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COMPARATIVE COST ANALYSES: TOTAL FLOW VS OTHER POWER CONVERSION SYSTEMS FOR THE SALTON SEA GEOTHERMAL RESOURCE

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ABSTRACT

Cost studies were done for Total Flow, double flash, and multistage flash binary systems for electric energy production from the Salton Sea Geothermal Resource. The purpose was to provide the Department of Energy's Division of Geothermal Energy with information by which to judge whether to continue development of the Total Flow system. Results indicate that the Total Flow and double flash systems have capital costs of $1,135 and $1,026 /kW with energy costs of 40.9 and 39.7 mills/kW·h respectively. The Total Flow and double flash systems are not distinguishable on a cost basis alone; the multistage flash binary system, with capital cost of $1,343 /kW and energy cost of 46.9 mills/kW·h, is significantly more expensive. If oil savings are considered in the total analysis, the Total Flow system could save 30% more oil than the double flash system—$3.5 billion at 1978 oil prices.

INTRODUCTION

The Geothermal Energy Group at Lawrence Livermore Laboratory (LLL), with substantial assistance from two industrial firms, conducted a set of economic analyses for utilizing resources of the high-temperature high-salinity (HT/HS) Salton Sea Known Geothermal Resource Area (SSKGRA), located in the Imperial Valley in Southern California. The object of these studies was to develop relative performance and cost data for selected candidate power conversion systems. These data were to be used by the Department of Energy's Division of Geothermal Energy in deciding whether to continue support of the LLL geothermal program for developing advanced conversion systems, with specific emphasis on the Total Flow system. A major factor influencing the decision was to be the estimates of expected electric energy costs.

The basic work for the power conversion system studies was performed by Rogers Engineering Company and Bechtel Corporation, under direction of LLL. Both firms participated in an initial study to help select leading candidate systems for the SSKGRA and to develop detailed study specifications and requirements that would assure comparability between systems and a realistic performance and cost base.

This final report summarizes results of the subcontractor studies and, using these studies as a base, discusses the major technical and economic factors involved in selecting a power conversion system for the SSKGRA

The three power conversion system concepts selected for study were the double flash, multistage flash binary, and Total Flow systems. Rogers Engineering performed the double flash studies and Bechtel the multistage flash binary and Total Flow studies. The study format for each system was as follows. On the basis of study specifications and requirements, a specified system logic, wellhead brine properties, and a computer program for calculating process brine properties (BPROP),[1] system performance was calculated and a system conceptual design developed that included all major plant equipment, major piping, and the site layout. Then capital cost estimates were derived for all major items and an economic analysis performed to arrive at system capital costs in \$/kW and levelized busbar energy costs ($\overline{\text{BBEC}}$) in mills/kW·h.

Both firms were also asked to perform limited studies of the effect on system performance of variation in important parameters such as turbine backpressure and brine salinity. Appendix A contains the details of the performance calculations and Appendix B a detailed breakdown of costs.

SYSTEM DESCRIPTIONS

Figures 1-3 are schematic drawings of the double flash (DF), multistage flash binary (MSFB), and Total Flow (TF) systems. Figure 4 shows a variation on the Total Flow (steam condensation) base case, in which the turbine exhaust mixture goes directly to the condenser. This variation is called the brine condensation case. Major differences between these systems and "standard" geothermal plant configurations are noted below:

- *Acidification.* Acidification for scale control is accomplished in all three systems by injection of hydrochloric acid into the liquid portion of the brine, which has been separated without additional flashing at the plant inlet. In the multistage flash binary system, extra acidification is required between the flash vessels to compensate for additional CO_2 release that would raise the pH level.

The materials in some of the vessels and pipes exposed to acidified brine flow are of special alloys[2] to withstand the pH levels.

- *Full reinjection.* For resource and environmental conservation, a reinjection of a minimum of 98% of the production brine flow is required. To achieve this high level of reinjection and to avoid possible plugging of the reservoir from impure water sources, the condensate from the plant operations must be used. In the multistage flash binary system, the process itself recombines the condensate and the brine flow in every flash stage. In the other two systems, surface condensers are employed and the resultant steam condensate is remixed for reinjection. Makeup water from the environment cannot be used for reinjection without special and expensive treatment for drastic reduction of the sulfate ion concentration.[2]

- *Makeup water treatment.* Since the plant condensate is used for reinjection, the cooling tower makeup water must come from external local water sources, in this case the Alamo River. To minimize this use of the local water supply, a special water treatment plant was specified[3] that allows for a much higher acceptable cooling-tower total-dissolved-solids (TDS) concentration and saves on blowdown water consumption.

- *Evaporation ponds.* Because of the agricultural surroundings it was specified that no liquid or solid effluent be emitted into the local environment, even into the Salton Sea. Consequently, evaporation ponds are used to accept the concentrated cooling tower blowdown liquid. The solid residue from the ponds is to be trucked away for disposal.

- *Steam scrubbers.* The steam from the double flash system flash tanks entrains both salts and acid. Consequently, scrubbing is required to wash and neutralize the steam prior to its use by the turbines.

INITIAL SPECIFICATIONS AND REQUIREMENTS

Rogers and Bechtel submitted specification outlines and requirements based on LLL guidance. These are presented in Ref. 2. The primary criteria for the PCS studies set out in this specification are summarized here:

Plant performance

50-MWe net output
30-yr plant life
80% capacity factor

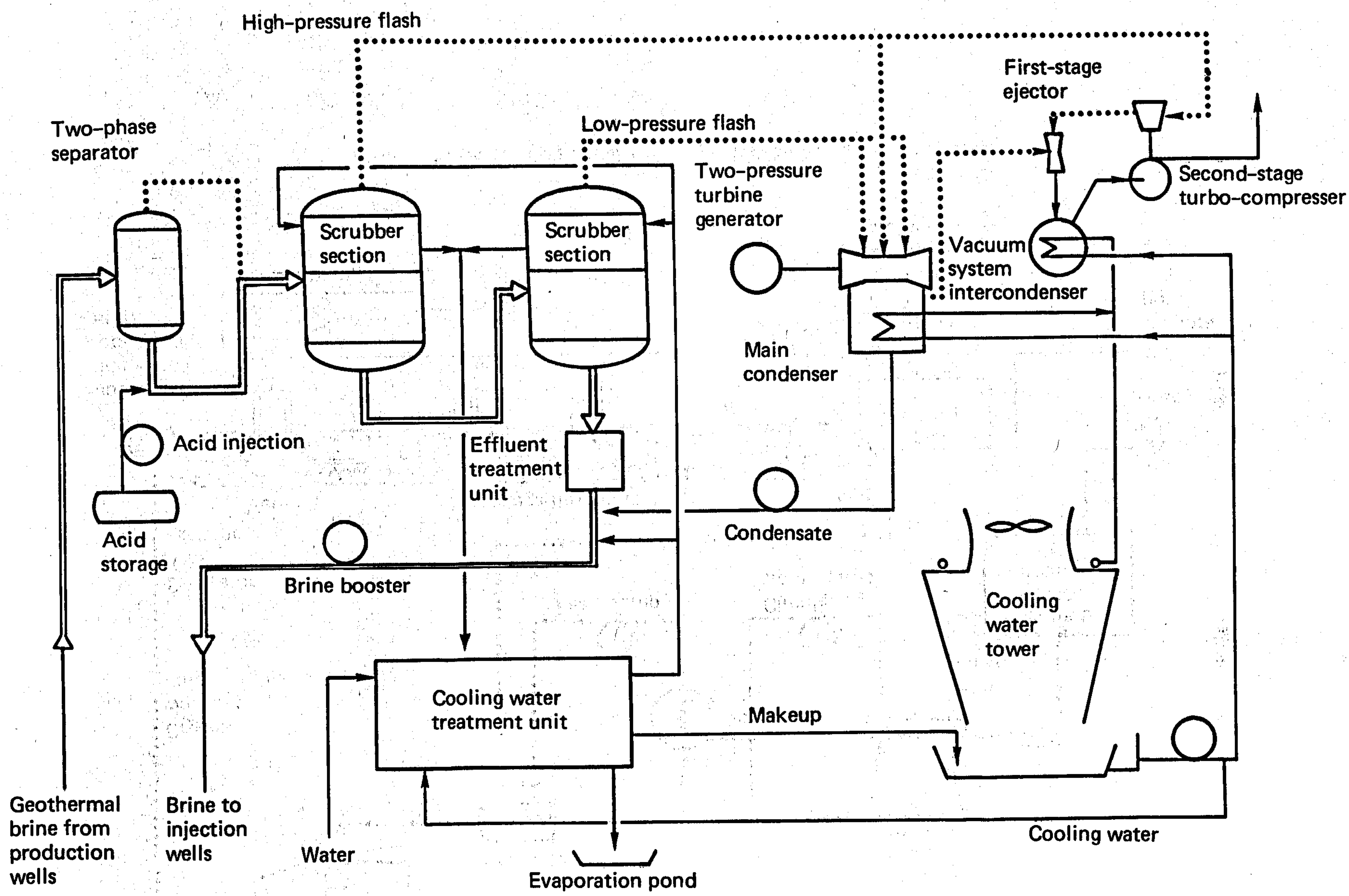

FIG. 1. Schematic diagram of double flash power conversion system.

