GREENLEE COUNTIES

The only two Known Geothermal Resource Areas (KGRA's) in Arizona are in the Clifton/Morenci area of central Greenlee County. Arizona's highest temperature thermal springs, Gillard Hot Spring, 84°C (183°F) and Clifton Hot Springs, $30 - 72^{\circ}\text{C}$ ($86^{\circ} - 162^{\circ}\text{F}$) occur in the Clifton - Morenci Region. Lands

adjacent to the springs are designated as KGRA's by the U.S. Geological Survey and are awaiting competitive lease sale.

The Clifton Hot Springs consist of numerous thermal springs and seeps which discharge along the San Francisco River in and north of Clifton. The discharge from individual springs is less than .3 l/sec (5 gpm). The composite flow rate is estimated to be 75.6 l/sec (1.198 gpm). These thermal springs have a sodium-chloride chemistry with total dissolved solids between 7,000 and 14,000 mg/l. Variations in chemistry suggest that thermal waters mix with non-thermal water as they flow to the surface. The natural heat loss of the system is estimated to be 18 to 27 megawatts of thermal energy per annum.

Gillard Hot Springs discharge 80° to 84°C (176° to 183°F) water along the banks of the Gila River. These springs discharge sodium chloride bearing water with equal concentrations of sulfate and bicarbonate. Total dissolved solids range between 1200 and 1500 mg/l. Chemical geothermometers predict subsurface temperatures of 130° to 139°C (266°F to 282°F) at depths less than 2500 meter (8,200 ft). The natural surface discharge along the river banks is estimated to be 29.9 l/s (475 gpm) and convective heat loss into the Gila River is 7.8 megawatts.

The major potential utilizations for geothermal energy in these areas would be (a) for replacing coal and plant cooling water for a new hybrid geothermal/coal-fired power plant and (b) for use in the large integrated copper mining/flotation/leaching/smelting operations at Morenci. The details for hybrid geothermal/coal plants are discussed in the chapter of Northern Arizona Counties, and the details for utilizing geothermal energy in the copper industry were given for Pima County. A third application of geothermal energy would be for irrigation pumping in the fertile valley near

Safford, using geothermal-driven turbines connected directly to irrigation pumps. Such developments could then lead logically into cascade systems for the agricultural industry.

POTENTIAL UTILIZATION OF GEOTHERMAL ENERGY IN COCHISE/SANTA CRUZ COUNTIES

The major geothermal resources are in the Willcox area. Twelve water wells in the Willcox basin produce 31°C (88°F) to 54°C (129°F) thermal water from depth of 214 m (702 ft) to 832 m (2,730 ft). The warmest well produces 54°C (129°F) water from a depth of 445 m (1,460 ft). Three areas north and northwest of the town of Willcox have been identified as probable geothermal resource areas. Based on chemical geothermometers of selected wells in the Willcox basin, temperatures of 70°C (158°F) are probable at depths of less than 1000 m (3,281 ft) within the three areas. Additionally, one deep well drilled to 2,028 m (6,654 ft), but outside of the three areas, encountered a bottom hole temperature of 87°C (198°F). The estimated temperature gradient was 35°C/km (1.9F/100 ft). The average estimated temperature gradient for wells within the three areas is 74°C/km (4.0°F/100 ft).

However, an unexplored area in these counties may have the highest geothermal temperatures in all of Arizona. This is the San Bernadino Valley in the extreme southeast corner of Arizona. The requests for geothermal leases on 16,591 acres have been pending for some time. If and when the Federal government takes care of its obligations on these requests, the extent of geothermal resources in this valley may become known.

Potential uses of geothermal energy in Cochise/Santa Cruz counties include possible use in hybrid geothermal/coal-fired power plants near Willcox, irrigation pumping in several valleys, and the usual heating and cooling applications. One interesting potential not evaluated is the geothermal cooling of the large number of produce warehouses near Nogales and

the Mexican border, where a large trucking industry distributes Mexican winter products to all regions of the United States.

