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AN ASSESSMENT OF SOLAR-GEOTHERMAL HYBRID SYSTEM CONCEPTS

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FOREWORD

This report summarizes the results of system engineering studies of solar-geothermal hybrid systems, conducted under Task 1 of DOE Contract No. EY-76-C-03-1101, in support of DOE hybrid system project activities. The Aerospace Corporation is providing systems engineering studies and technical and management support under that contract under the cognizance of Mr. R. Hughey, Director of the Division of Solar Energy, and Dr. S. D. Elliott and Mr. L. Prince, Programs Managers, DOE/SAN.

The report was prepared by the Energy Projects Group under the direction of Dr. E. L. Katz, Director, and Dr. P. N. Mathur, Project Manager. The thermodynamic analyses were conducted by Mr. M. Masaki.

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ABSTRACT

Studies were conducted to assess the technical and economic merits and limitations of advanced solar-geothermal hybrid electric power plant concepts. Geothermal resource characteristics and technologies were reviewed to determine the best possible ways of combining solar and geothermal technologies into a hybrid operation (Section 1).

Potential hybrid system concepts are defined (Section 2) and their performance, resource usage, and economics are assessed relative to the individual solar and geothermal resource development techniques (Sections 3 and 4). Key results are presented in Section 5.

1.0 ASSESSMENT OF GEOTHERMAL RESOURCE AND TECHNOLOGY

A review of the geothermal resource availability, compatibility with solar sites, resource characteristics, power conversion techniques, and technology development issues is presented to identify the best ways of combining geothermal with solar.

1.1 GEOTHERMAL RESOURCE CHARACTERISTICS

Regional but abundant water-dominated geothermal resources are available in the western United States. Many geothermal sites are compatible with good insolation availability for hybrid operation.

Geothermal energy is presently being utilized in many countries for the generation of commercial electric power. The Geysers fields in northern California, at present, represent the only commercial operation in the United States with approximately 500 MWe of electric production capacity.

Geothermal resources in the U.S. include hydrothermal reservoirs and other thermal reservoirs such as dry hot rocks. The hydrothermal reservoirs, mostly located in western states, constitute the primary geothermal resource. A large majority of these hydrothermal reservoirs are the water-dominated variety (hot brine reservoirs) as opposed to steam-dominated Geysers fields which can be utilized for power generation without significant extrapolation of conventional steam power technology.

Estimates of known geothermal resources, with the wellhead fluid temperatures exceeding 300°F, approximate 0.8×10^6 MWe-year energy (Reference 1) or the total electric energy production from 270 geothermal plants each with a 100 MWe capacity and 30-year operating life. Estimates of total energy resource potentials, considering discovered and undiscovered resources, exceed 4.5×10^6 MWe-years.

A major limitation of a hot brine resource is its low grade heat (250-500°F, 50-400 psi) resulting in poor thermodynamic efficiencies as shown in Figure 1-a. The hot brine reservoirs with fluid temperatures at 300°F or lower are considered submarginal for electric production using conventional geothermal power technology.

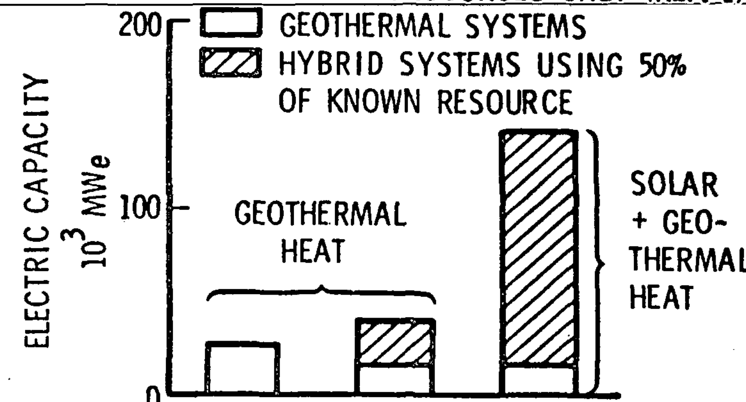
The thermodynamic efficiencies and, consequently, electric power generation capacity of a given geothermal resource can be enhanced substantially by solar-geothermal hybrid operation as indicated by the bar chart, Figure 1-b.

FIGURE 1

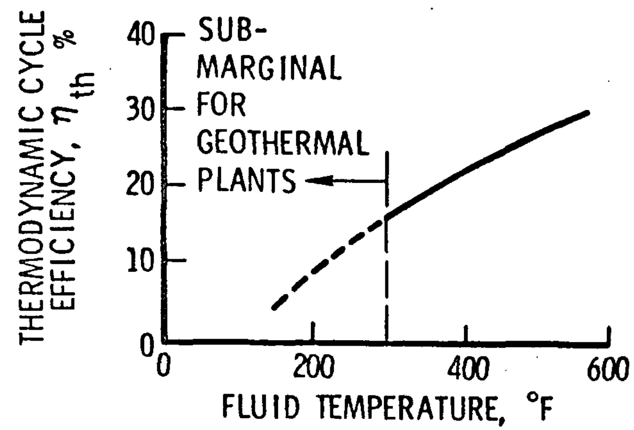
Resource Characteristics

- COMMERCIAL ELECTRICITY FROM GEOTHERMAL SOURCES
  - FIRST OPERATION IN 1904, LARDERELLO ITALY
  - CURRENT OPERATION IN U.S., MEXICO, ITALY, NEW ZEALAND AND OTHER COUNTRIES
  - GEYSERS, CALIFORNIA, ONLY COMMERCIAL OPERATION IN U.S.
- GEOTHERMAL RESOURCES IN U.S.
  - MOST SITES IN WESTERN STATES
  - PREDOMINANTLY WATER DOMINATED RESOURCE
  - 6×10^9 MW_e-HRS KNOWN RESOURCE
  - 35×10^9 MW_e-HRS POTENTIAL RESOURCE
- RESOURCE CHARACTERISTICS
  - LOW GRADE HEAT
  - 250°F-500°F / 50-400 psi HOT BRINE
  - LOW CONVERSION EFFICIENCIES
  - MANY SITES COMPATIBLE WITH GOOD INSOLATION

- KNOWN RESOURCES ONLY (REF. 1)



(b)



(a)

1.1 GEOTHERMAL RESOURCE CHARACTERISTICS (continued)

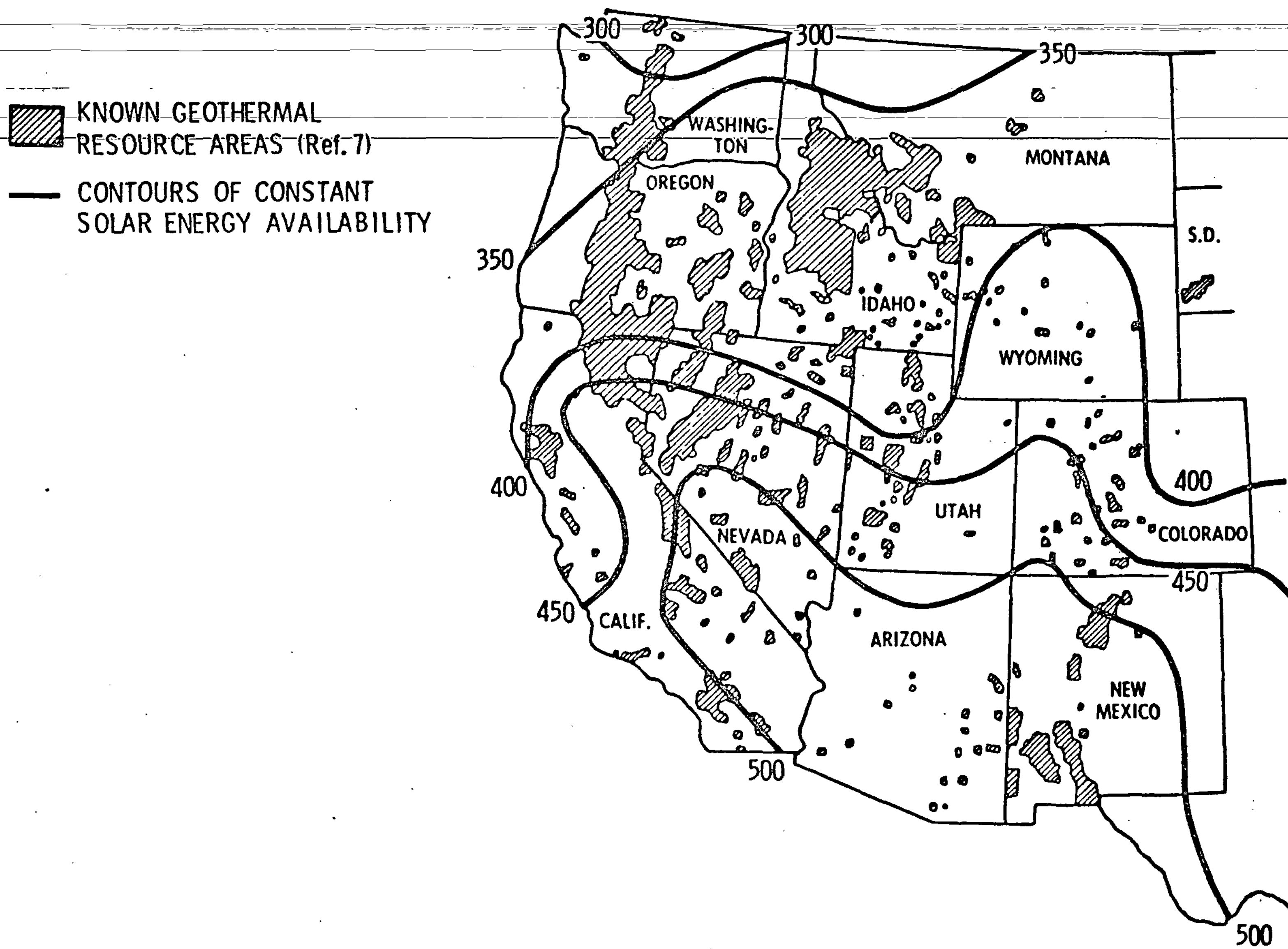
The known geothermal (hydrothermal) resource areas (KGRA) in the CONUS are shown in Figure 2 along with the contours of representative daily solar energy availability. As can be seen, a large number of KGRA are in the southwestern states with good insolation for the operation of solar-geothermal hybrid plants. Approximately 60% of the KGRA are on government land.