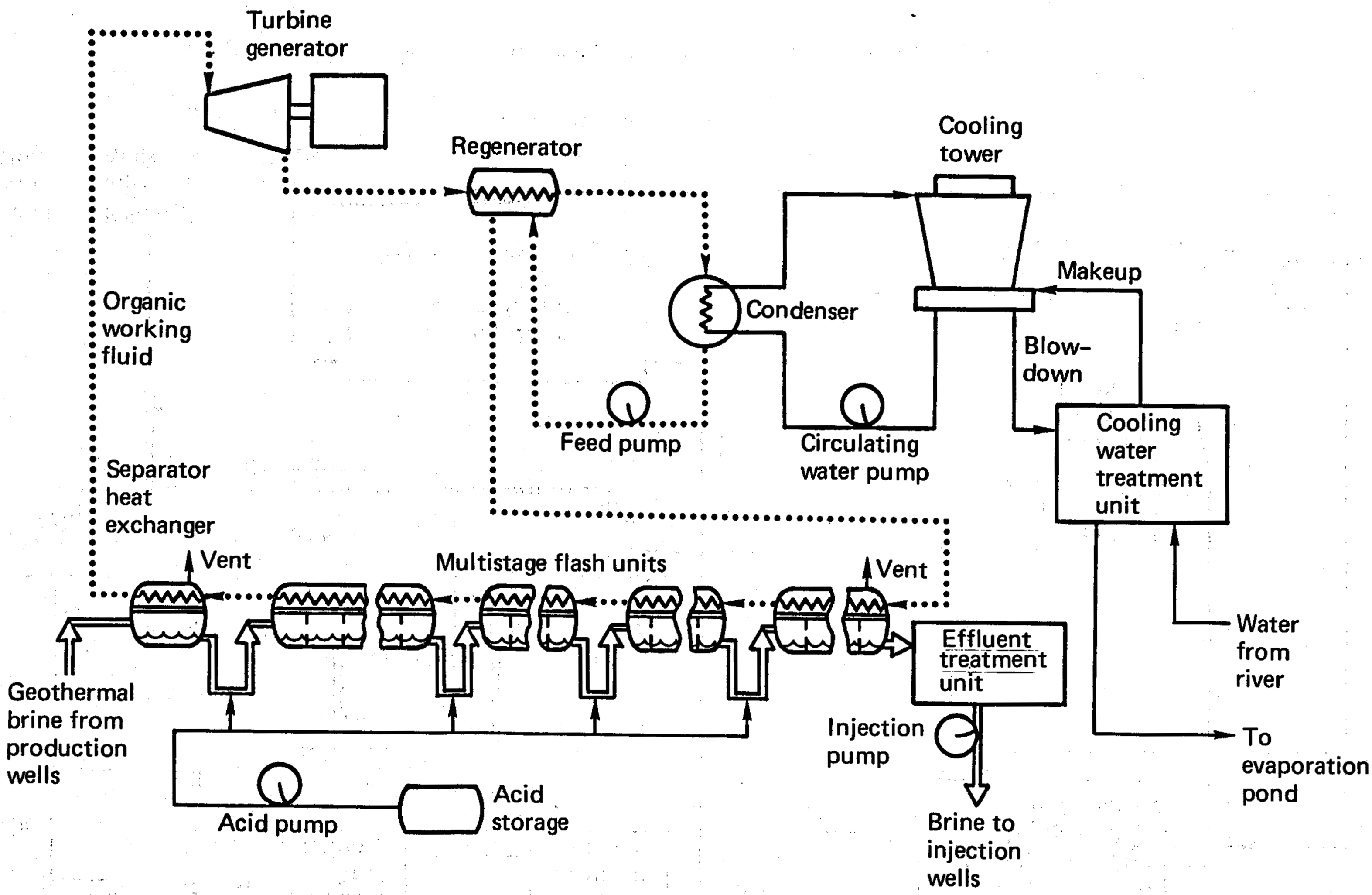

FIG. 2. Schematic diagram of multistage flash power conversion system.

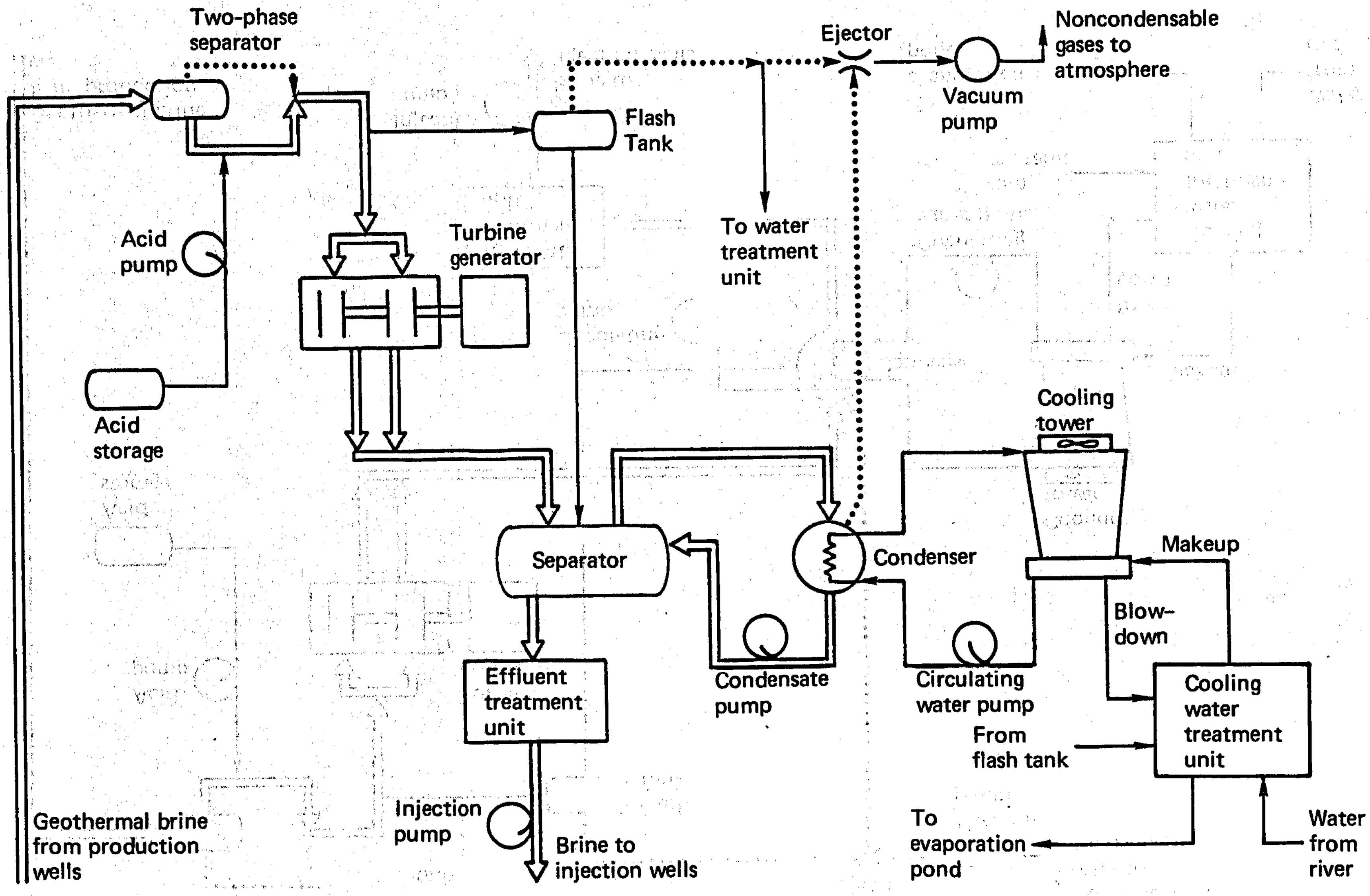

FIG. 3. Schematic diagram of Total Flow power conversion system (steam condensation case).

