The Technical and Economic Feasibility of Salt-Gradient Solar Ponds at the Truscott Brine Lake of the Red River Chloride Control Project

**A Report to the House-Senate
Committee on Appropriations of
the Ninety-Seventh Congress**

September 1982

**A Joint Publication of
Tulsa District, US Army Corps of Engineers
and Pacific Northwest Laboratory**

**Tulsa District
US Army Corps of Engineers**

**Pacific Northwest Laboratory
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THE TECHNICAL AND ECONOMIC
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BRINE LAKE OF THE RED RIVER
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EXECUTIVE SUMMARY

1.0 OBJECTIVE

The Conference Committee on the Energy and Water Development Appropriation Act, 1982 (Public Law 97-88), on page 23 of House Report No. 97-345, directed the Department of Energy and the U. S. Army Corps of Engineers to prepare a joint report with recommendations concerning the technical and economic feasibility, costs, and funding alternatives for construction of power generation facilities using salt-gradient solar ponds at Area VIII/Truscott Brine Lake of the Arkansas-Red River Basin Chloride Control Project.

2.0 SCOPE

The Truscott Brine Lake study consisted of four tasks:

- Survey of Suitability of Truscott Lake Site
- Review of Solar Pond Technology
- Preconceptual Design of Solar Salt Pond Power Plant
- Economic Evaluation

The level of detail was limited to a preconceptual design because of the short time period dictated by Public Law 97-88.

3.0 LOCATION OF TRUSCOTT BRINE LAKE PROJECT

The Truscott Brine Lake is being constructed to impound highly brackish water from a number of sources which would normally flow into the Wichita River, a tributary of the Red River in Knox County, Texas. A 35.4-km (22-mile) pipeline is being constructed to carry the brines from their primary source to the Truscott Brine Lake site. The reservoir is designed to contain 100 years of brine emissions from three chloride emission areas in the Wichita River Basin (see Figure 4.1). The solar ponds and power generating facilities would be located in the Bluff Creek Arm of Truscott Brine Lake, which is approximately four miles due west of Truscott, Texas.

4.0 POWER FROM SALT GRADIENT SOLAR PONDS

The solar pond is a device for trapping and storing the solar thermal energy absorbed in a pond. The salt gradient in a solar pond achieves this by means of a salt concentration gradient, increasing from low salinity at the pond surface to high salinity a meter or two below the surface. Hence, deeper waters are heavier than the waters above them. Thermal bouyancy convection is suppressed, impeding that upward movement of warmed water that is the principal mechanism of heat loss in an ordinary pond.

In practice, the salt gradient solar pond has three layers or zones:

1. The surface convecting zone--a thin layer of low-salinity water
2. The nonconvecting or salinity gradient zone--a layer in which salt concentration increases from a low concentration at the top of the zone to a high concentration at the bottom
3. The storage zone--an area of uniformly high salt concentration that is used for heat storage.

In operating salt gradient ponds in the United States, temperatures in the storage zone as high as the boiling point of saline water have been achieved. By coupling the solar pond with an organic Rankine-cycle engine, it is possible to generate electric power. Electric power has been generated successfully by this method in Israel, and studies are under way to employ the technology elsewhere.

5.0 TECHNICAL FEASIBILITY

The technical feasibility of the Truscott Brine Lake solar salt pond is determined by the intrinsic technical feasibility of the solar pond concept and by the suitability of the site.

5.1 Intrinsic Technical Feasibility

Any questions on the intrinsic technical feasibility of power from salt gradient solar ponds have been essentially eliminated by the operation of a 150-kWe generator receiving thermal power from a one-hectare pond located at Ein Bokek on the Dead Sea in Israel. Nevertheless, questions remain concerning

facility performance and cost of power generated by salt gradient solar ponds. The technology involved in construction of solar ponds and the accompanying power generating equipment does not require any technical breakthroughs to obtain technical feasibility; indeed, the required technology essentially represents the state of the art. Nevertheless, solar salt pond power generation has not been developed to the point of technological readiness, and existing uncertainties in the design and performance of the pond could markedly affect the unit cost of power and hence the economic feasibility of the project. The areas of uncertainty include:

- thickness of the upper convecting zone
- maintainable thickness of the gradient zone
- pond clarity
- heat loss to the ground
- requirements for maintaining gradient zone thickness
- heat extraction from the pond
- wind effects on large ponds
- heat exchanger design and cost
- soil-brine interactions in unlined ponds

5.2 Site Suitability

Analysis indicates that sufficient salt is available in a reasonable time to create a series of solar ponds in a part of the Truscott Brine Lake. Other aspects of the site were investigated, including:

- Brine Suitability Studies of: a) the initial brine makeup and concentration, b) the evaporation required to obtain usable salt concentrations, c) the possible formation and the effects of precipitants during evaporation, d) water clarity during initial operation of the ponds, e) stability of the salt gradient during both heating and operation of the ponds, and f) water/soil/chemical interaction. All these studies indicated that the design parameters for salt characteristics and pond conditions were within the limits considered acceptable for successful solar pond operation. The details of these studies are described by Mathews et al. (1982).