The greatest concentration of hydrothermal sites is in California and Nevada. Areas in which geothermal development is expected in the near future include Imperial Valley and Mono Long Valley, California and several sites in Nevada. All of these sites have hot brine reservoirs.

Estimates of potential electrical energy availability at the Salton Sea Geothermal Fields in Imperial Valley alone are 80,000 MWe, i.e., sufficient geothermal energy to operate 27 geothermal plants or 135 solar-geothermal hybrid plants each with a 100 MWe capacity and 30-year life.

FIGURE 2

Geothermal Resource Characteristics



1.2 GEOTHERMAL POWER CONVERSION TECHNOLOGIES AND OPTIONS

Power conversion machinery for a geothermal resource is similar to that for conventional low temperature Rankine systems but must be designed against scale deposition and corrosion effects of geofluids.

The equipment for conversion of hydrothermal energy into electrical power is similar to that utilized for the conventional low temperature steam and binary Rankine cycle technology. The geofluid loop, however, has distinctive characteristics as illustrated in Figure 3. Various techniques and options for electric power generation from geothermal sources include the following:

a. Conventional low temperature, low pressure steam Rankine cycle process utilizing direct steam from vapor dominated reservoirs. The cooled water from the condenser is reinjected into the reservoir by high pressure pumps through reinjection wells (see Figure 3-a).

b. Flashed steam process in which the hot brine is flashed into steam in one or more stages by lowering the fluid pressure in flash tanks. The residual fluids from the tank and the condenser are mixed and reinjected into the reservoir as illustrated in Figure 3-b.

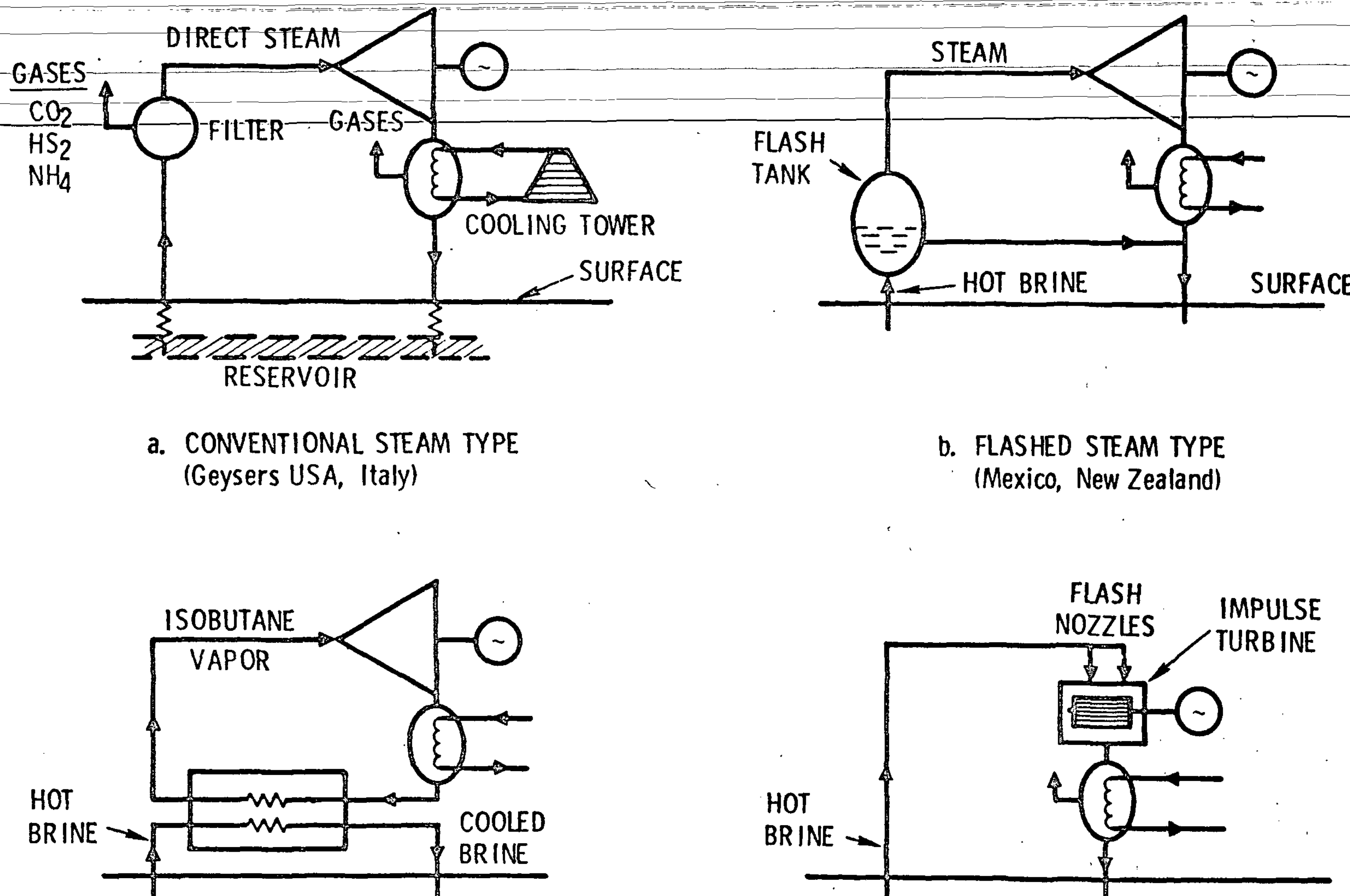
c. Binary process in which the geofluid serves as the boiler heat source for a secondary working fluid, such as isobutane, in a closed binary Rankine cycle. The cooled geofluid from the boiler/heat exchanger is reinjected into the reservoir (see Figure 3-c).

d. Total impulse process in which the wellhead brine is flashed through nozzles and two phase high velocity geofluid (fluid and vapor) is directly impinged on the buckets of turbine wheels to extract the maximum amount of energy (see Figure 3-d).

e. Hybrid processes in which the geofluid is utilized for preheating the working fluid (either in a direct loop or in a secondary loop such as in the binary process, Figure 3-c) for a high temperature solar or fossil steam Rankine cycle. These techniques are discussed in Section 2.

FIGURE 3

Geothermal Power Conversion Techniques



a. CONVENTIONAL STEAM TYPE (Geysers USA, Italy)

b. FLASHED STEAM TYPE (Mexico, New Zealand)

c. BINARY-HOT BRINE TYPE (under development)

d. TOTAL IMPULSE-HOT BRINE TYPE (under development)

1.3 GEOTHERMAL FLUID EXTRACTION AND REINJECTION

Extraction

The extraction system for geothermal energy is similar to oil and gas in that a well is drilled to a sufficient depth, cased, and cemented to provide a stable conduit for fluids. The lower part of the wellbore is usually an open hole. Fluid is forced to the surface because of the pressure differential between the reservoir and the surface. This pressure differential also controls the mass flow rate. Facilities are added to the well to control and transport the fluid to its point of utilization.