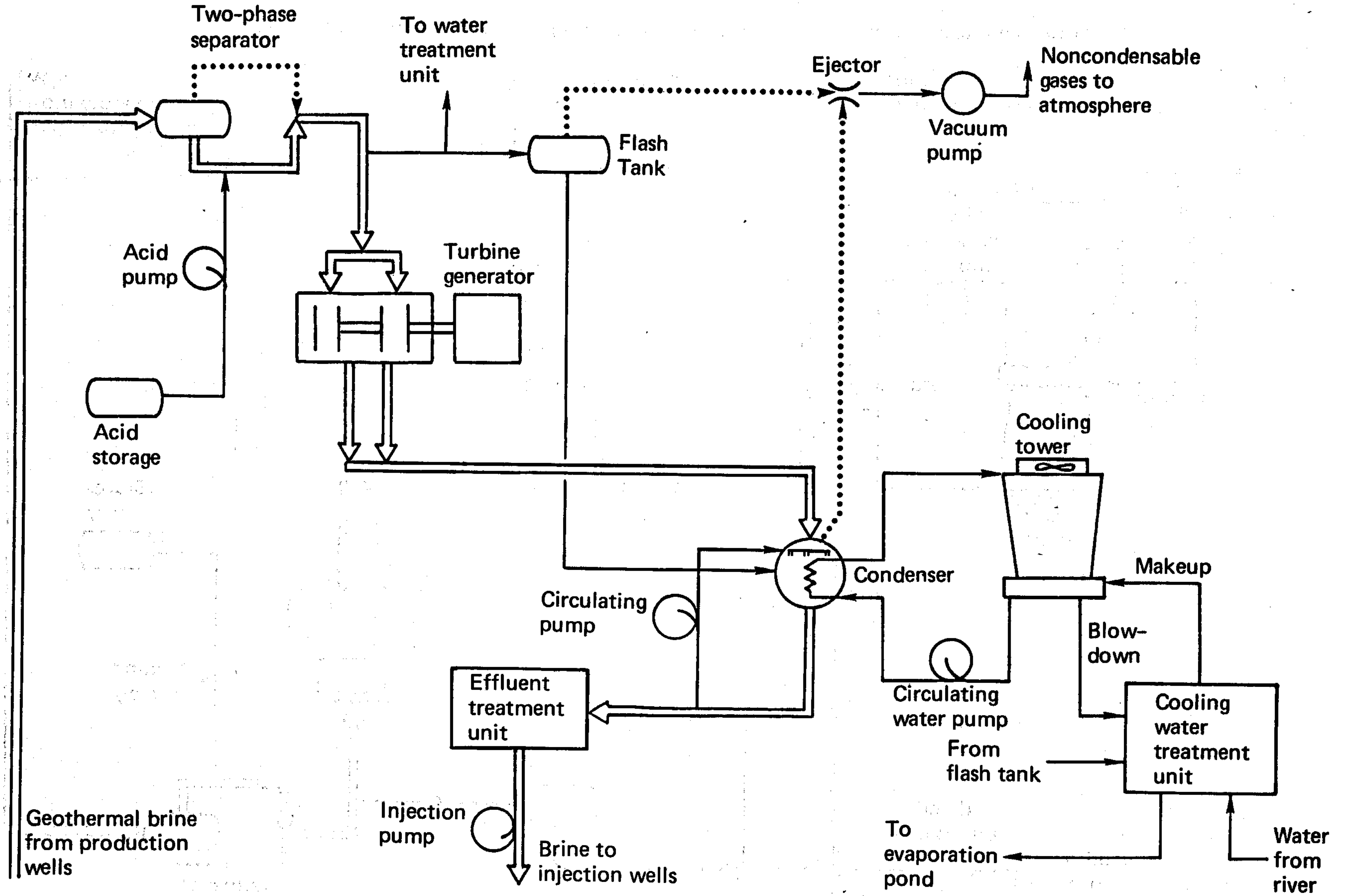

FIG. 4. Schematic diagram of Total Flow power conversion system (brine condensation case).

Turbine efficiencies

DF 75% low-pressure stage (steam turbine)

80% high-pressure stage (steam turbine)

MSFB 85% (organic vapor turbine)

TF 70%, 45% (steam water turbine)

Resource

SSKGRA at 290°C (554°F), 25% TDS

0.5% CO_2

0.04% NH_3

0.0015% H_2S

No flow or temperature decline with time

1.6-psia/lb/s drawdown factor

350-psia reinjection pressure required

Well field

Wellflow production 800,000 lb/h/well

Wellflow injection 1,6000,000 lb/h/well

4,000-ft depth

10-3/4-in. diam

500-yd^2 array well field

2 mi between production and reinjection fields

Environment

98% minimum reinjection required

H_2S venting allowed at 130-ft stack height

No liquid and no solid emissions allowed

79°F wet-bulb temperature

Minimum usage of makeup water

Scale and erosion control

Brine acidification required

Special vessel and pipe alloys

Hastelloy C-276 above 150°C

1 Cr 0.5 Mo below 150°C

Cooling water treatment plant required

Economic factors

Material and equipment at estimated or quoted cost plus 6% sales tax

Direct labor 17$/h

Contractor's overhead 65%

Contractor's profit 4%

Engineering service 10%

Contingency 20%

Owner's cost 8%

Allowance for funds during construction (AFDC) 8%

STUDY CASE DESCRIPTIONS

Table 1 lists the power conversion system studies that were done. A cost analysis was not carried out for all of the studies because in some cases the performance calculations indicated that further effort was not warranted. All of the performance calculation results are contained in Refs. 3 through 6 and are summarized in Appendix A. The base case is defined by the specifications and is principally described as having the reservoir brine at 25% TDS and the ambient wet-bulb temperature (T_{WB}) at 79°F. Some wells in the SSKGRA have brine at around 20% TDS, and this condition was used as a secondary case for performance comparisons. The brine condensation case applies to the Total Flow system only; it is the base case with the turbine exhaust mixture going directly to the condenser. The parametric studies investigated the effects on performance of variations in TF turbine exhaust pressure and lower ambient wet-bulb temperature.

Two performance calculations with turbine efficiency at 45% and four with efficiency at 70% were done for the Total Flow system. The 45% efficiency is based on the actual design tested in the laboratory; the 70% efficiency is the expected performance after further development work. Calculations indicate that with further development the Total Flow efficiency might be brought even higher than 70%. The necessary steps include reduction of droplet size and improved blade configuration.[7]

In the following discussions of cost results, attention is focused on the most attractive version of each concept for the base case: that is, 25% TDS and 79°F wet-bulb temperature.

TABLE 1. Power conversion system studies.

Contractor	System	Study type	Cost analysis?
Rogers	Double flash	Base case	Yes
	Double flash	20% TDS	Yes
Bechtel	45% Total Flow	Base case	Yes
	45% Total Flow	Brine condensation	No
	70% Total Flow	Base case	Yes
	70% Total Flow	Brine condensation	Yes
	70% Total Flow	20% TDS	No
	70% Total Flow	Parameter studies	No
	Multistage flash binary	Base case	Yes
	Multistage flash binary	20% TDS	No
	Multistage flash binary	Parameter studies	No

COST ANALYSIS RESULTS

The capital costs and energy costs ($\overline{\text{BBEC}}$) determined by the six cost analyses that were done are listed in Table 2 and given in more detail in Table 3. Complete performance and cost analysis results are contained in Refs. 3 through 6.

The costs for the Total Flow system at 45% efficiency are significantly higher than for all others in the base case group (Table 2). The 45% efficiency was obtained on actual tests of a prototype in the laboratory and was carried through the cost study as a "lower bound" for Total Flow performance. Clearly, these costs are high, and that initial design is not a candidate for application. The costs for a system using brine with only 20% TDS are lower, as expected, but not significantly lower within the accuracy of this study design. The costs for the other systems are essentially the same in view of the ± 20% expected accuracy of the study results, although the multistage flash binary system does have the highest costs at 1343 \$/kW and 46.9 mills/kW·h. Table 3 shows slightly lower costs for the brine condensation case, but this is a very small difference, given the expected accuracy of the estimates. Although performance was improved significantly in this system, the deletion of the separator and the line to the condenser was balanced by the increased complexity of the condenser needed to handle the mixture.