- Other site-specific characteristics and dust conditions were not investigated because of the limited time available for the study. Soil permeability was investigated, but conclusive results were not obtained. The soil-brine interaction must have further study to make sure no deleterious reactions might occur which would jeopardize the soil permeability. No influence of soil-brine reactions on the hydrodynamic stability or the brine clarity in the pond was observed during the studies of brine suitability noted above. Thus, there is currently no reason to believe that site suitability would be limited by any of these factors.
- Studies to determine maximum plant size and operating characteristics indicate that Truscott Brine Lake could support a much larger plant than could be built prudently at this time. Uncertainties in design parameters and operational characteristics of ponds tend to limit the extent of scale-up from existing experience that designers are willing to consider.
- The environmental impact of the Truscott Brine Lake solar pond project was evaluated, and the Army Corps of Engineers determined that there is no significant impact. The finding of no significant impact is included in Matthews et al. (1982).

6.0 ECONOMIC FEASIBILITY

Three factors determine the economic feasibility of a solar salt pond constructed in conjunction with the Truscott Brine Lake project: the value of the power produced, the life-cycle cost of the facility and the performance of the plant. The projected value of the power that would be produced depends on the "avoided cost" of power, i.e., the cost of power that would have to be obtained from other conventional sources if the solar pond power facility were not built. Several assumptions can be made as to the alternative conventional sources. Similarly, several assumptions can be made about financial arrangements that could be made to meet the life-cycle cost of the facility.

6.1 Alternate System Sizes

Although the maximum solar pond system that could be sustained by the Area VIII resources is about 12 MWe, several sources of technical information on solar ponds indicated that the risks of extrapolating the present state of the art, i.e., the uncertainties of using data obtained on a 150-kWe (0.75-hectare pond) to build a 12-MWe system (160-hectare pond) were too great. Two other sizes were considered: 1) a system to deliver to the grid the equivalent annual energy requirements of Area VIII (1.6 GWh/yr) and 2) a system equivalent to that planned for demonstration at the Salton Sea in California. Because of these constraints these plant sizes represent neither an optimum facility size nor the potential plant size for the total Arkansas-Red River Basin; consequently the projected costs and the benefit/cost ratio that have been determined do not represent the actual potential of solar pond technology.

6.2 Cost Estimates

The estimated cost of both the pond works and the power generating facilities include considerable uncertainty because of extensive support works (e.g., evaporative ponds to supply brine, piping, pond maintenance facilities) and the low efficiency and high capital cost of the power generating station. Moreover, optimization of the power cycle and plant layout could not be undertaken in the five-month period available. Table 1 summarizes the cost elements of the 1.90-MWe power plant associated with an 8-hectare (20-acre) solar pond.

TABLE 1. Cost Elements of the 8-Hectare (20-Acre), 1.9-MWe Project

<u>Cost Element</u>	<u>Cost in \$ (1982)</u>
Dams	744,000
Power Plant	3,811,000
Buildings	138,000
Engineering Design	328,500
Supervision and Administration	<u>234,500</u>
	\$5,256,000

6.3 Power Utilization Plans

The benefit/cost ratio was calculated for the smaller solar pond power concept noted above, an 8-hectare (20-acre) pond with 1.9-MWe capacity operating at a 15% plant capacity using five different assumptions as to the methods of financing the project and the market conditions under which the power would be sold. The scenarios used for the analysis were:

1. Pond and power plant are a federal project, and the power is marketed as federal power.
2. Pond and power plant are built by an investor-owned utility, and the power is marketed by them and displaces the need for peak power generated by gas turbines.
3. Pond and power plant are built by a rural generation-transmission electric cooperative, and the power generated displaces gas-turbine power.
4. Pond is built as a federal project (by the Corps of Engineers) while the plant is built by an investor-owned utility; generated power displaces gas-turbine power.
5. Pond is built as a federal project while the plant is built by a rural electric co-op.

6.4 Benefit/Cost Ratio

The best benefit/cost ratio, that of 0.88, resulted from the assumption of federal funding of the solar pond power project. Details of the economic parameters used are provided in Section 7.2.3 of the report. The primary source of the differences in the results arises from different assumptions about the cost of money and the value of displaced power.

6.5 Other Considerations

Although the evaluated benefit/cost ratio is marginally unfavorable, other intangible benefits warrant consideration, namely:

- The project represents a step forward in the development of what is believed to be a significant economic power source in the United States. A recent assessment of the power potential from solar salt ponds is about 3.5 quads.^(a)
- The prospects of reducing cost through optimization studies appear substantial with the opportunity of obtaining a better benefit/cost ratio.
- The marketing of power will be facilitated by a projected shortage in available power throughout the region between 1987 and 1990.

7.0 CONCLUSIONS

The following conclusions are based on the results of the Truscott Brine Lake solar pond study.

- Given the current state of solar pond technology and the conservative design developed for Truscott Brine Lake, it is concluded that a solar pond at Truscott Brine Lake is technically feasible, provided the activity is supported by a parallel R&D effort. This R&D must be directed at removing the main technical uncertainties that do exist and facilitate the scale-up from small existing research facilities through intermediate-size field tests.
- As currently designed, the Truscott Brine Lake solar pond project is marginally uneconomical because of the limitations in size dictated by present extent of experience with large ponds, but there is good reason to believe that ultimately solar pond power plants can be economical in the Arkansas-Red River Basin.
- A study by Lin and French (1982) of the Jet Propulsion Laboratory concluded that solar ponds have the potential to supply 5.5 quads of thermal energy and 3.5 quads of electric energy nationally which combined represents about 7% of the projected energy demand in the year 2000. The Red River Basin has the potential to supply 1.4 quads of thermal energy and 2.0 quads of electric energy.