POTENTIAL UTILIZATION OF GEOTHERMAL ENERGY IN NORTHERN ARIZONA COUNTIES

The Northern Counties Geothermal Development Plan evaluated five potential geothermal resource areas, four of which have low temperature ($<90^{\circ}\text{C}$, 194°C) potential and one possible igneous rock system, as shown in Figure 13 (7).

These counties are sparsely populated, except for Flagstaff and some of the western edge of the state along the Colorado River. The area consists of large Indian lands (including the large area of Navajo's).

The major points of interest in these counties from geothermal resources viewpoint are (a) the large coal reserves of the Black Mesa and (b) the geothermal resources that overlap the existing sites of coal-fired power plants. The potential sites for hybrid geothermal/coal fired power plants in Arizona were evaluated in considerable detail (14). Such plants would utilize geothermal energy, thus saving 12-17 percent of the plant coal requirements. Equally important, the geothermal brines could be used for boiler makeup and for cooling, replacing potable water.

THE EVALUATION OF GEOTHERMAL COOLING SYSTEMS IN ARIZONA

Arizona consumes nearly 50 percent more electricity during the peak summer season of May through part of October, due to the high cooling load met by electrical-driven air conditioning units. These cooling loads are concentrated in the metropolitan areas of Phoenix and Tucson. This study evaluates two geothermal-driven cooling systems that consume less electricity, namely, absorption cooling and heat pumps.

Absorption cooling requires a geothermal resource above 105°C (220°F) in order to operate at a reasonable efficiency and capacity. Geothermal

Figure 13: Locations of Potential Geothermal Resource Areas in Northern Arizona

resources at these temperatures or above are believed existing in the Phoenix and Tucson areas, but at such depths that geothermal-driven absorption systems have high capital investments. Such capital investments are uneconomical when paid out over only five months of operation each year, but become economical when cascaded with other geothermal uses. There may be other regions of the state, where geothermal resources exist at 105°C (220°F) or higher at much less depth, such as the Casa Grande/Coolidge or Hyder areas, which might be attractive locations for future plants of the high-technology industries.

Geothermal assisted heat pumps have been shown in this study to be economical for nearly all areas of Arizona. They are more economical and reliable than air-to-air heat pumps. Such systems in Arizona depend upon a low-temperature geothermal resource in the narrow range of $15.5 - 26.6^{\circ}\text{C}$ ($60 - 80^{\circ}\text{F}$), and are widely available in Arizona.

THE POTENTIAL OF HYBRID GEOTHERMAL/COAL FIRED POWER PLANTS IN ARIZONA

The sharp increase in the price of oil and natural gas during the past ten years has increased the importance of coal as fuel for electricity generation. Extensive coal resources are available in the United States, including the State of Arizona. Furthermore, improved materials and technology have resulted in an improvement of electrical generating facilities such that overall efficiencies have been increased from about 33 to about 39 percent.

The Department of Energy, Division of Geothermal Energy, together with the City of Burbank, initiated a program to study the technology and economics of combining geothermal energy with a coal-fired power plant. The study (completed in 1978) evaluated the available technology and concluded that the hybrid plant has a thermodynamic advantage over a conventional coal-fired plant. The study also evaluated actual geothermal sources in California, Nevada and Utah, concluding that some sites are more economical than all-coal-

fired power plants while others are not.

These detailed reports made it possible to use their results to evaluate several possibilities of future hybrid geothermal/coal fired power plants in Arizona.

The City of Burbank study concluded that using geothermal energy in a hybrid plant reduces the coal requirement, given a prescribed plant output; or, alternatively, permits a higher plant output, given a fixed coal supply. Besides the energy gained in steam preheating, a considerable amount of lower temperature heat could be supplied for various other plants uses. These include (a) coal drying and beneficiation, (b) air preheating, (c) flue-gas reheating, and (d) general heating.