Figure 4 shows a typical depth and diameter configuration of a geothermal well at Geysers. Completed wells at Geysers range in depth from 600 to 9,000 feet with fluid transport lines ranging up to two miles in length. Production rates at Geysers range from 40,000-300,000 pounds of steam per hour requiring several wells per plant.

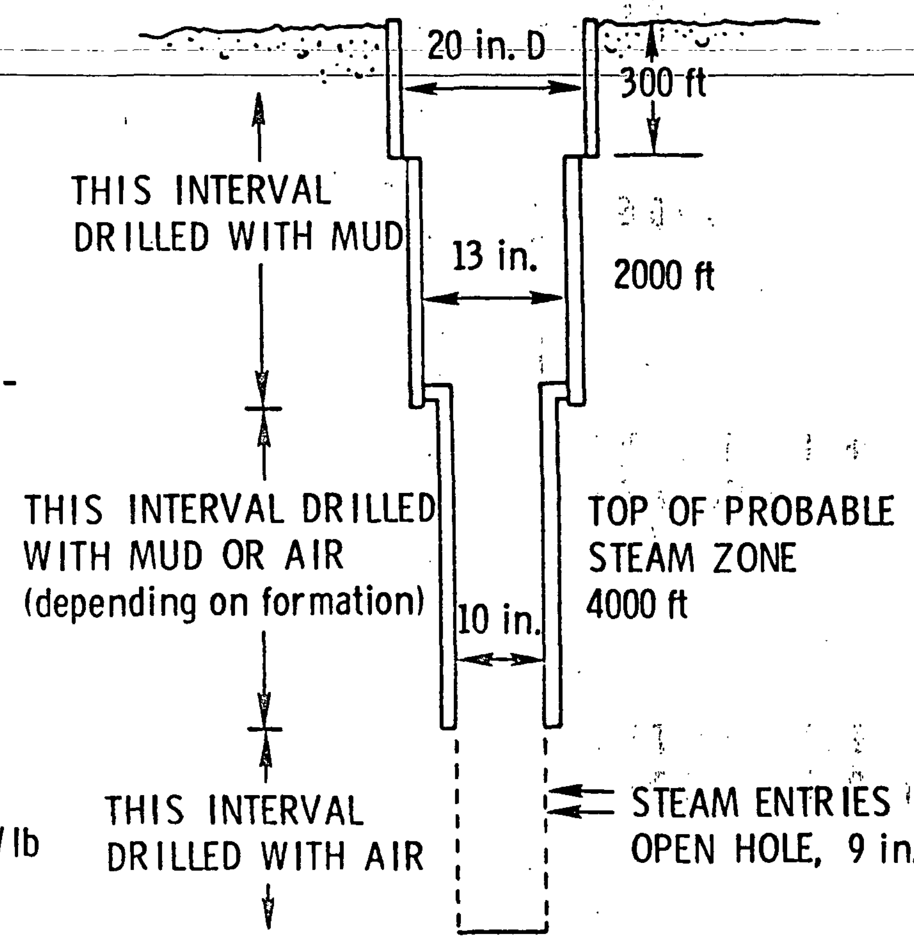
Reinjection

The high concentration of dissolved solids (primarily Si, $CaCO_3$, NaCl) generally precludes release of brine in fresh surface or ground water. The waste brine can be reinjected into the deep formations from which it is extracted at high pressures via reinjection wells to maintain reservoir pressure and minimize contamination of ground water.

FIGURE 4

Typical Geothermal Extraction Well (Geysers)

- UPPER PART DRILLED, CASED, AND CEMENTED
- LOWER PORTION LEFT AS OPEN HOLE
- AVERAGE DEPTH - 8000 ft
- AVERAGE STEAM PRODUCTION RATE - 140,000 lb/hr
- RESERVOIR TEMPERATURE - 475°F
- PRESSURES
  - RESERVOIR - 500 psi
  - WELLHEAD - 150 psi
- HEAT CONTENT OF STEAM - 1200 Btu/lb



1.4 GEOTHERMAL TECHNOLOGY DEVELOPMENT ISSUES

Major technology development issues of geothermal power systems are outlined in Figure 5. None of these problems negate the practical use of hot brine resource but will impact on plant operating costs. Proper solar hybrid configurations can minimize some of these problems.

Figure 5 outlines some of the important technology development issues of concern in the use of geothermal energy in hybrid operation with solar plants. These technology issues do not negate the practical use of geothermal energy but will impact on the operating economics of the geothermal plants, particularly at the water dominated thermal reservoirs.

The presence of large amounts of solids, particularly at the geothermal brine reservoirs in Imperial Valley, will cause precipitation of mineral deposits which form scales in pipes and machinery. Problems are most severe in the energy conversion machinery where large pressure and temperature drops can cause massive precipitation of solids. For solar hybrid applications it will be desirable to utilize the geothermal heat through a secondary loop heat exchanger (similar to that in a binary cycle, discussed above) to avoid scale deposits in the receiver and power conversion equipment and reduce down time and maintenance costs.

Hydrogen sulfide is toxic and the most troublesome of the various air pollutants noted in Figure 5. At hot water reservoirs the release of H_2S is expected to be higher. The H_2S release at Cerro Prieto, Mexico is estimated to be 480 tons/MWe/year, roughly ten times that at Geysers (Figure 5). Control techniques include use of scrubbers to reduce H_2S content to environmentally acceptable levels prior to venting. Appropriate power conversion cycles, such as those discussed in Section 2, can also minimize this problem.

Possible decline in reservoir temperature and pressure in time would reduce the plant electrical output. This loss of energy can be compensated for by drilling additional wells if adequate sites are available. The additional sites for the contingency wells must be included in the design.

The liquid to be reinjected into the formations must be free of suspended matter to avoid clogging of the pores of the formation. Loss of permeability will require increased pumping pressures to maintain the required reinjection flow rate. A maximum pumping pressure limit is set by the pressure that the well casing can withstand before rupture. As an alternative, a clogged well may be cleaned chemically in the cases where the obstructing species can be redissolved.

FIGURE 5

Geothermal Technology Development Issues

- PRECIPITATION OF SOLIDS
  - SCALE DEPOSITS IN PIPES, VALVES, TURBINES
  - CLOGGING OF VALVES, RESERVOIR PORES
  - MOST SERIOUS WITH CHANGES IN T, P (IN TURBINES)
  - CONTROL TECHNIQUES - ACIDIFICATION, SLURRY SEEDING, ALTERNATE CONVERSION CYCLES
- ENVIRONMENTAL POLLUTION (GEYSERS - tons/MW_e/yr)
  - CO_2 - 631
  - H_2S - 39
  - METHANE (TOXIC) AND AMMONIA - 90
  - CONTROL: SCRUBBERS, ALTERNATE CONVERSION CYCLES
- DECLINE IN WELL PRODUCTION
  - DECLINE IN FLOW RATES, TEMPERATURE, AND PRESSURE WITH TIME
  - CONTROL TECHNIQUE - PLAN DRILLING ADDITIONAL WELLS
- REINJECTION
  - UNKNOWN SUBTERRANEAN STRUCTURE
  - SUSPENDED MATTER MAY CLOG UP PORES
  - LOSS OF WELL PERMEABILITY REQUIRING INCREASED PUMPING PRESSURE
  - CONTROL TECHNIQUES - ACIDIFICATION, INCREASED PRESSURE

2.0 SOLAR GEOTHERMAL HYBRID SYSTEM CONCEPTS

Potential solar-geothermal and solar-fossil geothermal concepts that minimize geothermal technology problems and provide improvements in plant economics and operation are identified and discussed.

2.1 SOLAR-GEOTHERMAL HYBRID SYSTEMS - GENERAL CONSIDERATIONS

Considerations outlined in Figure 6 narrow down the potential solar-geothermal hybrid options to those utilizing geothermal heat for feedwater heating.

A variety of solar-geothermal concepts were screened on the basis of considerations outlined in Figure 6. For example, a hybrid concept involving pressurization of wellheat fluid and the addition of solar heat prior to flashing provides higher quality steam and thermodynamic advantage over a geothermal flash system. However, the introduction of hot brine into receiver loop and the steam from hot brine into the EPGS cycle would result in problems of scale deposition and corrosion much more severe than those of a pure geothermal flashed steam plant.

The candidate concepts thus should involve appropriate combinations of solar thermal system elements utilizing a high performance steam Rankine cycle with partial or total feedwater heating by geofluid using a heat exchanger.