(a) A quad is 10^{15} Btu.

- Other benefits that tend to offset the only-marginal attractiveness of the project when considered strictly from a financial point of view include
 - advances in solar pond technology
 - resolution of technical uncertainties
 - resolution of economic uncertainties
 - developing solar pond expertise for U.S. manufacturers and designers
 - support demonstrated by local interests in solar ponds.

These benefits derive from the Truscott Brine Lake solar pond in conjunction with a parallel R&D program that includes field testing of intermediate-size solar ponds.

CONTENTS

EXECUTIVE SUMMARY	iii
1.0 OBJECTIVES AND SCOPE	1.1
2.0 POWER FROM SALT GRADIENT SOLAR PONDS	2.1
3.0 SOLAR POND POTENTIAL	3.1
4.0 LOCATION AND PROJECT EVOLUTION	4.1
4.1 THE TRUSCOTT BRINE LAKE PROJECT	4.1
4.2 CHARACTERISTICS OF TRUSCOTT BRINE LAKE	4.3
4.2.1 Ambient Conditions	4.3
4.2.2 Brine Availability and Suitability	4.3
4.2.3 Soil Permeability	4.4
4.2.4 Brine/Soil Chemical Interactions	4.5
4.2.5 Conclusions Concerning Site Characteristics	4.5
4.3 EVOLUTION OF SOLAR POND PROJECT	4.5
5.0 PROJECT DESCRIPTION	5.1
5.1 TRADE-OFF STUDIES	5.1
5.1.1 Plant Size	5.1
5.1.2 Plant Operating Scenario	5.2
5.2 DESCRIPTION OF SELECTED DESIGN	5.4
5.2.1 Solar Pond	5.6
5.2.2 Evaporation Pond	5.7
5.2.3 Cooling Ponds	5.7
5.2.4 Energy Conversion Subsystem	5.7
6.0 TECHNICAL FEASIBILITY	6.1
6.1 STUDIES CONCERNING TECHNICAL FEASIBILITY	6.1

6.2	STATUS OF POND TECHNOLOGY	6.2
6.2.1	Thickness of Upper Convecting Zone	6.3
6.2.2	Maintainable Thickness of Gradient Zone	6.4
6.2.3	Pond Water Clarity	6.4
6.2.4	Heat Loss to the Ground	6.5
6.2.5	Maintenance Requirements of the Nonconvecting Zone	6.5
6.2.6	Heat Extraction From the Pond	6.5
6.2.7	Wind Effects on Large Ponds	6.6
6.2.8	Heat Exchanger Design	6.6
6.3	CONCLUSIONS ON POND TECHNICAL FEASIBILITY	6.7
7.0	ECONOMIC FEASIBILITY	7.1
7.1	REGIONAL POWER REQUIREMENTS	7.1
7.1.1	Market Region	7.1
7.1.2	Power Demand and Growth	7.2
7.1.3	Generation Resources	7.3
7.1.4	Potential for SSP Contribution to System Requirements.	7.5
7.2	ECONOMIC AND FINANCIAL COMPARISON OF SOLAR SALT POND POWER VIS-A-VIS A CONVENTIONAL POWER PLANT	7.5
7.2.1	Method of Economic Analysis for Federally Owned and Operated Facility	7.6
7.2.2	Method of Economic Analysis for Non Federal Ownership and Operation	7.7
7.2.3	Ownership Scenarios	7.8
7.3	POWER COSTS FROM THE TRUSCOTT SOLAR POND	7.10
7.3.1	Facility Cost Estimate	7.11
7.3.2	Economics and Costs Used for Comparative Assessment	7.11
7.3.3	Comparative Costs	7.14

8.0 OTHER BENEFITS	8.1
9.0 CONCLUSIONS	9.1
REFERENCES	R.1
APPENDIX A	A.1
APPENDIX B	B.1

FIGURES

2.1	Schematic Diagram of a Salt-Gradient Solar Pond	2.2
4.1	Location of US Army Corps of Engineers Truscott Brine Lake/Solar Pond Project	4.2
4.2	Chloride Control Area VIII, Truscott Brine Lake	4.2
4.3	Percentage of Solar Radiation Transmitted through Saline Waters	4.4
5.1	Plant Size Cost Comparison	5.2
5.2	Generalized Power Values: Federal Energy Regulatory Commission	5.3
5.3	General Layout of Truscott Brine Lake Solar Pond Power Plant	5.4
5.4	Truscott Brine Lake Solar Pond Power Plant	5.5
5.5	System Schematic Flow Diagram	5.6
7.1	Market Area for Power from the Truscott Brine Lake	7.2