Because transport of high-temperature geothermal fluid over large distances is generally impractical, the hybrid plant must be located near the geothermal resource area. In general, the geothermal resource is not optimally sited with respect to sources of coal, fresh water, or transmission networks. Therefore, despite its thermodynamic superiority, the hybrid plant's economic competitiveness depends heavily upon bringing coal close to the geothermal resource at an economical price.

The key results of an economic analysis (summarized above) were based on an 85% plant capacity factor, 5% per annum inflation rate, 5% per annum operating and maintenance (O/M) escalation rate, 8% per annum coal cost escalation rate and bond interest for capitalization at 6% annually. For Case 2, Table 1, the total capital cost, estimated at \$385,841,000 in 1976 dollars for the plant within the battery limits was converted to dollars per year equivalent annual cost in 1976 dollars, taking into account interest during construction, inflation, 30 year economic life, and the cost of money. The other two cases were treated in the same manner.

For Case 2, annual fuel consumption for the hybrid plant is 1,933,000 tons of coal. Coal consumption for an all coal fired plant of the same generating capacity as the hybrid plant, with the same heat rate calculated for the all-coal plant, is estimated at 2,195,000 tons per year. Therefore, an estimated net coal savings of 252,000 tons per year or 13 percent would be realized with the hybrid plant.

In Case 2, cooling tower makeup water and condensate makeup water requirements for the hybrid geothermal/coal fired power plant were provided from surface and ground water sources near Roosevelt Hot Springs, Utah. The cost of cooling water was estimated in the City of Burbank Report for a 750 MW hybrid plant to be approximately 0.23 mills per kilowatt hour, or about \$1,300,000 per year.

TABLE 1. ESTIMATED AVERAGE ANNUAL COST FOR ELECTRICAL POWER (1976 Dollars)

Cost Item	Case 1 ^a		Case 2 ^b		Case 3 ^c	
	750 MW Net*		715 MW Net*		715 MW Net*	
	M\$/yr	Mills/kWH	M\$/yr	Mills/KWH	M\$/yr	Mills/KWH
Coal	43.725	7.824	35.139	6.615	33.887	6.380
Operations (O/M)	11.880	2.126	13.207	2.486	13.703	2.580
Geothermal (O/M)	--	--	1.786	0.329	1.786	0.329
Transmission	15.594	2.936	15.594	2.936	15.594	2.936
Depreciation	27.752	4.966	30.956	5.828	31.207	5.875
Cooling Water	1.166	0.209	1.298	0.244	--	--
Other	2.100	1.280	1.347	0.254	1.347	0.254
Total Estimated Cost of Power at Victorville	107.17	19.341	99.327	18.692	97.524	18.354

*Factoring of costs is not linear with respect to plant electrical generating capacity.

^aCase 1 -- All Coal Fired Plant (Estimated by City of Burbank).

^bCase 2 -- Hybrid Geothermal/Coal Fired Plant with geothermal feedwater heating only (Estimate by Ralph M. Parsons Company).

^cCase 3 -- Hybrid Geothermal/Coal Fired Plant with feedwater heating, air preheating, flue gas reheating and plant space heating by geothermal energy (Estimate by Ralph M. Parsons Company).

The advantages of using spent geothermal fluids for makeup water are significant since the quantity of raw water to be purchased in an area where ground and surface water are scarce and costly is considerably reduced. Likewise, spent geothermal fluid that is not used for makeup water must be reinjected into the ground at additional cost.

Average continuous makeup water requirements at full load for the hybrid plant were estimated at 50,000 pounds per hour for condensate makeup and 4,500,000 to 5,200,000 pounds per hour for cooling tower makeup. The total geothermal fluid flow for the hybrid plant, at full load is 4,600,000 pounds per hour. Approximately all the geothermal fluid leaving the feedwater and condensate heating system can be treated and used for condensate and cooling tower makeup water. For Case 3 above, where geothermal brines are used for makeup, the estimated cost for providing geothermal makeup water to the hybrid plant is \$2,720,000. This cost is more than compensated by savings in the cost of fresh raw water makeup that would be required in a conventional plant.