FIGURE 6

Solar-Geothermal Hybrid Systems General Considerations

REVIEW OF GEOTHERMAL RESOURCE CHARACTERISTICS AND TECHNOLOGY ISSUES (Section 1) SUGGESTS AN INDIRECT USE OF GEOTHERMAL HEAT THROUGH FEEDWATER HEAT EXCHANGER (FWH-X) IN THE SOLAR EPGS CYCLE. THIS APPROACH WILL:

- LIMIT SCALE FORMATION AND CORROSION PROBLEMS TO FWH-X
- MINIMIZE IMPACT OF SOLID AND GAS POLLUTANTS (geofluid in closed loop)
- MINIMIZE CHANGES IN COMPOSITION OF REINJECTED FLUID
- PROVIDE MORE EFFICIENT USE OF GEOTHERMAL RESOURCE
- MINIMIZE RISK OF PREMATURE DEPLETION OF RESOURCE AT PLANT SITE (plant can operate as pure solar)
- REDUCE THE NUMBER OF WELLS REQUIRED PER PLANT

2.2 HYBRID CONCEPT A

This concept represents a relatively simple, solar-geothermal hybrid configuration but results in an unacceptable power profile with no flexibility in power delivery.

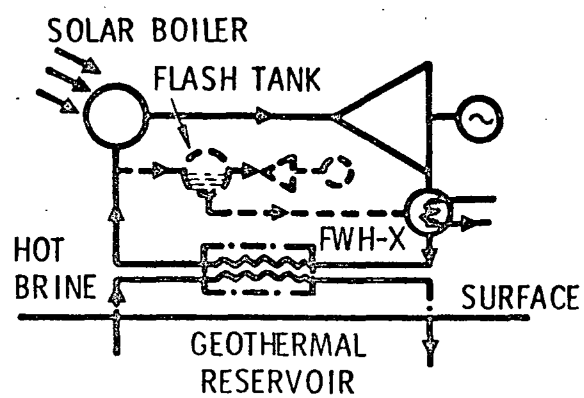
The simplest hybrid concept involves the use of current technology solar steam system with no storage in combination with geothermal heating of cycle feedwater as illustraged in Figure 7. In this case the conventional steam bleed lines from the turbine used for heating the feedwater have been eliminated. This results in an increased flow through the turbine or increased power output if slightly larger EPGS equipment is used. In this concept the geothermal heat is converted to electricity at the hybrid plant efficiency which is much higher (1.7 times) than that for a pure geothermal plant.

At nighttime or during cloud cover, the feedwater can be heated by geothermal fluid and flashed into a lower temperature steam cycle to generate power as shown in Figure 7. However, as a result of lower efficiency and low heat content steam cycle, only a fraction of the installed capacity can be generated during non solar operation. The resulting power profile is unsatisfactory. It suggests the use of a storage-coupled solar system with high cycle efficiency.

FIGURE 7

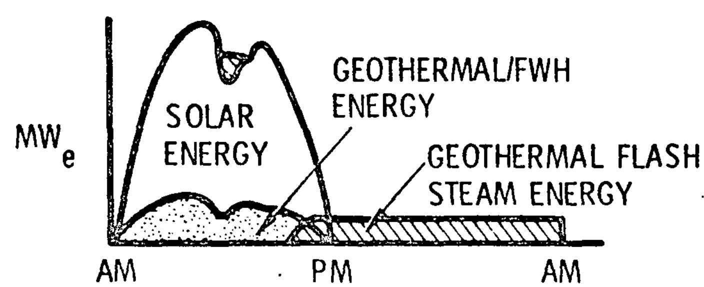
Solar-Geothermal Concept A

- CONCEPT
  - SOLAR STEAM SYSTEM CYCLE NO STORAGE (——)
  - GEOTHERMAL PREHEAT FWH-X (—·—)
  - FLASHED STEAM POWER DURING NIGHT (– –)



- ADVANTAGES
  - IMPROVED PERFORMANCE OVER PURE GEOTHERMAL SYSTEM
  - REDUCED SCALING AND EMISSION PROBLEMS FROM GEOTHERMAL SOURCE
  - POSSIBLE ECONOMIC ADVANTAGE OVER SOLAR STAND-ALONE

- POWER PROFILE



- DISADVANTAGES
  - POOR POWER PROFILE, CAPACITY CREDIT
  - NO FLEXIBILITY IN PLANT OPERATION/DISPATCH

2.3 HYBRID CONCEPT B

This concept represents a more complex configuration but provides an acceptable power profile, high performance, and a much greater flexibility of operation.

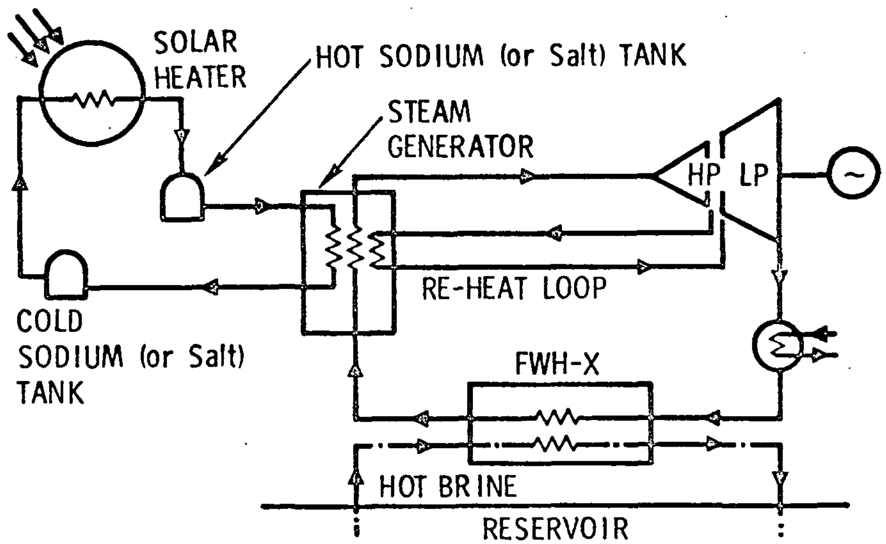
This hybrid concept combines the high performance features of the Sodium or Salt ACR system with a low cost geothermal feedwater heating equipment to generate electricity. This concept improves the power profile (see Figure 8) since the plant can operate on storage at its peak capacity during nighttime or during cloud cover. The performance and economics of this and other hybrid concepts are discussed in Section 3.

A disadvantage of this system for intermediate operation is the requirement of daily start-up and shutdown of the geothermal flow. However, this problem can be eliminated by adding conventional flash steam power generation equipment, such as that used in configuration A, to provide additional power and continuous operation of geothermal wells.

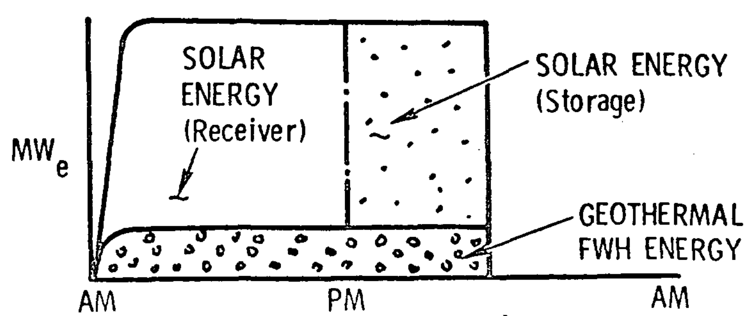
FIGURE 8

Solar-Geothermal Hybrid Concept B

- CONCEPT
  - SODIUM (or Salt) ACR CYCLE-STORAGE (——)
  - GEOTHERMAL PREHEAT FWH-X (—·—)



- POWER PROFILE



- ADVANTAGES
  - SUBSTANTIALLY IMPROVED PERFORMANCE OVER GEOTHERMAL SYSTEM (Efficiency Ratio, $\eta_{HYBRID}/\eta_{GEO} > 2.0$)
  - IMPROVED POWER PROFILE OVER CONCEPT A
  - POSSIBLE ECONOMIC ADVANTAGE OVER STAND-ALONE ACR
  - ELIMINATION OF MOST PROBLEMS OF GEOTHERMAL FLASH STEAM PLANT
  - INSURANCE AGAINST PREMATURE DEPLETION OF WELLS
- DISADVANTAGES
  - DISCONTINUOUS GEOTHERMAL OPERATION
  - COMPLEX SYSTEM

2.4 SOLAR GEOTHERMAL FOSSIL HYBRID CONCEPTS

These concepts are modifications of Concepts A and B in which the storage is replaced by a hybrid fossil heater or boiler. These concepts are expected to show an economic advantage over Concepts A and B for a range of fuel costs and fuel escalation rates.