TABLES

3.1	Potential of Salt Gradient Solar Ponds in United States	3.3
6.1	Results of Pond Performance Sensitivity Analysis	6.3
7.1	Area Utilities Installed Capacity by Fuel Type--1980 (MWe)	7.3
7.2	Scheduled Generating Capacity Additions and Retirements--1980-1989	7.4
7.3	Area Utilities--Total Capabilities, Peak Demand, Reserves and Needed Capacity	7.4
7.4	Summary of Economic Scenarios	7.10
7.5	Summary of Plant Capital Costs	7.12
7.6	Solar Pond and Natural Gas Power Plant Cost Data	7.12
7.7	Schedule of Expenditures for Solar Ponds and Gas Turbine Plants	7.13
7.8	Economic Assumptions Applicable to All Cases	7.13
7.9	Base Case Economic Assumptions	7.14
7.10	Sensitivity Analysis Economic Assumptions	7.14
7.11	Levelized Energy Costs for Base Case Economic Assumptions	7.15
7.12	Levelized Energy Costs for Sensitivity Analysis Economic Assumptions	7.16

1.0 OBJECTIVES AND SCOPE

This report documents the results of a study conducted in accordance with the directives set forth by the Conference Committee on the Energy and Water Development Appropriation Act, 1982 (Public Law 97-88) on page 23 of House Report No. 97-345 dated November 19, 1981. This law directed the U.S. Department of Energy (DOE) and the U.S. Army Corps of Engineers (USACE) to develop by September 30, 1982, a joint recommendation which addresses the economic feasibility, cost, and funding alternatives for construction of potential power generation facilities using stratified solar brine ponds of the Arkansas-Red River Basin Chloride Control Project. The objective of the study was to determine if a salt gradient solar pond power plant located at Truscott Brine Lake was technically and economically feasible and to identify funding options. The study consisted of four tasks:

Task 1 – Survey of Suitability of Truscott Lake Site. This task was directed by the USACE and involved a variety of site investigations including brine and soil suitability tests conducted at the Ohio Agricultural Research and Development Center (OARDC).

Task 2 – Preconceptual Design of Solar Salt Pond Power Plant. Conducted by Solar Energy Research Institute (SERI) under the direction of the USACE, this task consisted of preparing a preconceptual design of the solar pond and the power generating facility. The task included hydrodynamic modeling conducted by the USACE Waterways Experiment Station (WES) facility.

Task 3 – Review of Solar Pond Technology. This task, conducted by the Pacific Northwest Laboratory (PNL), consisted of reviewing the current status of solar pond technology.

Task 4 – Economic Evaluation. This task consisted of conducting an economic evaluation of the preconceptual design developed in Task 2. The work was done by the USACE with assistance from PNL.

The study outlined above included a comprehensive review of all relevant subjects, but the short time period mandated by Public Law 97-88 limited the amount of detail in the study, particularly in the development of the preconceptual design.

2.0 POWER FROM SALT GRADIENT SOLAR PONDS

The solar pond is a device for trapping and storing solar thermal energy absorbed in a pond. Several types of solar ponds have been proposed, but the salt gradient solar pond appears to be the most attractive and has been the subject of extensive research and development. The solar pond proposed for Truscott Brine Lake is a salt gradient solar pond.

The primary difficulty in using a normal pond to collect solar energy is that warm water is less dense than cool water and will rise to the surface of the pond where heat is lost to the air. This process is called natural convection. Because of natural convection, a normal pond cannot reach temperatures significantly above the ambient temperature. The salt gradient pond is intended to prevent warm water at the bottom of the pond from rising to the surface. This is achieved by having the bottom of the pond filled with water that contains a large amount of salt (brine), which is more dense than fresh water. The top of the pond then contains water with little salt so that it is less dense than the water in the bottom of the pond. As the water in the bottom of the pond heats up, its density will decrease, but, because of the high concentration of salt, its density will still be greater than the density of the fresh water on the top of the pond--so convection will not occur.

In an actual pond, salt diffuses slowly from the bottom to the top of the pond. Over a period of time this produces a homogeneous pond which again would exhibit convection. To prevent this, the surface of the pond is flushed with fresh water to remove the salt that diffuses upward, and makeup brine is added to the bottom. The pond would then remain stable with an upper zone containing a low-salt concentration and a lower zone with a high-salt concentration. Between these zones is an intermediate zone where the salt concentration increases at a constant rate from the top to the bottom. The intermediate zone or gradient zone does not exhibit convection because of the change in salt concentration. The upper and lower zones are at constant salt concentrations so they do exhibit convection. The key to the solar pond operation is the gradient zone because it prevents convection and acts as insulation for the bottom

zone. Many of the areas of uncertainty associated with solar ponds are related to the gradient zone stability, thickness and maintenance. A schematic diagram of a solar gradient salt pond is shown in Figure 2.1.

In operation, light from the sun passes through the upper convecting zone and the gradient zone into the storage zone where it is absorbed. Unfortunately most of the light is absorbed by the water in the upper convecting zone and the gradient zone. Normally only 20 to 30% of the light reaches the storage zone. This emphasizes the importance of water clarity. Clear water will allow the most light to enter the storage zone. Cloudy water would absorb most of the light in the upper convecting zone where the energy would be lost to the air. The thickness of the upper convecting zone also affects pond performance. Because the upper convecting zone blocks energy from reaching the storage zone and yet provides no insulating value, an upper convecting zone of minimum thickness is desirable. However, in real ponds wave action and other factors cause the formation of the upper convecting zone. The minimum maintainable thickness of the zone is an area of current research.