Consequently the total electricity generation cost for the hybrid plant with geothermal makeup water systems is lower than for the base case hybrid plant. Therefore, it was concluded that the hybrid geothermal/coal fired power plant should include the geothermal makeup water systems. For such systems the total coal replacement can be in the range of 13-17 percent.

Examining the cost of electricity for a hybrid power plant for the City of Burbank project at Roosevelt Hot Springs, it is seen that the costs are distributed as follows:

	<u>Percentage of Total Cost, %</u>
Depreciation	10
Plant Operations	10
Geothermal Well Cost	1
Geothermal Well Operations	1
Coal Feedstock	56
Cooling water	1
Electricity Transmission (300 mi)	<u>11</u>
TOTAL	100

In Arizona, there are coal-fired power plants at six locations, with two additional sites planned. In addition, there is a coal/water slurry pipeline taking coal from the Black Mesa area of Arizona to the Nevada border near Davis Dam, to supply the Mohave power plant in extreme southeast Nevada. Four of these plant sites overlap inferred geothermal resources. Seven additional geothermal resource areas, where hybrid geothermal/coal fired power plants might be located were also evaluated. It was beyond the scope of this study to make detailed economic evaluations of hybrid plants at these locations because (a) the detailed data needed for such studies are not available and (b) the objectives of geothermal utilization evaluation in Arizona did not include such details. However, this study provides further information on the suggested eleven sites in Arizona for possible future hybrid geothermal/coal fired power plants.

Primary Sites

It is obvious from previous studies that the cost of coal and its transportation costs to the power plant site are usually the dominant economic factors. These factors are balanced to some extent by the third most

important economic factor, namely, the cost of electric power transmission to use areas. In Arizona there is a fourth important factor, i.e., the availability of cooling water. Consequently, most coal-fired power plants sites in Arizona were influenced by the cooling water situation, as shown below:

1. Navajo Units at Page -- Coal is transported from the Black Mesa in Northeast Arizona by a railroad, built especially for this purpose. At Page, large supplies of cooling water are available from the Colorado River.
2. Mohave Units Across Nevada Border -- Peabody Coal Co. constructed a coal/water slurry line to move Black Mesa coal across Northern Arizona to the Nevada border. Again, the use of Colorado River water for cooling was a key factor.
3. Cholla, Coronado and Springerville Sites -- All of these areas have adequate water supplies for cooling, due to (a) water runoff from the White Mountain area and (b) the waters in the valleys serving the Little Colorado River.

Two potential primary sites in Arizona for future hybrid geothermal/coal fired power plants are (a) near the existing coal-fired power plant units at St. Johns (Coronado units) and (b) near the coal-fired power plant units currently under construction at Springerville.

Potential Hybrid Geothermal/Coal Fired Power Plant at St. Johns

Two Coronado units of 350 MW each are being operated at St. Johns, Arizona, owned 70% by Salt River Project and 30% by others. A third unit is planned, for the future, the date to begin construction is indefinite. Thus, there may be time to consider the merits of backing out part of its coal requirements by means of geothermal energy. This is suggested as a primary site, because if the power plant site is currently considered attractive, then

there may be a sufficient geothermal resource to make it even more attractive.

Potential Hybrid Geothermal/Coal Fired Power Plant at Springerville

Tucson Electric Power Company has under construction and will own the first of three 350 MW coal-fired power plants at Springerville, Arizona. The first unit is scheduled for completion in 1985, the second in 1987 and the third in about 1991. It may be possible to modify the design for the 1991 unit in time to utilize geothermal energy in the proposed mode of a hybrid geothermal/coal fired power plant.

Secondary Sites

There are two other sites in Arizona where geothermal resources appear to exist at locations of existing coal-fired power plants. These are at Willcox, Arizona and Tucson, Arizona.