The Concept C utilizes a sodium (or salt) ACR solar-fossil hybrid arrangement in conjunction with geothermal feedwater heating. The resulting system configuration is similar to Concept B discussed above except that the large storage tanks have been replaced by small buffer tanks, and a fossil heater is added in a sodium (or salt) bypass loop as shown in Figure 9.

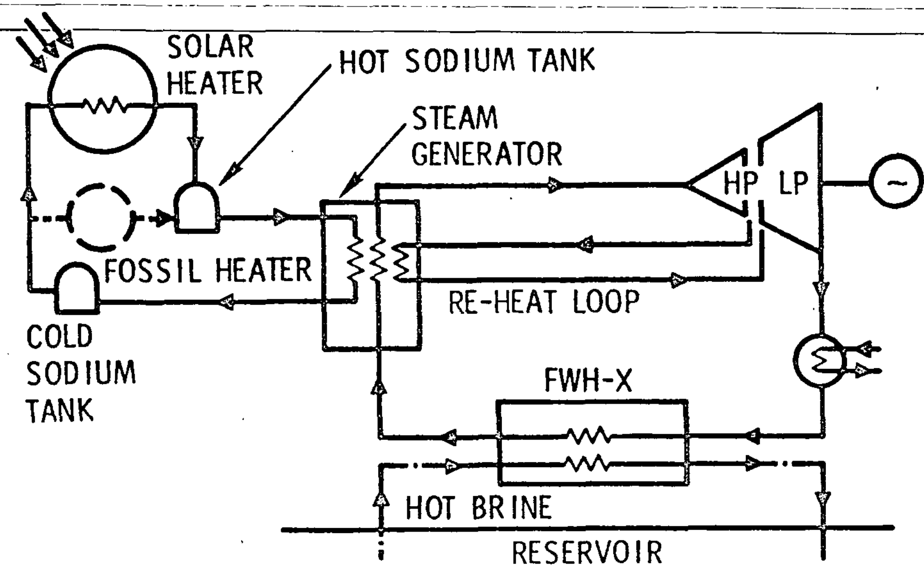
The power profile and the advantages and disadvantages of this concept are similar to that of Concept B. This concept utilizes three energy sources but is expected to show a cost advantage over the other options for a range of fuel costs and fuel escalation rates.

Concept D utilizes first generation steam technology solar-fossil hybrid equipment instead of ACR solar-fossil hybrid equipment. The power output from the geothermal heat is lower for Concept D than that for Concept C because of a lower cycle efficiency.

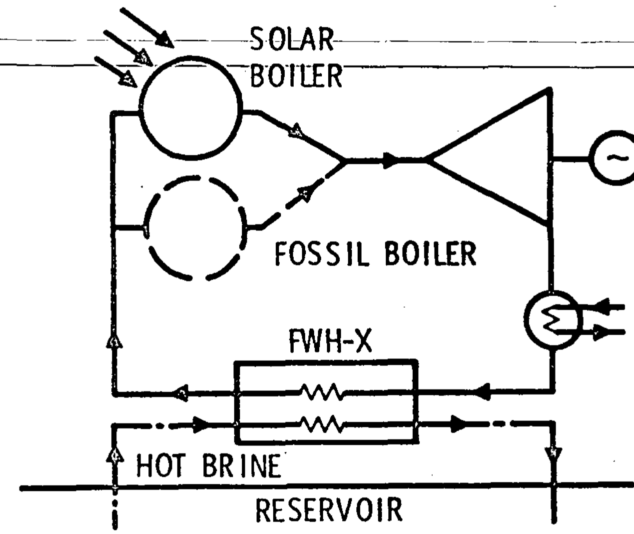
FIGURE 9

Solar-Geothermal-Fossil Hybrid Concepts

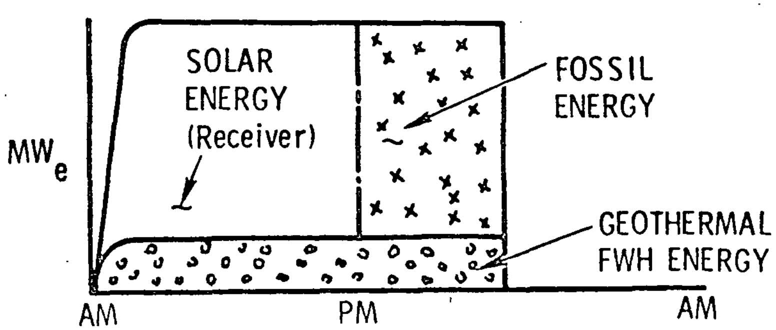
- ACR HYBRID CONCEPT C



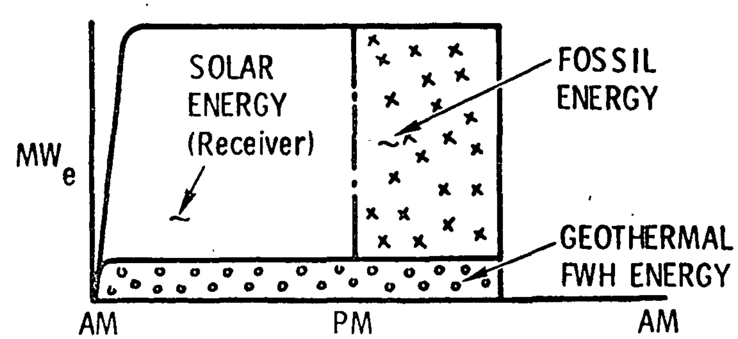
- SOLAR STEAM HYBRID CONCEPT D



- POWER PROFILE



- POWER PROFILE



3.0 HYBRID SYSTEMS PERFORMANCE CHARACTERISTICS

Performance characteristics of solar, solar geothermal hybrid, and geothermal stand-alone systems are defined and compared as a function of geothermal resource temperature. Estimates of relative improvements in resource utilization by a hybrid technique and other figures of merit for hybrid systems are presented.

3.1 GEOTHERMAL AND HYBRID CYCLE PERFORMANCE

Use of the hybrid concept substantially improves the thermodynamics of power conversion from geothermal energy. Hybrid cycle efficiency is slightly reduced from that for pure solar because of the heat addition to the system at lower temperatures.

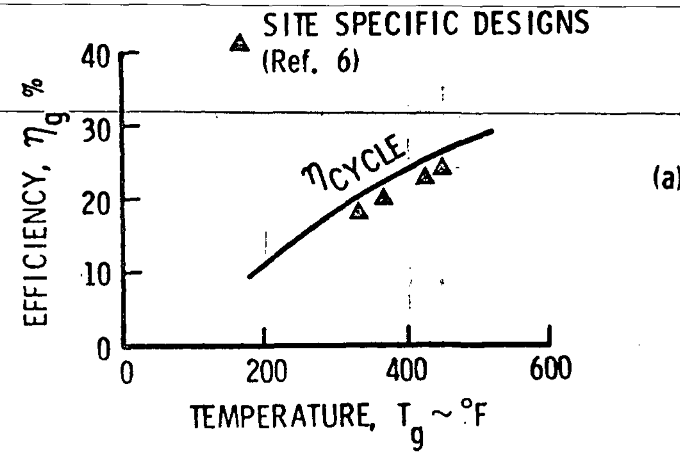
The performance and economics of the various hybrid configurations discussed above have been conducted by utilizing the methods and data developed in References 3, 4, 5, 6, and 7. Reference 4 presents an excellent analytical treatment of the analysis of hybrid systems' performance. References 5, 6, and 7 developed design, costs, and technology data on geothermal and fossil-geothermal hybrid plants.

Figure 10-a shows estimates of cycle and plant efficiencies for a dual flash geothermal power conversion cycle as a function of wellhead fluid temperatures. Due to low grade geothermal/heat, the power conversion efficiency, η_g, is low. The geothermal energy, when utilized to provide feedwater heat in a solar plant cycle, provides a significant thermodynamic advantage since the geothermal energy is converted into power at a much higher efficiency as shown in Curve A, lower Figure 10. This reduces the need for regeneration from internal cycle steam extracted from the turbine. The cycle efficiency of the hybrid system is somewhat lower than that for pure solar system since internal regeneration is being replaced by external heat addition at lower temperature (feedwater temperature). As more and more external geothermal heat is added to the feedwater, the cycle efficiency decreases as shown in Figure 10-b, Curve B. At a geothermal to solar energy fraction, $Q_g/Q_s = 0.20$, the geothermal fluid provides all the necessary feedwater heat.