As the pond is exposed to sunlight, the brine in the storage zone will warm up until the temperature reaches a desired operating temperature. At this point brine is pumped from the pond to a heat exchanger where heat is removed from the brine and is used to produce vapor for a Rankine-cycle power plant. The brine is then returned to the pond for recycling.

FIGURE 2.1. Schematic Diagram of a Salt Gradient Solar Pond

The solar pond concept has the advantage of having energy storage built into the system. Once the pond heats up, the mass of brine in the storage zone is so great that the temperature will not be significantly affected at night or during other interruptions of solar energy. The pond will only show significant temperature changes over long periods such as months. This is a significant advantage when compared to other solar concepts which have daily variations in output.

A salt gradient solar pond can be used to provide either process heat or electric power. When electric power is produced, the hot brine is used as a source of heat for a Rankine-cycle power plant. Normally an organic working fluid is used in the Rankine cycle. Waste heat from the power plant is rejected to the air either in a cooling tower or in a cooling pond.

Solar pond technology has achieved a state of development such that a number of small (less than one hectare) ponds are in operation. One installation has been designed for process heat applications, and one small power generating installation is in service in Israel. One larger power generating facility is under construction in Israel. In the United States a large power generating facility has been studied for the Salton Sea by DOE, the California State Energy Commission, and the Southern California Edison Company. The initial installation at the Salton Sea would have a capacity of 5 MWe with an ultimate capacity of 600 MWe.

3.0 SOLAR POND POTENTIAL

As an energy technology, solar ponds have been shown to have a significant potential in terms of possible installed capacity and in competitive energy costs. DOE and the U.S. Department of Defense (DOD) have sponsored a comprehensive assessment of the regional applicability and potential of salt gradient ponds in the United States. The assessment was conducted by the Jet Propulsion Laboratory (JPL), and the results, presented by Lin and French (1982), are summarized here with particular emphasis on the Red River Basin.

The JPL study was a comprehensive evaluation of solar pond potential; therefore a site-by-site evaluation was avoided because it would have diluted the nature of the study. The study considered general characteristics of twelve geographic regions in the United States. The following topics were investigated:

- availability of natural resources
- meteorological and hydrogeological conditions
- potential pond sites
- estimates of regional pond output
- a study of selected pond design cases
- an evaluation of major potential markets
- an economic analysis considering relevant performance and cost factors
- a comparison of solar pond energy costs with conventional energy costs.

Solar ponds were considered appropriate for five applications; space heating, industrial process heat, agricultural process heat, electric power production, and desalination. Solar ponds were considered applicable to a particular market section in a specified region if four conditions were satisfied:

- The need existed for low temperature thermal energy or electric power.
- The necessary sunshine, salt, water, and land were available.
- The pertinent physical conditions were suitable.
- The pond energy was economically competitive with alternative energy sources before the year 2000.

Solar pond potential in an applicable region is defined as the solar pond energy producing capacity that has not yet but may become a reality by the year 2000. The results of the JPL study are presented in Table 3.1. Column two shows the thermal energy supply potential, which combines space heating, industrial process heat, agricultural process heat, and the desalination sectors. The thermal energy costs and electric energy costs include a high and low value. The low value for thermal energy corresponds to a pond capital cost of $\$31/\text{m}^2$ with a discount rate of 11%, while the high value corresponds to a capital cost of $\$87/\text{m}^2$ with a discount rate of 20%. The low values for electric energy corresponds to a capital cost calculated for a 600-MWe electric plant located at the Salton Sea. The high value corresponds to a 5-MWe electric plant located at the same site. In both electric power cases the discount rate was assumed to be 11%.

The results of the JPL study indicate that solar ponds have the potential to supply 5.48 quads^(a) per year of thermal energy and 3.46 quads per year of electric energy by the year 2000. This would represent a combined total of 8.94 quads which would be 7% of the total U.S. energy consumption in the year 2000. Of the twelve regions, the Red River region, which includes Truscott Brine Lake, has a potential to supply 1.41 quads of thermal energy and 2.03 quads of electrical energy making the Red River region (including Texas, Oklahoma, and Kansas) the area with the largest potential for solar pond applications. Our conclusion, based on the JPL results, is that solar pond technology does have the potential to affect U.S. energy use, particularly in the Red River area.

(a) A quad is 10^{15} Btu

TABLE 3.1. Potential of Salt Gradient Solar Ponds in the United States
(reproduced from Lin (1982))

Region	Thermal Energy Supply Potential (quad/yr)	Electric Supply Potential (quad/yr)	Thermal Energy Cost (¢/kWht)		Electric Energy Cost (¢/kWhe)		Total Pond Area (10 ³ hectares)
			Low	High	Low	High	
Pacific Northwest	0.32	--	4.0	13.0	14.1	50.9	33.6
Salt Lake	0.33	0.55	2.7	8.8	10.0	30.4	285.8
Southwest	0.68	0.25	2.0	3.6	8.5	23.5	124.4
Black Hills	0.13	--	5.0	15.8	11.2	34.8	17.2
Red River ^(a)	1.41	2.03	2.8	9.1	21.5	83.9	526.7
Great Lakes	0.59	--	5.7	18.7	12.8	83.9	88.4
Tennessee Valley	0.87	--	3.3	10.7	11.8	39.1	427.8
Gulf Coast	0.54	0.63	3.1	9.8	11.8	39.1	427.8
Atlantic Northeast	<u>0.61</u>	<u>--</u>	6.3	21.1	25.9	104.0	<u>102.0</u>
United States	5.48	3.46					4155.3

(a) This area includes the states of Texas, Oklahoma, and Kansas.