The Tucson Electric Power Company currently operates its large Irvington unit on natural gas, but has obtained approval to retrofit the plant to a coal-fired unit. This will take some time to achieve. It may or may not be too late to consider a hybrid geothermal/coal-fired system during this transition, thus backing out a certain amount of coal that must be shipped to Tucson. It could also replaced some of the critical potable water of the Tucson basin by geothermal brines for cooling. The cost of producing electric power in Tucson from a hybrid plant should be lower than that for a conventional coal-fired plant.

Potential Sites

In order to consider other potential sites in Arizona for hybrid geothermal/coal-fired power plants, one should give consideration to the relative costs of transporting coal versus electrical power transmission. Railroads and slurry pipelines are usually the alternatives for high tonnage, long distance transport of coal. Railroads often have competitive tariffs

when no new trackage has to be constructed. Otherwise, pipelines are more economical. It is also important to notice that the price of railroad transportation increases more rapidly than pipelines during inflationary periods.

Transmission of electricity by Extra High Voltage (EHV) accounts usually for about 10% of the price of electricity. The cost of EHV transmission results mainly from the losses of power and the initial investment for the power line. Therefore, geothermal assisted new coal-fired power plants in Arizona could be located closer to Phoenix, or even Tucson, for a hybrid geothermal/coal unit, because one could base the location more on the above economics without concern for a source of cooling water -- the geothermal brines would serve that purpose. Secondly, since the cost of transporting coal is cheaper than electrical power transmission, this would also lower electricity generating costs. In summary, hybrid geothermal/coal plants should show lower costs, and less cooling water requirements. These comments apply to the seven new sites suggested for consideration below, as follows:

1. Pinta, Arizona -- Located on the AT & Santa Fe railroad, northeast of Holbrook, it would supplement coal-fired plants now existing at St. Johns (south) and at Joseph City (Holbrook). Access to Black Mesa coal could be by railroad or a reasonably short slurry pipeline.
2. North Flagstaff -- This area may have a geothermal resource, as it is close to the San Francisco Peaks, where the most recent volcanic action in Arizona (some 900 years ago) occurred. However, there are some questions about having sufficient water, and geothermal brine available in the area.

3. Southeast Kingman -- There is a potential geothermal resource area to the southwest of Kingman. This is also close to the coal slurry line serving the coal-fired plant near this area, just across the Nevada border. Thus, a parallel coal slurry pipeline could be constructed, and the geothermal brines used for cooling water; one would not be concerned with using the Colorado River for cooling water.
4. Northeast of Wenden-Salome -- This location is close to the open aqueduct bringing Colorado River water to Phoenix and Tucson. If the dissolved solid content of the water is low, the geothermal brine might be used for cooling water and later could be blended with Colorado River water in the aqueduct. In general, Arizona appears to have geothermal resources at intermediate or lower temperatures than neighboring states. However, this may be a blessing as, at lower temperatures the geothermal water appears to have lower dissolved solids. Thus, they may replace valuable potable water being pumped from the ground.
5. West of Goodyear, Arizona -- This location, west of Goodyear, Arizona, and in the extreme southwest of metropolitan Phoenix, would help serve the large electric demand of Phoenix. A location could be selected that would not pollute Phoenix and would not disturb the geological structures under the nuclear power plant of that area, say, staying ten miles of metropolitan Phoenix. The hybrid plant could use the geothermal brines for cooling, whereas it has been necessary to construct a special water line from Phoenix to the nuclear plant (some 50 miles) to provide it with treated sewage waste water for cooling purposes.

6. Eloy, Arizona -- This location is in the corridor between Phoenix and Tucson, and sufficiently distant from Casa Grande to prevent pollution of this community. The power generated at such a location could be added to the electrical network serving Phoenix and Tucson as well as the growing communities in its vicinity.
7. Clifton, Arizona -- This location is near a large copper production operation. If sufficient need for additional electrical power develops in the future, an interesting cascade or integrated geothermal system might be designed. First, there is excess water available as runoff in the mountains north of this area, all the way to Springerville. A coal slurry line might transport both coal and waters further south where it is in more demand, analogous to some extent how Northern California water is needed in the more arid Southern California. Secondly, the geothermal resource could be used for its energy in the hybrid geothermal/coal fired power plant, and then in cascade fashion be used for copper dump leaching. The latter would extract the last amount of available energy (all above ambient temperature is beneficial) and simultaneously back out more valuable potable water. In addition, a portion of the geothermal waters should be used for the flotation operations of the copper concentrating plant.