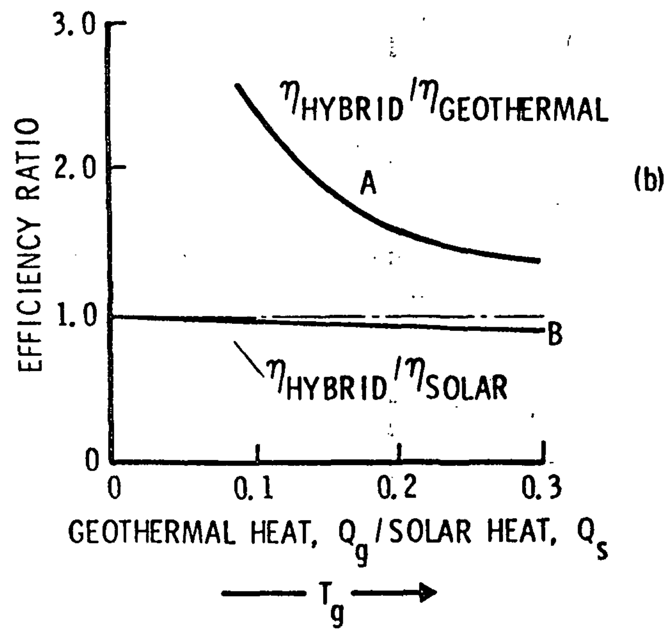
FIGURE 10

Geothermal and Hybrid Cycle Performance

- GEOTHERMAL PLANT
  - GEOTHERMAL DUAL FLASH CYCLE PLANT
  - REINJECTION FLUID TEMPERATURE, Tr = 115°F
  - 50 MW_e PLANT CAPACITY
  - WELLHEAD FLUID TEMPERATURE, T_g



- SOLAR-GEOTHERMAL HYBRID PLANT
  - SOLAR-GEOTHERMAL HYBRID CONCEPT B
  - 100 MW_e PLANT CAPACITY
  - GEOTHERMAL TO SOLAR INPUT HEAT FRACTION - Q_g/Q_s
  - EFFICIENCIES
    - SOLAR-GEOTHERMAL HYBRID, η_H
    - GEOTHERMAL ALONE, η_g



3.2 RELATIVE ELECTRICAL ENERGY OUTPUT OF A HYBRID PLANT

Estimates of various figures of merit indicate that hybrid systems substantially enhance the utilization of a geothermal resource and may have economic or operational advantages over the individual solar or geothermal utilization methods.

Figure 11 presents estimates of the relative merits of energy production from hybrid techniques. Figure 11-a shows that the hybrid plants offer a more efficient utilization of a geothermal resource compared to the geothermal plants. For example, a geothermal system at 350°F can develop 50 MWe; a hybrid system for the same geothermal energy will develop twice as much electrical energy at 100 MWe capacity. Also, abundant hydrothermal resources that are submarginal for geothermal plants ($T_g \leq 300°F$) may be utilized efficiently to produce electricity through hybrid operation. Since steam extraction from the turbine is reduced in the hybrid cycle, the excess steam can be used to increase the output of the turbine as shown by the Curve B.

Figure 11-b illustrates the dependence of energy utilization factor on geofluid temperatures. Thus, if a geothermal system at 300°F can develop 50 MWe, a hybrid system utilizing the same geothermal resource plus a solar resource will provide a capacity of about 500 MWe. Approximately 100 MWe of this capacity is provided by the geothermal heat.

In Figure 11-c the performance of a hybrid plant is compared with the combined performance of a solar and a geothermal plant for the same total energy resource (solar + geothermal). The ratio α is a measure of unit cost of geothermal heat relative to that of solar heat. For the example case, the hybrid system at $\alpha = 1.0$ (i.e., when unit cost of geothermal heat is equal to the unit cost of solar heat) shows an advantage over two individual stand alones. This is because the hybrid system is still utilizing the geothermal heat efficiently. Section 4 examines the relative economics of various options in more detail.

FIGURE 11

Relative Electrical Energy Output of a Hybrid Plant

- FIGURES OF MERIT

GEOTHERMAL RESOURCE UTILIZATION FACTORS

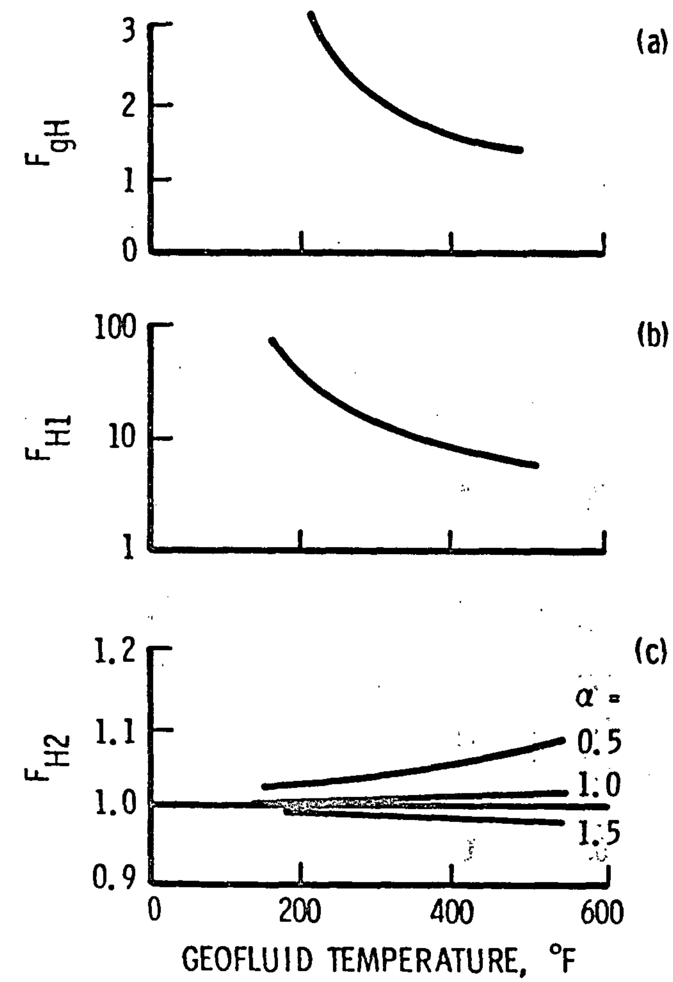
$$F_{gH} = \frac{\text{OUTPUT OF HYBRID PLANT FOR HEAT, Qg IN FWH}}{\text{OUTPUT OF GEOTHERMAL PLANT WITH HEAT, Qg}}$$

$$F_{H1} = \frac{\text{TOTAL OUTPUT OF HYBRID WITH HEAT (Qs + Qg)}}{\text{OUTPUT OF GEOTHERMAL PLANT WITH HEAT, Qg}}$$

- FIGURE OF MERIT OF A HYBRID PLANT OVER SEPARATE SOLAR AND GEOTHERMAL PLANTS

$$F_{H2} = \frac{\text{TOTAL OUTPUT OF HYBRID WITH HEAT (Qs + Qg)}}{\{\text{(Output of Solar with Heat, Qs + Output of Geothermal Plant with Heat, Qg)}\}}$$

$$\alpha = \frac{\text{UNIT COST OF GEOTHERMAL}}{\text{UNIT COST OF SOLAR}}$$



4.0 ECONOMIC CONSIDERATIONS

Estimates of Busbar energy costs for various solar-geothermal, other hybrid systems, and individual solar and geothermal plants are made on the basis of a uniform and consistent set of assumptions. Sensitivity to parameters such as heliostat unit cost, geothermal equipment and possible fuel costs, and fossil fuel cost escalation rates is shown.

4.1 RELATIVE ECONOMICS OF SOLAR-GEOTHERMAL HYBRID AND STAND ALONE PLANTS-CONCEPTS

Solar-geothermal Concept B shows an economic advantage over the corresponding solar stand-alone system. A similar economic advantage is not apparent when hybrid costs are compared with those of a geothermal stand alone. However, hybrid operation offers a much more efficient utilization of resources than geothermal plants, i.e., hybrids can provide twice as much electricity from the same geothermal reservoir.

Figure 12 presents comparative energy costs of solar-geothermal hybrid, pure solar, and pure geothermal plant concepts. All costs have been normalized with respect to the cost of first generation steam system reference.

The modified solar-geothermal concept (Concept A1, Figure 12-a) incorporates solar storage in Concept A (Figure 7) to improve the plant power profile. Two cases of solar-geothermal hybrid system costs are presented as shown by the two columns on the right in Figure 12-a. The two cases refer to a variation in the cost of geothermal equipment from the design estimates to twice the estimated cost. The geothermal costs include facilities costs, hardware costs, cost of production and reinjection wells, and pumps, piping and installations at a hot brine reservoir site.