NOTE: Alaska, Puerto Rico and Hawaii were not included because of either no potential or a lack of information.

4.0 LOCATION AND PROJECT EVOLUTION

The Truscott Brine Lake solar pond project would be a modification of the Truscott Brine Lake currently under construction. This section will describe the location and characteristics of the Truscott Brine Lake followed by an evaluation of the solar pond portion of the project.

4.1 THE TRUSCOTT BRINE LAKE PROJECT

In the Red River Basin, approximately 4,898,000 kg (5400 t) of salts flow into the drainage system each day from both natural and man-made sources. The majority of these salts come from the natural salt domes that underlie much of the area. The water in many of the drainages is unfit for irrigation or for drinking by either human beings or livestock.

To reduce the chloride concentration in the Red River, the Corps of Engineers has initiated construction at one of 10 natural chloride areas in the Red River Basin. Natural drainages are diverted from springs or minor drainages that are sources of unfit water. The water is then piped to large brine lakes where it is allowed to evaporate.

Three of the major chloride areas are located on the North, South, and Middle Forks of the Wichita River. Sources in these forks introduce approximately 765,000 kg (843 t) of salt each day into the river. The South Fork zone accounts for approximately 292,000 kg (322 t) each day. To divert and contain the briny sources, the Corps of Engineers is constructing a 1214-hectare (3000-acre) brine lake near Truscott, Texas, approximately 201 km (125 miles) east of Lubbock (Figures 4.1 and 4.2). The Truscott Brine Lake is planned to receive brines from drainages designated Areas VIII and X.

In 1984, the Area VIII pumping station (also known as the Bateman Station) will commence diverting brine from the South Fork by pipeline to Truscott Brine Lake. Areas VII and X stations are projected for later years.

FIGURE 4.1. Location of U.S. Army Corps of Engineers Truscott Brine Lake Solar Pond Project

FIGURE 4.2. Chloride Control Area VIII, and Truscott Brine Lake

An area-wide search for natural basins on impermeable earth, or earth that could easily be made impermeable, was conducted before brine impoundment locations were decided on. As a result, brine impoundment areas can be a considerable distance from the sources of the brines. For example, Area VIII brine must be pumped through a 35-km (22-mile) pipeline to reach the Truscott Brine Lake. Brine pumping thus constitutes a substantial power demand. The Area VIII pumping requirement is 178 kWe annual average with peaks to 540 kWe. The aggregate requirement for Areas VII, VIII and X is 795 kWe annual average with peaks to 2,041 kWe.

4.2 CHARACTERISTICS OF TRUSCOTT BRINE LAKE

A successful solar pond site requires sunlight, salt, water, and a location with impermeable soil. In the case of Truscott Lake, the salt and water are supplied by brine from the Bateman Pumping Station. A site-specific review of the Truscott Brine Lake indicated that the site has all the characteristics of a successful solar pond site.

4.2.1 Ambient Conditions

Ambient conditions relevant to solar pond operation were taken from data supplied by the U.S. Weather Bureau. Insolation measurements were not available directly, therefore, insolation levels were calculated using methods suggested by SERI Truscott Lake Task Force (1981). In general the Truscott Lake has desirable ambient conditions, including high insolation levels and evaporation rates.

4.2.2 Brine Availability and Suitability

Brine from the Bateman Pumping Station is available to provide surface flushing water for a solar pond and cooling water for a solar pond power plant. When the brine is highly concentrated by evaporation, it can be used for filling the solar pond storage and gradient zones. The most important characteristics of the brine are its optical properties, particularly clarity. A pond using water with low clarity will be inefficient because a small fraction of the solar radiation will reach the storage zone. Tests conducted by the Ohio Agricultural Research and Development Center on samples of Truscott Lake brine indicated that the water was very clear and suitable for use in a solar pond.

During the concentration process calcium sulphate precipitated out of solution, forming a film on the surface. The precipitate ultimately settled out, but the test did indicate that brine from evaporation ponds may need to be filtered. Figure 4.3 compares the Truscott Lake brine clarity with the clarity of various types of seawater and with Salton Sea water. In general, the Truscott Lake water has excellent optical properties.

4.2.3 Soil Permeability

A successful solar pond requires a pond with a relatively impermeable bottom. Seepage through the pond bottom increases the cost of the pond and adversely affects performance because additional concentrated brine must be produced to replace the brine lost by seepage and because the moist soil below the pond will conduct heat away from the pond more rapidly than dry soil. In addition, seepage may cause contamination of ground water.