Complete cost analysis, however, must consider two additional factors as part of the total cost of the system. The first is the indirect cost or benefit that results from effective utilization of the energy source. This cost is based on system performance results, usually expressed as the specific net energy output in W·h/lb brine, or converted to barrels of oil saved through utilization of the resource (SSKGRA). The performance results for the base case are given in Table 4.

The second factor is the cost associated with achieving the system reliability needed to attain the specified system capacity factor (80% in these studies). These costs include research and development, possible interim-life major item replacement (e.g., turbines, pumps, heat exchangers), and possible higher operation and maintenance costs.

TABLE 2. Total capital costs and energy costs for six power conversion systems.

System	Capital cost, \$/kWe	Energy cost,[a] mills/kW·h
Base case		
Double flash	1026	39.7
45% Total Flow	1514	55.9
70% Total Flow	1135	40.9
70% Total Flow brine condensation	1080	39.1
Multistage flash binary	1343	46.9
20% TDS case		
Double flash	997	37.8

[a]Levelized busbar energy cost ($\overline{\text{BBEC}}$).

TABLE 3. Cost analysis results for six power conversion system studies.

System	Capital costs, thousands of dollars ($/kWe)			Energy costs, mills/kW·h[a]		
	Wells	Plant	Total	Wells	Plant	Total
Base case						
Double flash	12,314 (246)	39,016 (780)	51,330 (1026)	18.3	21.4	39.7
45% Total Flow	13,110 (262)	62,600 (1252)	75,710 (1514)	20.6	35.3	55.9
70% Total Flow	8,970 (179)	47,800 (956)	56,770 (1135)	14.3	26.6	40.9
70% Total Flow brine condensation	7,780 (156)	46,200 (924)	53,980 (1080)	12.9	26.2	39.1
Multistage flash binary	8,970 (179)	58,200 (1164)	67,170 (1343)	14.3	32.6	46.9
20% TDS case						
Double flash	11,731 (235)	38,102 (762)	49,833 (997)	17.1	20.7	37.8

[a]Levelized busbar energy cost (BBEC).

These power conversion system studies have not systematically investigated the requirements associated with reliability and their subsequent costs. In this summary review, a qualitative assessment is made to arrive at relative rankings of the systems. This reliability assessment is based on the following major uncertainties of each system.

- *Double Flash*

Brine flow operations. Scaling, erosion, corrosion.

Steam scrubber effectiveness. The scrubber must clean particles and chemicals (brine, acid, etc.) from the steam to protect the turbines. While the design approach is known, the actual field operation is unproven.

Turbine blade reliability. Operation and subsequent life of the turbine (due to temporary) upset conditions in the scrubber.

Cost and availability of special turbine blade materials. For example, titanium alloys.

Actual turbine operational efficiencies. The efficiencies used in the LLL PCS studies are considered maximum, and have not been demonstrated.

- *Multistage Flash Binary*

Brine flow operations. Scaling, erosion, corrosion.

Staging operations. Maintenance of proper interstage differential pressures under the unsteady flow and noncondensables characteristic of the Niland geothermal wells.

MSF vessel heat exchanger and demister fouling. A major maintenance consideration.

Integrity of binary fluid tubes. In the interfaced multivessel design at high temperatures and/or temperature changes.

50 MWe binary turbine size. This size has not been built. The high (85%) efficiency has yet to be proved and the cost verified.

Operation and maintenance requirements. Associated with safe operation of the binary fluid plant.

TABLE 4. Base case performance results.

	70% Total Flow	Multistage flash binary	Double flash
Specific net energy W·h/lb brine	13.2	12.8	10.2
Net system thermal efficiency, %	11.7	11.3	9.0
Electric energy from SSKGRA,[a] MW·yr	81,500	78,700	62,700
Barrels of oil saved, 10^6bbl	1100	1010	830

[a]USGS Circular 726[9] estimates that 83,600 MW·yr of electrical energy could be produced from the SSKGRA by a system with 12% conversion efficiency.

- *Total Flow*

Brine flow operations. Scaling, erosion, corrosion.

Turbine efficiency. The high turbine efficiency has not yet been demonstrated. It depends on reducing droplet size and improving blade design and spacing.

Turbine blade reliability. Operation and subsequent life of the turbine under brine flow have not been demonstrated. Static blade tests strongly indicate that titanium alloys are capable of acceptable performance.

Turbine costs. Unknown. The number used in the LLL study was on the high side at 180 $/kW, to be conservative. This is the largest single uncertainity in the study, since no real analysis of a specific design was done. Hence, the 180 $/kW is no more than a guess.

Allowing for these uncertainties and the state of the art of each system, the relative costs of reliability are estimated as follows (where 1 has the lowest expected cost):

1 Double flash
2 45% Total Flow
3 70% Total Flow
4 Multistage flash binary.

The double flash system ranked lowest because the ability to handle the flashing brine flow is its greatest uncertainty, a characteristic common to all the systems. The 45% Total Flow system is second because its performance is credibly based on actual tests, the major unknown being the demonstration of a brine-tolerant turbine. The 70% Total Flow turbine, while technically difficult to achieve, can be developed by means of relatively inexpensive laboratory experiments (droplet size, nozzle design). If these are successful, a prototype (2-MW) turbine system can be field tested quickly and at a relatively low cost to determine reliability. The multistage flash binary system is ranked most costly to achieve because a complete field plant must be built and operated to demonstrate its capabilities.

CONCLUSIONS

The three major cost factors can be ranked to provide a comparative assessment of the systems. These ranking numbers are qualitative estimates and are applicable only within each cost-factor category (that is, across each row, below). For example, the $\overline{\text{BBEC}}$ and the reliability costs of the double flash system are not equal, even though both are ranked 1, or "best" in their categories.

Parameter	System			
	Double	70% TF	MSFB	45% TF
$\overline{\text{BBEC}}$ (direct costs)	1	1	1	2
Performance (indirect cost/benefit)	2	1	1	3
Reliability (R&D, operations)	1	3	4	2

Clearly, if the indirect cost/benefit owing to better performance is not a significant consideration, the double flash system is the best candidate for the SSKGRA. This system has the highest probability of being on line in the shortest period of time, with the lowest probable $\overline{\text{BBEC}}$. If the required power-on-line date is 1983, with the consequent commitment to plant construction by 1979,[8] the double flash system is definitely the best system for this first plant.

If, however, the "total cost" is considered to include resource utilization, the cost benefits achieved with better performance must be assessed and weighed against the reliability achievement costs. One important measure of the cost benefit of increased system efficiency is the more effective utilization of the resource and the resultant reduction in the ultimate use of fossil fuels. For example, the USGS has estimated[9] that the SSKGRA has enough stored geothermal energy to produce about 83,600 MWe·yr of electric energy if conversion systems can function at 12% thermal efficiency. Hence, utilization of the SSKGRA could save as much as 1.1×10^9 bbl of oil that otherwise would be burned in power plants operating at, say, 40% thermal efficiency.

The more efficient 70% Total Flow system (Table 4) if fully developed could save 270 million barrels of oil more than could the conventional double flash system, over the usable life of the resource. At the present (1978) cost of oil of $13/bbl, this saving represents at least a $3.5 billion benefit. The development costs for advanced conversion systems, through a field testing program, will be no more than a few tens of millions, at most; hence, the benefit/cost ratio is of the order of 1000. The advisability of continued development of advanced conversion systems is obvious.

While the energy cost estimates indicate no clear economic advantage of one system over the others, the lack of system field test data makes the accuracy of the estimates questionable. Further, in view of the potential benefits of advanced systems, which even in the early stages of development appear competitive with conventional systems, the cost study results by themselves are considered here to be inadequate for the purpose of judging the relative merits of the various systems. As yet, no system has been shown to provide reliable production of electric power from the hypersaline brines of the SSKGRA. The detailed studies described in this report do indicate, however, that the Total Flow and double flash systems merit further development for utilization of this important resource.