It is noted that (1) the solar geothermal hybrid plant costs are lower than that for solar stand-alone plant and (2) the energy costs for the hybrid system are not very sensitive to the uncertainties in the cost of geothermal elements.

Figure 12-b presents similar results for the hybrid Concept B utilizing ACR solar system technology. The energy costs of pure geothermal plants are also presented for comparison. The solid shaded portions in these columns represent the sensitivity to the added cost of geothermal energy ($1.0/M BTU) due to factors such as leasing costs. It should be noted that the hybrid systems do not offer any economic advantage over pure geothermal plants unless the geothermal capital costs or geothermal energy costs increase substantially over current estimates (References 5 and 6).

FIGURE 12

Relative Economics of Solar-Geothermal Hybrid and Stand Alone Plants

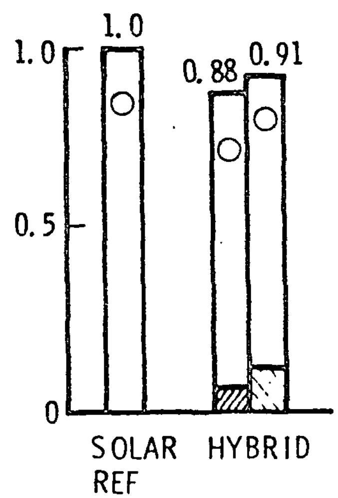
- ○ COST OF SOLAR
- COST OF GEOTHERMAL
- 2 x COST OF GEOTHERMAL
- IF GEOFLUID COST = 1.0 \$/MBtu

- ALL PLANTS 100 MW_e
- 1990 START, 30 yr LIFE
- UNIFORM ECONOMIC ASSUMPTIONS
- 100 \$/M^2 HELIOSTATS

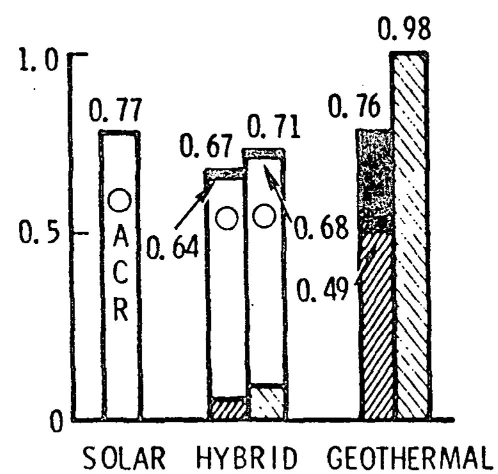
FIRST GENERATION STEAM SOLAR

- BARSTOW TYPE STEAM SOLAR 6 hr STORAGE AT 70 MW_e (reference plant)
- GEOTHERMAL FWH-X

- ACR SODIUM SOLAR 6 hr STORAGE AT 100 MW_e
- GEOTHERMAL FWH-X



a. MODIFIED CONCEPT A-1



b. CONCEPT B

4.2 RELATIVE ECONOMICS OF SOLAR, SOLAR-FOSSIL, SOLAR-GEOTHERMAL-FOSSIL, AND GEOTHERMAL PLANTS

Solar-geothermal-fossil hybrid system concepts offer significantly lower energy costs compared to the solar-geothermal hybrid system for a wide range of fuel escalation rates but still do not show an economic advantage over less efficient pure geothermal plants.

The economic viability of plants utilizing fossil fuel is strongly dependent upon the fuel costs and the fuel escalation rates. Figure 13 presents relative costs of geothermal hybrid, solar-fossil hybrid and stand-alone systems as a function of fuel escalation rates utilizing sodium ACR technology. Each point on these curves represents a constant fuel escalation rate, i.e., fuel is assumed to escalate at a fixed percentage rate each year beginning with reference year 1978. In all cases, energy costs have been normalized with respect to the cost of the ACR sodium stand-alone plant. Comparison of Figures a and b illustrate the sensitivity of economics to heliostat unit cost varied from 100 $\$/M^2$ in Figure a to 70 $\$/M^2$ in Figure b .

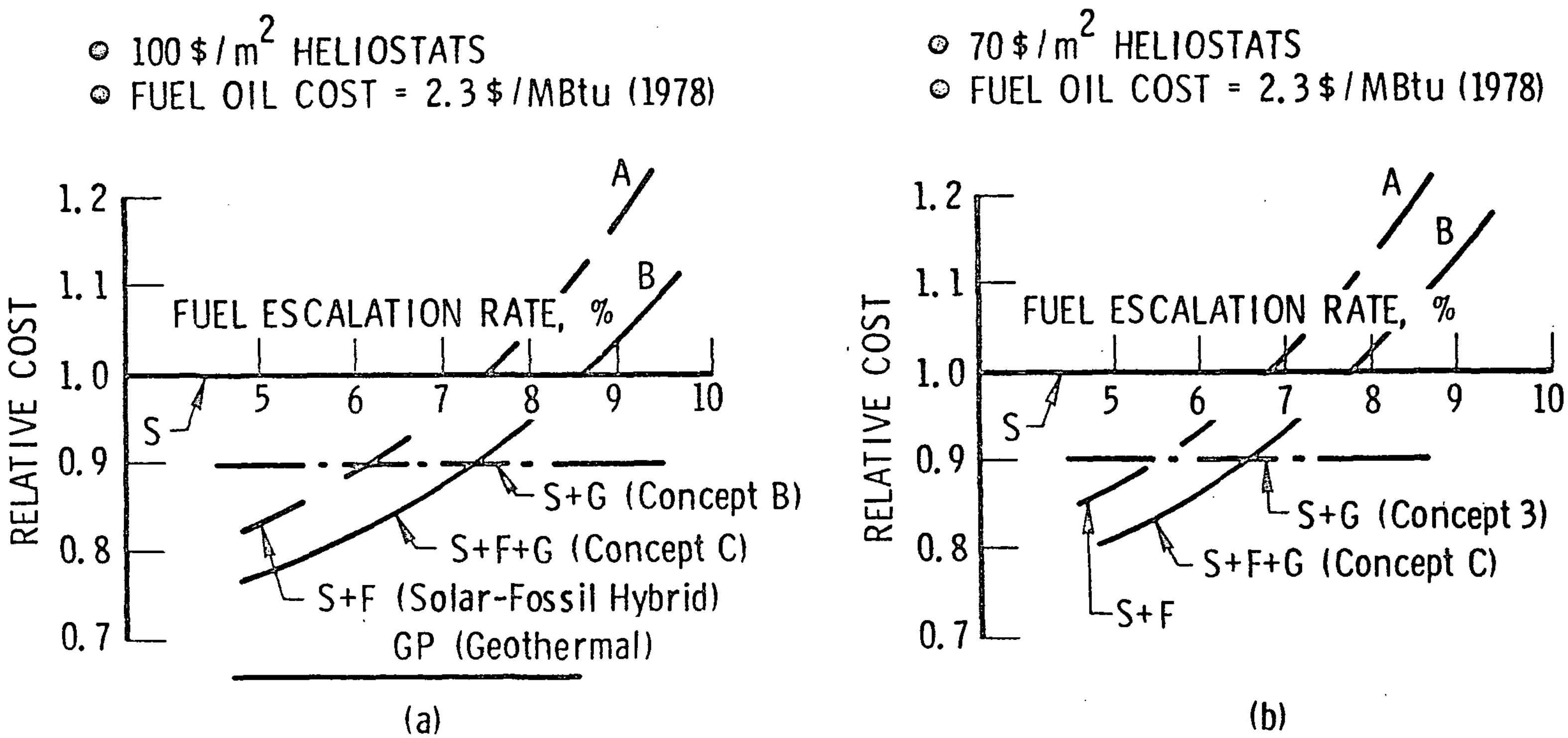
The results show that the solar-geothermal-fossil hybrid system (Concept C, solid Curve B) offer significantly lower costs than the solar-fossil hybrid system (Curve A), particularly for the case where the heliostat costs are high (compare Figures a and b). The use of geothermal feedwater heating results in a lower cost because of low capital costs of the geothermal equipment.

The lowest cost hybrid systems (Configuration C) do not show economic advantage over the low performance pure geothermal plants unless the geothermal systems incur additional costs, as discussed in Section 4.1.