FIGURE 4.3. Percentage of Solar Radiation Transmitted through Saline Waters

Preliminary tests on soil permeability were inconclusive, but there is no reason to believe that the use of liners will be necessary to achieve acceptable seepage rates. Soil permeability will be investigated as part of any additional site-specific testing, as will the location of ground water, the danger of outgassing and subsidence, and the mechanical properties of local construction materials.

4.2.4 Brine/Soil

As part of the brine test program the possibility of brine/soil chemical interactions was investigated. Although chemical reactions between the brine and the soil have the possibility of adversely affecting the optical properties of the brine, the preliminary testing with Truscott soil and concentrated brine did not indicate any interaction which influenced brine optical properties.

4.2.5 Conclusions Concerning Site Characteristics

Based on the site investigations conducted to date, the site of the Truscott Brine Lake appeared to be suitable for solar pond applications. The clarity of the brine was particularly encouraging.

4.3 EVOLUTION OF SOLAR POND PROJECT

The original design of the pumping stations in the Wichita River Basin and the Red River Basin was developed assuming that electricity for pumping would be purchased from local electrical cooperatives. The availability of salt, water, and sunlight at the Truscott Brine Lake site suggested that a solar salt pond power plant should be considered for providing pumping power. Starting in September 1980, a series of studies was conducted investigating the feasibility of using electrical power generated from a salt gradient solar pond power plant located at Truscott Lake. Several systems have been considered, ranging from systems to provide power for the entire Wichita River Basin to a summer peaking system that would provide power for Area VIII and the Bateman Pumping Station only.

The original study, conducted by SERI for the USACE, prepared a preconceptual design of a salt gradient solar pond power plant which would provide the

power needs of the pumping stations in the Wichita River Basin without using power from any utility. The utility-independent design consisted of a solar pond power plant capable of producing a net base load output of 1.3 MWe with a peak load capacity of 2.2 MWe. The plant was designed to meet the power demand of the pumping stations which varied throughout the year. The plant design included 55 hectares (135 acres) of solar ponds and eight 300-kWe turbines, which would allow flexibility in meeting any power demand by the Wichita River Basin pump stations without purchasing power from the local utilities.

The results of the Utility-Independent Study were encouraging, but it was obvious that a more efficient and cost effective system could be developed if the ground rules were changed to allow cooperation with the local utilities. It was assumed that a power trade agreement could be reached with the local utilities to allow a more efficient operating scenario. The only constraint placed on the system was that the average net annual power delivered would be at least equal the average annual power demand for the Wichita River Basin pumping stations. SERI developed designs for two power generating systems, a base load system with year round operation and a summer peaking system that would operate from June to September. Both of these systems utilize 63 hectares (156 acres) of solar ponds. The base load scenario used three 500-kWe turbines with a net output of 1004 kWe. The summer peaking scenario used three 1200-kWe turbines with a net power output of 1825 kWe.

Following the completion of the utility-dependent scenario, the results were presented by the USACE to several local utilities who indicated a high degree of interest in the project and encouraged the USACE to develop solar pond technology. The utilities indicated that they would be most interested in the summer peaking system for power trade agreements. This system would provide the most valuable power during a time when the irrigation pumping power demands of the predominantly agricultural community were at a maximum.

While the initial investigation of the nature of operation for summer peaking was starting, the Congressional Committee on Appropriations directed DOE and USACE to study the feasibility of a solar pond at the Truscott Brine Lake. The feasibility study was conducted by the USACE with overall direction and ultimate responsibility for the study resting with DOE. The feasibility

study consisted of the analysis of several plant configurations with the selection of one configuration for inclusion in the report to Congress. The actual design was conducted by SERI but the level of detail was limited by the short time frame dictated by Congress. Supporting studies were conducted by the Ohio Agricultural Research and Development station on brine and soil properties, by WES on diffuser design and pond hydraulics, by PNL on site comparisons and technical uncertainties, and by other consultants on required power needs and replacement power costs. The results of the feasibility study conceptual design are described in Section 5.0.

5.0 PROJECT DESCRIPTION

The design of the solar pond power plant proposed in this study is the result of a series of trade-off studies intended to identify a conservative design with reasonable economic performance. Several of the more important trade-off studies are described in the first subsection. The actual design of the proposed project is described in Subsection 5.2. Capital costs are discussed in Section 7, which describes pond economic feasibility.

5.1 TRADE-OFF STUDIES

While the short time period mandated by Public Law 97-88 precluded a detailed optimization and engineering design study, a significant number of trade-off studies were conducted in order to give confidence that the proposed design was reasonable. Trade-off studies included consideration of:

- plant size
- plant operating scenario (capacity factor)
- turbine-generator configuration
- power conversion system working fluid
- power conversion system and heat exchanger size
- pond design and zone thickness
- piping layout
- cooling options.

The first two trade-off studies were the most important and will be discussed in detail. The others were mentioned to give an indication of the scope of the design process.