COMMENT

A cautionary and perhaps educational note is here offered to those who might naively believe that the energy costs determined by geothermal cost analyses can be used directly to arrive at valid relative system costs. It is obvious that each system cost is strongly a function of the conditions and assumptions used in determining it. Nevertheless, there is a tendency to believe that for the same conditions, variations in energy or investment costs are minor and generally permit valid comparisons to be made. This is definitely not true. Variations in cost by factors of two between studies of the same system for the same site can be found, while differences of from 35 to 50% are not uncommon. Accordingly, the following is offered as an aid to verifying or adjusting study results for comparative purposes.

First, a familiarity with the basic sequence used to arrive at energy costs is helpful in evaluating study results. In the LLL power conversion system studies, the seven basic steps shown in Table 5 were used in the estimation of the $\overline{\text{BBEC}}$. The general requirements for and results of each step are also shown.

Two general criteria must be satisfied if valid system cost comparisons are to be made:

Criterion 1: System designs must have equivalent technical bases.

For example:

- What is the cost estimate system design base? (Theoretical? eonceptual? Ratioed from other studies? Final?)
- For a given site are the study resource and environmental parameters the same for all studies? (e.g., wellhead and plant inlet brine properties, wet-bulb temperatures, wellflow capabilities, well size, fluid disposal, effluent limits, etc.).
- Are the required plant performance conditions the same? (e.g., output, life, capacity factor, percent reinjection, special systems such as water treatment, heat exchanger approach temperatures, etc.)

Criterion 2: All economic factors and calculational methodologies must be the same between systems.

For example:

- Are the same factors used to arrive at basic field construction cost (labor cost, indirect costs, overhead)?
- Are the same capital burden factors used to arrive at the total field construction capital cost (engineering service, contingency, owner costs, AFDC)?
- Are the factors in and method for calculating the capital investment levelized annual cost (capital rate of return, taxes,

TABLE 5. Estimating levelized base bar energy costs ($\overline{\text{BBEC}}$).

Step	Requirements	Results
1. Perform conceptual system design	Technical specs. Fluid properties	Performance char. System configuration Component requirements
2. Estimate basic field construction expenditures	Conceptual design Manufacturers costs Labor costs, overhead	Basic materials and Equip. and install. cost, M$
3. Calculate total capital investment	Capital burden factors (engineering service., contingency owners cost, AFDC)	Total field construction cost, M$ & $/kW
4. Calculate present value of capital investments (CIpv)	Methodology for ΣCI, Escalation rate	CIpv, M$
5. Calculate capital investment levelized annual cost	Economic factors (ROR, taxes, debt ratio) Levelized annual cost methodology	Capital levelized annual cost, M$/yr
6. Estimate recurring annual costs	Economic factors (Royalties, operation and maintenance, insurance, general and administration)	Operation and maintenance annual costs, M$/yr
7. Calculate energy costs	Capital levelized annual cost (4) Operation and maintenance annual costs (5) Capacity factor	$\overline{\text{BBEC}}$, mills/kW·h

debt ratio, escalation, etc.) and methodologies to arrive at the levelized capital fixed charge rate the same?

- Are the well costs comparable?
- Are the monetary bases the same? (Current, constant, or escalated dollars?)
- Are the spare-well allowances equal?
- Have major equipment redundancies and/or interim-life replacement been accounted for in the same manner?

Given these conditions for valid comparisons between system cost studies, the most valid cost comparisons would be obtained if those studies were made by the same firm. The second level of validity would be if the studies were performed to a common specification (e.g., these LLL power conversion system studies). Any other cost comparisons are suspect. If they are to be used, the major items must be crosschecked and adjusted to achieve some degree of conformation to the criteria listed above. Finally, of fundamental importance to any cost study is the use of valid laboratory and field test data on performance of components, subsystems, and complete systems.

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APPENDIX A
PERFORMANCE RESULTS

PERFORMANCE RESULTS OF ALL SYSTEMS

The performance quantities that were developed while preparing the cost analyses are tabulated and discussed here, and the various efficiency quantities are defined.

For the base case (25% TDS), the following conditions are specified:

T_1 = Reservoir temperature 290°C (554°F, 1014°R)
T_0 = Sink temperature 26°C (79°F, 539°R)

By means of Ref. 1, the following thermodynamic properties can be determined:

h_1 = 391.8 Btu/lbm
h_0 = 5.4 Btu/lbm
s_1 = 0.5121 Btu/lbm°R
s_0 = 0.0056 Btu/lbm°R

State 1 is the pressurized liquid in the reservoir; state 0 is the saturated liquid leaving the condenser. The maximum theorectical thermal efficiency is:

$$\eta_T = \frac{h_1 - h_0 - T_0 (s_1 - s_0)}{h_1 - h_0} \; .$$

For the specified thermodynamic conditions for the base case,

$$\eta_T = \frac{391.8 - 5.4 - 539\ (0.5121-0.0056)}{391.8-5.4} \; ,$$

$$\eta T = 0.293 \; .$$

The gross and net thermal efficiency, η_G and η_N , are:

$$\eta_G = \frac{\text{Gross electric power}}{(h_1 - h_0) \times \text{Brine flow rate}}$$

$$\eta_N = \frac{\text{Net electric power}}{(h_1 - h_0) \times \text{Brine flow rate}} \; .$$

The net resource utilization efficiency of a system is defined as:

$$\eta_U = \frac{\text{Net electric power}}{[h_1 - h_0 - T_0(S_1 - S_0)] \times \text{Brine flow rate}} \; .$$

Table A-1 lists the performance results used in the cost analyses, including efficiency values for comparison. The required rate for makeup water is also listed.

Table A-2 lists the performance results for the case of 20% TDS.

Table A-3 lists the performance parameters for a number of variations on the Total Flow system, to check off-design performance. Turbine exhaust pressure, wet-bulb temperature, and noncondensable gas load were varied. Also listed is the brine condensation case, wherein the exhaust mixture goes directly to a surface condenser. Two cases for the Total Flow turbine at 45% efficiency are shown.

Table A-4 lists the results of calculations for the multistage flash binary system with variations of the noncondensable load and the wet-bulb temperature.

A brief discussion of these results follows the tables.

TABLE A-1. Power conversion system performance results for base case, 25% TDS.

	System			
	Total Flow		Multistage flash binary	Double flash
	45%	70%	85%	75/80%
Net electrical power, MWe	50	50	50	50.5
Gross electrical power, MWe	60.0	55.8	55.3	55.1
Brine flow rate, 10^6 lb/h	6.37	3.79	3.91	4.96
Net brine rate, lb brine/h/kWe	127.3	75.8	78.2	98.3
Net specific energy, W·h/lb brine	7.9	13.2	12.8	10.2
Isopentane flow rate, 10^6 lb/h	–	–	5.71	–
Max. theoretical system thermal efficiency, %	29.3	29.3	29.3	29.3
System net thermal efficiency, %	6.9	11.7	11.3	9.0
System gross thermal efficiency, %	8.3	13.0	12.5	9.9
System net utilization efficiency, %	23.6	39.7	38.5	30.6
Makeup water rate, Acre ft/yr/MWe net	72.7	40.3	36.6	41.2

TABLE A-2. Power conversion system performance results for 20% TDS.

	System		
	Total Flow 70%	Multistage flash binary 85%	Double flash 75/80%
Net electrical power, MWe	50	50	50
Gross electrical power, MWe	55.8	55.2	54.4
Brine flow rate, 10^6 lb/h	3.51	3.68	4.4
Net brine rate, lb brine/h/kWe	70.4	73.7	87.2
Net specific energy, W·h/lb brine	14.2	13.6	11.5
Isopentane flow rate, 10^6 lb/h	–	5.7	–
Max. theoretical system thermal efficiency, %	29.3	29.3	29.3
System net thermal efficiency, %	12.6	11.4	9.8
System gross thermal efficiency, %	14.0	12.6	10.7
System utilization efficiency, %	42.9	38.5	33.7

TABLE A-3. Plant performance parameters of Total Flow 50-MWe (net) power conversion systems.