In summary, these seven potential sites for new hybrid geothermal/coal-fired power plants all have unique site characteristics. Obviously, more detailed studies are required, becoming so complicated that they are beyond the scope of this study.

ADDITIONAL RELATED REPORTS

The following fifteen reports were prepared by the Evaluation of geothermal Utilization group:

1. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Maricopa County, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 79-8.
2. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Pima County, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 79-9.
3. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Graham/Greenlee Counties, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 79-10.
4. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Pinal County, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 79-11.
5. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Yuma County, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-18.
6. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Cochise - Santa Cruz Counties, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 80-9.
7. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Northern Arizona Counties, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076, and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 80-10.
8. Goldstone, L.A. and White, D.H., 1982, Maryvale Terrace: Geothermal Residential District Space Heating and Cooling, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076, and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-11.

9. Goldstone, L.A. and White, D.H., 1982, Geothermal Heating for the Arizona Environmental Research Laboratory Greenhouses, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076, and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-12.
10. White, D.H. and Goldstone, L.A., 1982, Evaluation of Geothermal Cooling Systems in Arizona, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-13.
11. White, D.H. and Goldstone, L.A., 1982, Irrigation Pumping Using Geothermal Energy, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076, and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-15.
12. White, D.H. and Goldstone, L.A., 1982, Geothermal Energy for Copper Dump Leaching, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076, and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-15.
13. White, D.H. and Goldstone, L.A., 1982, Geothermal Energy for Copper Flotation Enhancement and Leaching of Tailings, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076, and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-10.
14. White, D.H. and Goldstone, L.A., 1982, The Potential of Hybrid Geothermal/Coal Fired Power Plants in Arizona, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076, and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-8.
15. Malysa, L.M. and White, D.H., Hahman, W.R., Mancini, F., and Goldstone, L.A., 1980, Arizona Geothermal Institutional Handbook, prepared for the U.S. Department of Energy, Contract No. DE-FC07-79ID12015, and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 80-7.

GLOSSARY OF GEOLOGICAL TERMS

Anomalously shallow depth - unusually or unexpectedly shallow depth.

Basin-range graben bound by deep faults - an area usually ten to hundreds of km² in area that has been down dropped along deep faults relative to the surrounding mountains; the grabens become filled with sediments to become valleys.

Curie-depth - the depth at which rocks become hot enough to lose their magnetic properties, ~ 525^oC. Curie temperature within 5-10 km of the surface are an indicator of geothermal resource potential.

Deep circulation - the natural movement or flow of ground water, as a result of convection, whereby it descends and becomes heated at depth and then rises toward the surface.

Deep sediment-filled, faulted basin - see basin - range graben.

Depth of Curie-isotherm analysis - technique used to estimate depth to the Curie temperature.

Hot dry rock production - a method for extracting useful heat in a deep dry hole; accomplished by fracturing the hot rock between two deep holes, and pumping cold fluid into one and bringing hot fluid out of the other.

Geothermometer - an empirical formula, based on the temperature-dependent solubility of certain minerals, used for estimating deep fluid temperatures in a geothermal reservoir.

Magnetotelluric survey - an electromagnetic method in which natural electric and magnetic fields are measured. Models of the crust can then be constructed and resistivities at great depth can be predicted.

Major range bounding faults - fractures or fracture zones along which mountains have risen relative to down dropped grabens.

Shallow magmatic intrusion - a body of magma that has intruded its way upward into shallower crust.

Na-K-Ca geothermometer -- (also, quartz geothermometer, chalcedony geothermometer) - see geothermometer.

Tectonic history - the cycle that relates the larger structural features of the Earth's crust to gross crustal movements and to the kinds of rocks that form in the various stages of developments of these features.