FIGURE 13

Relative Economics of Solar, Solar Fossil Hybrid, and Solar-Geothermal Fossil Hybrid Plants

- ACR SODIUM SOLAR SYSTEM REFERENCE, S
- HYBRID CONCEPTS B AND C
  HYBRID GEOTHERMAL FWH-X
- GEOTHERMAL PLANT (1 x cost), GP
- 100 MW_e PLANTS
- 1990 START
- 30 yr LIFE
- CONSTANT FUEL ESCALATION RATES



5.0 KEY RESULTS AND CONCLUSIONS

5.1 KEY RESULTS AND CONCLUSIONS

Geothermal resources in the United States are mostly hot brine reservoirs located in the western states. A large fraction of the resource areas are compatible with good insolation sites. The known resources alone have been estimated to provide approximately 27,000 MWe electric capacity by using geothermal power plants. Corresponding capacity using solar-geothermal hybrid plants having twice the cycle efficiency and using 20% of geothermal energy in the plant is approximately 270,000 MWe.

The mineral laden hot brine, as opposed to steam supply at Geysers, California, presents major technical problems for the solar receiver, storage, and EPGS equipment in terms of scaling, corrosion, and erosion which will result in excessive down time. Experience at Cerro Prieto, Mexico indicates that these problems can be serious. Environmental problems including emissions of non-condensable gases, particularly the toxic and offensive H_2S, are also of significant concern.

Examination of these problems and the other factors such as the low heat contents of the resource fluid suggest that the best way to combine solar and geothermal energy is to utilize geothermal heat into feedwater heaters (FWH) of the solar EPGS cycle through a heat exchanger (FWH-X). In this way, FWH-X is the only equipment in the EPGS cycle exposed to brine. In this scheme the geothermal heat is converted to electricity at higher cycle efficiency, i.e., approximately at solar EPGS cycle efficiency or at roughly twice the efficiency of conventional geothermal cycle. This technique, however, necessitates the use of solar storage or a hybrid fossil boiler to provide capacity during night and during cloud cover.

Combining a high performance solar system like sodium (or salt) ACR or ACR-fossil-hybrid with geothermal FWH heating results in significant reductions in the energy costs of solar-geothermal hybrid systems (Concepts B and C) compared to those of a solar stand-alone.

Figure 14
Key Results and Conclusions

- SUBSTANTIAL GEOTHERMAL RESOURCES ARE AVAILABLE AT GOOD INSOLATION SITES
  - HOT BRINE RESOURCE, WESTERN US SITES
  - POTENTIAL FOR > 27,000 MW_e CAPACITY USING GEOTHERMAL PLANTS
  - POTENTIAL FOR MUCH LARGER CAPACITY USING HYBRID PLANTS
- MAJOR CONCERNS OF GEOTHERMAL POWER TECHNOLOGY INCLUDE
  - SCALING, EROSION, AND CORROSION OF MACHINERY PLANT, DOWN TIME
  - BRINE REINJECTION
  - ENVIRONMENTAL EMISSIONS
  - PREMATURE DEPLETION OF SITE RESOURCE
- GEOTHERMAL FEEDWATER HEATING IN ACR SOLAR EPGS CYCLE IS THE BEST HYBRID OPTION
  - BRINE EXPOSURE LIMITED TO FWH EXCHANGER
  - INCREASED CONVERSION EFFICIENCY FOR GEOTHERMAL RESOURCE ENERGY
  - CLOSED GEOFLUID LOOP MINIMIZES EMISSIONS
  - STORAGE OR FOSSIL BOILER IS REQUIRED TO PROVIDE RELIABLE POWER
- HYBRID PLANT OFFERS ECONOMIC ADVANTAGE OVER OTHER SOLAR PLANTS
  - ENERGY COSTS 10 - 15% LOWER THAN SOLAR STAND-ALONE
  - SOLAR-FOSSIL-GEOTHERMAL ACR HYBRID OFFERS LOWEST COST OF ENERGY FOR FUEL ESCALATION RATES < 7%

5.1 KEY RESULTS AND CONCLUSIONS (continued)

Solar-geothermal system (Concept B) and other hybrid configurations (Concepts C and D) do not appear to offer economic advantage over the stand-alone geothermal plants unless geothermal costs increase due to technology uncertainties. The solar-geothermal plants can become cost competitive with geothermal stand-alone plants if the geothermal plant equipment costs increase by factors ≥ 1.5 over the current design estimates or the leasing of other site related costs result in geothermal energy costs ≥ 0.75 $/MBTU.

Hybrid plants, however, offer other advantages over the geothermal plants. Hybrid plants provide the most efficient utilization of national resources. The electric energy produced from solar and geothermal resource is approximately ten times that produced by pure geothermal plants using the same amount of geothermal resource energy and site insolation. Other major advantages are noted in Figure 14.

Figure 15

Key Results and Conclusions — continued

- HYBRID PLANTS DO NOT SHOW ECONOMIC ADVANTAGE OVER GEOTHERMAL STAND-ALONE PLANTS
  - ENERGY COSTS ARE HIGHER THAN THOSE FOR TWO STAGE FLASH AND BINARY GEOTHERMAL PLANTS
- HYBRID PLANT MAY BECOME COMPETITIVE WITH GEOTHERMAL PLANTS IF COSTS INCREASE DUE TO UNCERTAINTIES
  - GEOTHERMAL PLANT EQUIPMENT COSTS INCREASE BY FACTORS ≥ 1.5 OVER CURRENT ESTIMATES
  - LEASING COSTS OF SITE AND/OR GEOFLUID BECOME ≥ 0.75 \$/MBtu
- HYBRID PLANTS OFFER OTHER ADVANTAGES OVER GEOTHERMAL PLANTS
  - MORE EFFICIENT USE OF GEOTHERMAL RESOURCE AND INSOLATION SITES
  - LESS SENSITIVE TO UNCERTAINTIES IN GEOTHERMAL EQUIPMENT COSTS AND RESOURCE LIFE
  - REDUCED ENVIRONMENTAL EFFECTS
  - MAY BE ABLE TO UTILIZE LOWER TEMPERATURE RESOURCES WHICH ARE SUBMARGINAL FOR GEOTHERMAL PLANTS

6.0 LIST OF REFERENCES

LIST OF REFERENCES

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AF recommends 2 sites for missile support bases

SALT LAKE CITY (UPI) — The Air Force confirmed that it prefers to locate the primary support base for the proposed MX missile system in Coyote Springs, Nev., and the secondary base at Milford, Utah.

Ken Olson, Utah coordinator for the MX proposal, said he was informed by Air Force officials that a draft environmental impact statement on the nuclear weapons system would list the two communities as recommended sites to house support personnel.

Coyote Springs, about 60 miles northeast of Las Vegas, would serve as the primary support base for the mammoth $33 billion missile system, while about 6,500 hundred Air Force workers and their families would live near Milford — located 45 miles east of the Utah-Nevada state line in Beaver County.

Olson said the Air Force environmental statement would be released during the second week of December. Utah and Nevada officials will then take about 90 days to analyse and respond to the document.

"We presume that during that 90-day period the new Reagan Administration will also be formulating its policy concerning basing modes for the MX," he said.

Pentagon officials have recommended building 4,600 concrete launch sites in the Great Basin of Utah and Nevada to house 200 multiwarhead missiles. The missiles would be rotated among the bunkers in efforts to thwart enemy detection of specific missile locations.

Olson said preliminary studies by the Utah MX office indicate Milford would be a good site for location of a support base.

"One advantage of the Milford site is that it is about equidistant from Cedar City and Beaver — allowing all three communities to share the social impacts and economic benefits of the settlement of thousands of military personnel," he said.

But Olson said the draft EIS probably would not include Air Force recommendations on the best way to provide housing and services for its MX workers.

The Air Force has indicated it might house all of the technicians, security personnel and their dependents on the base itself, he said. But he also said those workers might be located off-base if communities in the area had available housing.

"Unfortunately, what that does is to rely excessively on the free market when the housing industry is in really bad shape," Olson said. "If they prefer to have their employees live off-base, we think they should look at providing federal funds to help communities provide water, sewer and streets services associated with housing."

He said such federal investment in localities would help contractors build additional housing units more quickly and cheaply.

Eventually, at least 16,000 people might move to the Milford area to work on the MX if that site is approved for a secondary base, the Utah coordinator said.

Balloons used to treat male sterility

...IMORE (UPI) — Doctors at ...kins Hospital are treating one ... causes of male sterility ... a process they said is ...ossibly cheaper than ...

...diologist, said ...ns in blood ...ose veins ...es a

it will take at least three years to tell if the men can father children.

About half the men in the United States who are sterile have varicoceles, studies indicate.

Doctors thread a catheter — a hollow, narrow tube — through a vein or artery until it reaches its destination, then send a narrower tube with a balloon attached to its end through the catheter.

A special X-ray dye is injected into the balloon to inflate it until it fits snug against th...

...cath...