	Total Flow												
	Turbine efficiency = 70%											Turbine efficiency = 45%	
	Steam condensation case										Brine cond. case	Steam cond. case	Brine cond. case
	Base	1[a]	2	3	4	5	6	7	8	9			
Cycle variables													
Concentration, %	25	25	25	25	25	20	20	25	25	25	25	25	25
Booster pump head, psia	—	125	25	25	25	25	25	25	25	25	—	—	—
Turbine exhaust pressure, psia	2.75	2.75	2.75	2.50	2.25	2.25	2.25	2.44	2.02	1.70	1.4	2.75	1.4
Noncondensable gases, %	0.5	0.5	0.5	0.5	0.5	0.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5
Wet bulb temperature, F	79.0	79.0	79.0	79.0	79.0	79.0	79.0	73.0	63.0	53.0	79.0	79.0	79.0
Performance parameters													
Net plant output, kW	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Auxiliary power, kW	5.8	6.6	6.3	5.6	5.5	5.8	7.2	6.1	6.1	6.1	5.0	9.9	8.7
Gross electric power, kW	55.8	56.6	56.3	55.6	55.5	55.8	57.2	56.1	56.1	56.1	55.0	59.9	58.7
Brine flow rate, 10^6 lb/h	3.79	4.02	3.82	3.72	3.63	3.51	4.04	3.88	3.76	3.67	3.24	6.37	5.41
Specific net energy, W·h/lb brine	13.2	12.4	13.1	13.5	13.8	14.2	12.4	12.9	13.3	13.6	15.4	7.9	9.1
Net brine rate, lb brine/h/kWe	75.8	80.4	76.5	74.3	72.6	70.4	80.8	77.6	75.2	73.3	64.8	127.3	110.2
Max. theoretical system thermal efficiency, %	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.8	30.6	31.4	29.3	29.3	29.3
System gross thermal efficiency, %	13.0	12.4	13.0	13.2	13.5	14.0	12.5	12.6	12.8	12.9	15.0	8.3	9.6
System net thermal efficiency, %	11.7	11.0	11.6	11.9	12.2	12.6	10.9	11.3	11.4	11.5	13.6	6.9	8.2
System net utilization efficiency, %	39.7	37.4	39.4	40.5	41.4	42.9	37.3	37.7	37.3	36.6	46.4	23.6	29.3

[a]Turbine efficiency = 67%

TABLE A-4. Plant performance parameters of Multistage flash binary 50-MWe (net) power conversion system.

	Multistage flash binary system (Turbine efficiency = 85%)					
	1	2	3	4	5	6
Cycle variable						
Concentration, %	25	25	25	25	20	25
Noncondensable gases, %	0.5	0.5	0.5	0.5	0.5	1.5
Wet bulb temperature, °F	79	77	67	57	79	79
Performance parameters						
Net plant output, kW	50	50	50	50	50	50
Auxiliary power, kW	5.3	5.1	4.8	4.5	5.2	5.3
Gross electric power, kW	55.3	55.1	54.8	54.6	55.2	55.3
Brine flow rate, 10^6lb/h	3.91	3.86	3.62	3.42	3.68	3.72
Specific net energy, W·h/lb brine	12.8	13.0	13.8	14.6	13.6	13.5
Net brine rate, lb brine/h/kWe	78.2	77.1	72.4	68.4	73.7	74.3
Max. theoretical system thermal efficiency, %	29.3	29.5	30.3	31.1	29.3	29.3
System gross thermal efficiency, %	12.5	12.6	13.1	13.6	12.6	12.5
System net thermal efficiency, %	11.3	11.4	11.9	12.4	11.4	11.3
System net utilization efficiency, %	38.5	38.6	39.3	39.9	38.5	38.3

DISCUSSION OF PARAMETER STUDIES

Table A-5 summarizes changes in system performance with variation in specified parameters, with specific net energy output expressed as a percentage change from the base case.

All systems show better performance with a reduced load of dissolved minerals, as expected.

Performance of the Total Flow system with lowered turbine exhaust pressure was investigated in order to determine if any significant future design effort to minimize the turbine downstream flow pressure losses would be worthwhile. Decreasing the exhaust pressure from 2.75 and 2.25 psia did improve 70% Total Flow performance by approximately 4.5%. However, under the specified conditions of ambient wet-bulb temperature of 79°F and steam condensation at 2 psia, the 2.25 psia is probably the minimum achievable back pressure, indicating that attaining it probably would be costly.

Both Total Flow and multistage flash binary system performances were calculated at several points of lowered ambient wet-bulb temperature, to check off-design system performance. For the 70% Total Flow system, decreasing T_{WB} from 79°F to 53°F only slightly increased the specific net energy, by about +3%. For the multistage flow binary system, dropping T_{WB} from 79°F to 57°F substantially improved the system specific net energy, by some 14%.

An increase in noncondensable gas from the base 0.5% to 1.5% of the total brine flow rate decreased 70% Total Flow performance by 14.5% (Table A-3, Cases 5 and 6) and multistage flash binary system performance by only 0.7% (Table A-4, Cases 5 and 6). The reason is that the multistage flash binary system vents out the noncondensables from above atmospheric pressure while the Total Flow system must pump them out of the subatmospheric condenser.

The brine condensation case (Fig. 4) investigated the possibility of utilizing the lower equilibrium pressure of brine to reduce the turbine exhaust pressure and thus improve Total Flow performance. The concept eliminates the turbine exhaust separators and separator-to-condenser piping by having the two-phase turbine flow exhaust directly into a heat exchanger, causing cooling and condensation at or near a minimum brine temperature.

This also minimizes the exhaust-piping flow pressure drop. At the base case conditions of 25% TDS and 79°T_{WB}, the brine condensation configuration gives a turbine exhaust pressure of 1.4 psia, which achieves a performance improvement of 16.7% over the steam condensation base case. Details of this configuration are given in the brine condensation case study.[6]

TABLE A-5. Summary of results of parameter studies: Specific net energy output expressed as a percentage change from the base case.

System	20% TDS	Lower turbine exhaust pressure	Lower T_{WB}	Raised NC gas to 1.5%	Brine cond.
Double flash	+12.3	–	–	–	–
45% Total Flow	–	–	–	–	+15.2
70% Total Flow	+ 2.9	+4.5	+ 3.0	-14.5	+16.7
Multistage flash binary	+ 6.2	–	+14.0	- 0.7	–

APPENDIX B
DETAILED COST BREAKDOWN

Tables B-1 through B-17 are excerpts from the detailed cost studies, Refs. 4-6. For reference, the plant performance parameters from these reports are repeated, including more detail than presented in Tables A-1 through A-3.

TABLE B-1. Plant performance parameters, double flash power plant, base case.[a]

Performance parameters[b]		
Gross electric power output, kWe		55,143
Auxiliary power (plant load), kWe		
Cooling tower fans	885	
Cooling water circulation pumps	1,711	
Condensate pumps	68	
Reinjection pump	1,527	
Makeup water river pump	72	
HC1 metering pump	0.6	
Water treatment equipment	160.4	
Miscellaneous	225	
Auxiliary subtotal	4,649	
Net electric power output, kWe		50,494
Brine requirements		
Brine flow rate, lb/h		4,964,700
Specific net output, W•h/lb brine		10.2
Net brine rate, lb brine/h/kWe		98.3
Efficiency		
Max. theoretical system efficiency (dimensionless)		0.293
System gross electric power efficiency (dimensionless)		0.099
System net electric power efficiency (dimensionless)		0.090
System net utilization efficiency (dimensionless)		0.306

[a]From Ref. 5.
[b]Parameters were calculated as defined in Rogers Engineering Foreign Print No. 23.

TABLE B-2. Double flash power plant cost estimate summary (25% TDS).[a]

Items	Thousands of dollars		
	Material and equipment	Installation	Installed
Field construction			
Land and rights			
Structures and improvements			
Site	161,500	344,200	505,700
Buildings	1,300,400	749,200	2,049,600
Boiler plant			
Flash equipment	647,600	143,300	790,900
Two-phase drum	82,900	16,100	99,000
Reinjection pumps	530,500	236,400	766,900
HC1	78,100	23,500	101,600
Piping to turbine	189,100	358,600	547,700
Turbogenerator			
Turbine generator	5,653,000	786,000	6,439,000
Condenser and systems	3,134,300	1,319,600	4,453,900
Cooling tower	1,404,100	120,100	1,524,200
Miscellaneous	386,900	328,300	715,200
Accessory electrical	760,600	421,600	1,182,200
Misc. power plant equipment			
Miscellaneous	450,200	422,600	872,800
Water treatment	1,076,100	577,500	1,653,600
Waste brine pond	161,300	1,104,200	1,265,500
Makeup pipe line	283,300	443,000	726,300
Substation			
Civil	25,400	29,600	55,000
Electrical	537,200	165,600	702,800
Subtotal field construction	16,862,500	7,589,400	24,451,900
Engineering services			3,423,300
Contingency			5,575,000
Subtotal construction cost			33,450,200
Owners cost			2,676,000
Allowance funds during construction			2,890,100
Total capital cost			39,016,300

[a]From Ref. 5.

TABLE B-3. Well field cost estimate summary, double flash system (25% TDS).[a]

Items	Thousands of dollars: Material and equipment	Installation	Installed
Production			
Well costs (8 wells)	Included	2,400,000	2,400,000[b]
Piping and supports	1,218,900	570,000	1,788,900
Valves and installation	423,300	33,900	457,200
Insulation	360,600	244,900	605,500
Subtotal	2,002,800	3,248,800	5,251,600
Reinjection			
Piping and supports	1,416,100	1,018,200	2,434,300
Wells (4 wells)	Included	1,200,000	1,200,000[b]
Insulation	248,400	168,700	417,100
Subtotal	1,664,500	2,386,900	4,051,400
Subtotal field construction	3,667,300	5,635,700	9,303,000
Engineering services			798,400[b]
Contingency			1,300,300[b]
Subtotal construction cost			11,401,700
Allowance funds during construction			912,100
Total capital cost			12,313,800

[a]From Ref. 5.
[b]Engineering services and contingency are included in the installed well cost.

TABLE B-4. Cost of power, double flash system well field.[a]

Financial conditions			
Cost of capital (return), %		20	
Bond interest, %		9.5	
Debt ratio, %		10	
Service life, yrs		30	
Salvage value		0	
Federal income tax rate, %		48	
State income tax rate, %		9	
Investment tax credit rate, %		10	
Guide line life, yrs		10	
Fixed cost, % of capital			
Level annual revenue requirement	32.446		
Property taxes	5.000		
Insurance	0.100		
Total	37.546		
Levelized annual cost, dollars			
Fixed costs			0.37546 × 12,313,800 = 4,623,300
Operation, maintenance, and royalty			1,796,400
Total well field			6,419,700
Unit cost well field			
Mills/kW·h			18.32
Mills/lb brine			0.1845

[a]From Ref. 5. The end results and decision criteria for the power conversion system studies are reflected in the economics of each system with respect to each other and possibly with other energy alternatives. Many assumptions are made in order to convert capital dollars into per unit dollars. The criteria and unit costs are set forth in Rogers Engineering Foreign Print No. 27.

TABLE B-5. Cost of power, double flash power plant[a]

Financial conditions			
Cost of capital (return), %		10	
Bond interest, %		9.5	
Debt ratio, %		50	
Service life, yrs		30	
Salvage value		0	
Federal income tax rate, %		48	
State income tax rate, %		9	
Investment tax rate, %		10	
Guide line life, yrs		22	
Fixed cost, % of capital			
Level annual revenue requirement	13.140		
Property taxes	2.500		
Insurance	0.100		
Total	15.740		
Levelized annual cost, dollars			
Fixed costs		0.1574 X 39,016,300 =	6,141,200
Operation, maintenance, and HC1[b]			1,353,800
Total power plant			7,495,000
Unit cost power plant			
Energy, mills per kW·h			21.39

[a]From Ref. 5.
[b]Acid costs were given and used at 10¢/lb on 100% basis.

TABLE B-6. Summary of energy costs for well field and double flash power plant.[a]

	Mills/kW·h		
	Well field	Power plant	Total
Return	7.04	8.91	15.95
Depreciation	1.41	4.08	5.49
Income taxes	2.94	1.64	4.58
Property taxes	1.76	2.78	4.54
Insurance	0.04	0.11	0.15
Royalty	1.83	–	1.83
Operation and maintenance	3.00	2.27	5.27
Administration and general	0.30	0.56	0.86
Acidification (HC1)	–	1.08	1.08
Total	18.32	21.43	39.75

[a]From Ref. 5.

TABLE B-7. Plant performance parameters for 50-MWe (net) power conversion systems.[a]

	Total Flow (70%)	Multistage flash binary
Net electric power output, MWe	50.0	50.0
Auxiliary power, MWe	5.8	5.3
Gross electric power output, MWe	55.8	55.3
Brine flow rate, 10^6 lb/h	3.79	3.91
Specific net output, W•h/lb brine	13.2	12.8
Net brine rate, lb brine/h/kWe	75.8	78.2
Max. theoretical system thermal efficiency, %	29.3	29.3
System gross electric power efficiency, %	13.0	12.5
System net electric power efficiency, %	11.7	11.3
System net utilization efficiency, %	39.7	38.5

[a]From Ref. 5.

TABLE B-8. Auxiliary (plant load) power requirements for 50-MWe (net) power conversion systems.[a]

	Electric power, kW	
	Total Flow (70%)	Multistage flash binary
Condensate pumps	10	—
Brine injection pumps	1,305	1,340
Cooling water pumps	2,605	2,180
Ejector condenser water pumps	100	—
Blowdown pump	5	—
Makeup water pumps	80	60
Vacuum pumps	470	—
Low pressure feed pumps	—	500
	4,575	4,080
Cooling tower fans	825	860
Water treatment unit (estimated)	110	110
Power for other services (estimated)	225	225
Total auxiliary power	5,735	5,275
Net electrical output from system	50,000	50,000
Gross power generated	55,735	55,275

[a]From Ref. 3.

TABLE B-9. Auxiliary (plant load) flow requirements for 50-MWe (net) power conversion systems.[a]

	Flow, 10^6 lb/h	
	Total Flow (70%)	Multistage flash binary
Brine from production wells	3.79	3.91
Brine to injection wells	3.78	3.90
Noncondensable gases to atmosphere	0.02	0.02
Brine to turbine	3.51	—
Brine to multistage flash units	—	3.90
Brine for auxiliary steam	0.28	0.018
Isopentane to turbines		5.71
Cooling water to main condensers	41.7	35.1
Cooling water to ejector condensers	1.6	—
Hot water to cooling tower	43.3	35.1
Cooling tower evaporation	.942	0.857
Cooling tower drift	0.002	0.002
Cooling tower blowdown	.057	0.052
Cooling tower makeup	1.001	0.910
Cooling tower makeup (acre-ft/yr)	2015.0	1830.0

[a]From Ref. 3.

TABLE B-10. Conceptual capital cost estimates for 50-MWe (net) 70% Total Flow power conversion system, base case.[a]

	Thousands of dollars							
	Materials and equipment		Installation		Subcontracts		Installed cost	
Mechanical equipment		14,542		1,851		1,200		17,593
Turbine generator	9,110		766		—		9,876	
Condenser-phase separators	609		13		—		622	
Condensers	1,194		28		—		1,222	
Cooling tower	—		12		1,102		1,114	
Pumps and drives	1,718		86		—		1,804	
Miscellaneous	551		217		—		768	
Water treatment[b]	1,360		729		98		2,187	
Piping and instrumentation		2,398		2,440		99		4,937
Power plant	2,308		2,159		89		4,556	
Water treatment[b]	90		281		10		381	
Electrical		1,800		1,563		—		3,363
Power plant	1,750		1,479		—		3,229	
Water treatment[b]	50		84		—		134	
Civil structural		906		1,668		1,060		3,634
Turbine building	—		—		170		170	
Control building	—		—		232		232	
Yardwork and miscellaneous	906		1,668		658		3,232	
Total field construction cost		19,646		7,522		2,359		29,527
Engineering services								4,173
Contingency								6,700
Total installed cost								40,400
Owner's costs								3,200
AFDC								4,200
Total capital cost[c]								47,800

[a]From Ref. 3.
[b]Total water treatment field construction cost = $2,750,000.
[c]Fourth quarter, 1977.

TABLE B-11. Conceptual capital cost estimates for 50-MWe (net) multistage flash binary power conversion system.[a]

	Thousands of dollars							
	Materials and equipment		Installation		Subcontracts		Installed cost	
Mechanical equipment		18,685		2,525		1,405		22,615
Turbine generator	3,822		575		—		4,397	
MSFB vessels	5,234		83		—		5,317	
Separator-heat exchanger	1,079		122		—		1,201	
Condenser	2,635		569		—		3,204	
Cooling tower	—		12		1,185		1,197	
Pumps and drives	2,584		204		—		2,788	
Regenerators	1,035		39		—		1,074	
Miscellaneous	936		192		122		1,250	
Water treatment[b]	1,360		729		98		2,187	
Piping and instrumentation		3,228		2,468		149		5,845
Power plant	3,138		2,187		139		5,464	
Water treatment[b]	90		281		10		381	
Electrical		1,818		1,569		—		3,387
Power plant	1,768		1,485		—		3,253	
Water treatment[b]	50		84		—		134	
Civil structural		914		1,678		1,525		4,117
Turbine building	—		—		170		170	
Control building	—		—		697		697	
Yardwork and miscellaneous[b]	914		1,678		658		3,250	
Total field construction cost		24,645		8,240		3,079		35,964
Engineering services								5,036
Contingency								8,200
Total installed cost								49,200
Owner's costs								4,000
AFDC								5,000
Total capital cost[c]								58,200

[a]From Ref. 3.
[b]Total water treatment field construction cost = $2,750,000.
[c]Fourth quarter, 1977.

TABLE B-12. Well field estimates for 50-MWe (net) power conversion systems.[a]

	Thousands of dollars			
	Total flow (70%)		Multistage flash binary	
	Surface facilities	Wells	Surface facilities	Wells
Brine supply lines				
Equipment and materials	380		380	
Installation	140		140	
Subcontracts	165		165	
	685		685	
Brine injection lines				
Equipment and materials	2,750		2,750	
Installation	630		630	
Subcontracts	—		—	
	3,380		3,380	
Geothermal wells				
Subcontracts		3,000		3,000
Total field cost	4,065	3,000	4,065	3,000
Engineering	570		570	
Contingency	930		930	
Total installed cost	5,565	3,000	5,565	3,000
AFDC	265	140	265	140
Capital cost	5,830	3,140	5,830	3,140
Total capital cost[b]	8,970		8,970	

[a]From Ref. 3.
[b]Fourth quarter, 1977.

TABLE B-13. Energy production cost estimates for 50-MWe (net) geothermal power conversion systems.[a]

	mills/kW·h	
	Total Flow[b] (70%)	Multistage flash binary
Power plant		
Depreciation	4.6	5.5
Return on investment	10.6	12.9
Income taxes	3.4	4.2
Ad valorem taxes	3.4	4.2
Plant insurance	0.1	0.2
Operation and maintenance	2.8	3.4
Administration and general	0.7	0.8
Acid injection	1.0	1.4
Total power plant costs	26.6	32.6
Well field		
Book depreciation	0.9	0.9
Return on investment	4.3	4.3
Income taxes	3.4	3.4
Ad valorem taxes	1.4	1.4
Operation and maintenance	2.6	2.6
Administration and general	0.3	0.3
Royalties	1.4	1.4
Total well field costs	14.3	14.3
Total energy costs[c]	40.9	46.9

[a]From Ref. 3.
[b]Base case fourth quarter, 1977.

TABLE B-14. Performance parameters for 70% Total Flow brine condensation case.[a]

Turbine generator output at generator leads, kW		54,820
Auxiliary power, kW		
LP injection pumps	135	
Main injection pumps	1,010	
Cooling water pumps	1,525	
Service water pumps	110	
Cooling tower fans	760	
Makeup pumps	60	
Vacuum pumps	710	
	4,310	
Water treatment unit	110	
Miscellaneous (unidentified)	100	
	4,510	
Transformer losses	300	
Total	4,820	
Net system output, kW		50,000
Wellbottom conditions		
Temperature, °F	554	
Pressure, psia	858	
Enthalpy, Btu/lb	436.84	
Brine concentration, %	25.0	
Wellhead conditions		
Temperature, °F	467.8	
Pressure, psia	385.3	
Enthalpy, Btu/lb	431.0	
Quality, %	8.58	
Brine concentration, %	27.33	
Total flow, lb/h	3.322×10^6	
Turbine generator performance		
Inlet temperature, °F	465	
Inlet pressure, psia	375	
Inlet enthalpy, Btu/lb	431	
Inlet quality, %	8.835	
Inlet brine concentration, %	27.4	
Turbine flow, lb/h	2.990×10^6	
Expansion efficiency, %	70	
Generator efficiency, %	98.5	
Exhaust pressure, psia	1.4	
Brine condenser performance		
Condenser pressure, psia	1.4	
Brine inlet flow (turbine exhaust), lb/h	2.990×10^6	
Brine outlet flow, lb/h	3.294×10^6	
Extracted vapor, lb/h	14,600	
Extracted gases, lb/h	17,000	
Condensate from ejector condenser, lb/h	56,000	
Auxiliary flash tank drain, lb/h	279,000	
Cooling water flow, lb/h	37.21×10^6	
Cooling water temperature rise, °F	24	
Cooling tower performance		
Design wet-bulb temperature, °F	79	
Approach, °F	8	
Cold water outlet temperature, °F	87	
Heated water inlet temperature, °F	111	
Evaporation (and drift), lb/h	864,000	
Blowdown, lb/h	52,000	
Makeup, lb/h	916,000	
Cycles of concentration	17.5	
Plant performance		
Specific net output, W•h/lb brine	15.05	
Net brine rate, lb brine/h/kWe	66.44	
Max. theoretical system thermal efficiency, %	29.3	
System gross electric power efficiency, %	14.7	
System net electric power efficiency, %	13.29	
System net utilization efficiency, %	45.29	

[a]From Ref. 6.

TABLE B-15. Conceptual capital cost estimates (power plant) for 50-MWe (net) 70% Total Flow power conversion system, brine condensation case.[a]

	Thousands of dollars							
	Materials and equipment		Installation		Subcontracts		Installed cost	
Mechanical equipment		15,574		1,739		1,279		18,592
Turbine generator	8,565		758		—		9,323	
Condenser-phase separators	28		1		5		34	
Condensers	4,374		31		—		4,405	
Cooling tower	—		—		1,176		1,176	
Pumps and drives	868		112		—		980	
Miscellaneous	379		108		—		487	
Water treatment[b]	1,360		729		98		2,187	
Piping and instrumentation		1,404		1,726		47		3,177
Power plant	1,314		1,445		37		2,796	
Water treatment[b]	90		281		10		381	
Electrical		1,772		1,410		—		3,182
Power plant	1,722		1,326		—		3,048	
Water treatment[b]	50		84		—		134	
Civil structural		906		1,668		1,060		3,634
Turbine building	—		—		170		170	
Control building	—		—		232		232	
Yardwork and miscellaneous	906		1,668		658		3,232	
Total field construction cost		19,656		6,543		2,386		28,585
Engineering services								4,005
Contingency								6,510
Total installed cost								39,100
Owner's costs								3,100
AFDC								4,000
Total capital cost[c]								46,200

[a] From Ref. 6.
[b] Total water treatment field construction cost = $2,750,000.
[c] Fourth quarter, 1977.

TABLE B-16. Conceptual capital cost estimates (well field facilities) for 50-MWe (net) 70% Total Flow power conversion system, brine condensation case.[a]

	Thousands of dollars		
	Surface facilities		Wells
Brine supply			
Equipment and materials	350		
Installation	150		
Subcontracts	170		
	670		
Brine injection lines			
Equipment and materials	2,000		
Installation	570		
Subcontracts	–		
	2,570		
Geothermal wells			
Subcontracts	–		3,000
Total field cost	3,240		3,000
Engineering	450		
Contingency	740		
Total installed cost	4,430		3,000
AFDC	210		140
Capital cost	4,640		3,140
Total capital cost[b]		7,780	

[a]From Ref. 6.
[b]Fourth Quarter, 1977.

TABLE B-17. Energy production cost estimates for 50-MWe (net) 70% Total Flow power conversion systems, brine condensation case.[a]

	mills/kW•h
Power plant	
Depreciation	4.4
Return on investment	10.8
Income taxes	3.2
Ad valorem taxes	3.3
Plant insurance	0.1
Operation and maintenance	2.6
Administration and general	0.7
Acid injection	1.1
Total power plant costs	26.2
Well field	
Book depreciation	0.7
Return on investment	3.7
Income taxes	3.0
Ad valorem taxes	1.3
Operation and maintenance	2.6
Administration and general	0.3
Royalties	1.3
Total well field costs	12.9
Total energy costs[b]	39.1

[a]From Ref. 6.
[b]Fourth Quarter, 1977.

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