5.1.1 Plant Size

A series of design studies was conducted for plants with sizes between 1 MWe and 12 MWe. The results are shown in Figure 5.1. Unlike most energy technologies, the Truscott Brine Lake does not show a decrease in cost as plant size is increased. This is due to two factors: the cost of the energy conversion subsystem was assumed to increase linearly with plant size, and

FIGURE 5.1. Plant Size Cost Comparison

site-specific factors caused a large increase in dike cost as the solar pond expanded out into the reservoir. The assumption that energy conversion costs increase linearly with plant size was required by the short time period of the study which precluded a detailed evaluation of energy conversion subsystem economies of scale. Neither of these factors would necessarily apply to other sites. Based on the results shown in Figure 5.1, the decision was made to develop a preconceptual design and cost estimate based on a solar pond system only large enough to meet the Area VIII, Bateman Pumping Station power requirements. This approach would limit the capital cost of the project and yet provide a power plant with a gross output of 1.90 MWe and an 8-hectare (20-acre) solar pond, both of which represent a logical stage in the development of solar pond technology. The net output of the system is large enough to make an attractive offer to the local utilities for a power trade agreement.

5.1.2 Plant Operating Scenario

Originally a capacity factor^(a) of 25% had been assumed for the trade-off studies. As part of the economic evaluation of the concept, it was decided

(a) capacity factor is defined as $\frac{\text{actual annual output}}{\text{plant rated output} \times 8760 \text{ hours per year}}$

to use generalized power cost values from the Federal Energy Regulatory Commission (FERC) for the value of the power produced by the solar pond power plant. The power cost data from FERC is shown in Figure 5.2. In order to determine the impact of operating scenario on power cost, a series of designs was developed for the Truscott Brine Lake, each with a different capacity. The results are also shown in Figure 5.2. It was apparent that there was a definite change in the FERC power value curve at a capacity factor of 15%. This is due to the change in the comparison from a coal-fired generating plant to a combustion turbine generating plant using petroleum fuel. When the levelized energy cost for the various solar pond scenarios are compared to the FERC data, it is obvious that a 15% capacity factor gave the best benefit-to-cost ratio. Therefore, the plant tentatively selected for more detailed study was an 8-hectare (20-acre) solar pond providing thermal energy to a power plant with a capacity of 1.90 MWe operating with a 15% capacity factor.

FIGURE 5.2. Generalized Power Values: Federal Energy Regulatory Commission

5.2 DESCRIPTION OF SELECTED DESIGN

The selected plan of development for a solar pond generating facility at Truscott Brine Lake consists of an 8-hectare (20-acre) pond associated with a 1.90 MW energy conversion system. SERI developed a preconceptual design and cost estimate based on the selected plan. The layout of the plant is shown in Figures 5.3 and 5.4.

The facility consists of four main components; the solar pond, evaporation ponds, cooling ponds and the power conversion unit. Each will be described in the following subsections. The arrangement of the components is shown on Figure 5.5.

FIGURE 5.3. General Layout of Truscott Brine Lake Solar Pond Power Plant

FIGURE 5.4. Truscott Brine Lake Solar Pond Power Plant

FIGURE 5.5. System Schematic Flow Diagram

5.2.1 Solar Pond

The purpose of the solar pond is to provide thermal energy to the energy conversion system. The operation of the solar pond is described in Section 3. The selected plant uses a solar pond with surface area of 8 hectares (20 acres). The pond consists of an upper convection zone with a thickness of 30 cm, a gradient zone with a thickness of 1.5 m, and a 2.0-m-thick storage zone. The pond design includes piping to extract hot brine for use in the energy conversion system and return it to the storage zone. The design also includes piping for low-concentration brine (for surface flushing) and piping for high-concentration make-up brine.

5.2.2 Evaporation Pond

The evaporation ponds take low-concentration brine from the Bateman Pumping Station and allow water evaporation until the brine concentration increases to the level required by the pond design. The concentrated brine can be used for the initial filling of the pond or for make-up brine to replace salt lost by surface flushing. The expedient initial filling of the pond requires that 40 hectares (100 acres) of evaporation pond be originally installed. This will allow the pond power plant to reach full power five years after the evaporation ponds are put in service. After the solar ponds have been established approximately 3.3 hectares (8 acres) of evaporation pond will be retained in two maintenance ponds to provide make-up brine.

5.2.3 Cooling Ponds

The cooling ponds provide cool water to the power conversion unit for waste heat rejection. Approximately 12.4 hectares (30.6 acres) of cooling ponds will be established in two ponds. These ponds will also be used to contain a portion of the storm-water runoff detained by the system.

5.2.4 Energy Conversion Subsystem

The energy conversion subsystem consists of a Rankine-cycle power plant, which uses the thermal energy from the pond to produce electricity. Hot brine is used in a heat exchanger to vaporize an organic working fluid such as Freon R-114. The vapor is expanded in a turbine, which drives a generator to produce electricity. Cooling water is used to condense the vapor R-114 in a heat exchanger. The liquid R-114 is returned to the hot brine heat exchanger to complete the cycle. The gross output of the organic Rankine cycle is 1.90 MWe. The net output with auxiliary loads and pumping requirements included is 1.60 MWe.

6.0 TECHNICAL FEASIBILITY

The following sections discuss the results of studies used to confirm the technical feasibility of electric power from solar ponds, the status of pond technology, and conclusions regarding technical feasibility.

6.1 STUDIES CONCERNING TECHNICAL FEASIBILITY

A variety of studies support the position that solar ponds are technically feasible at Truscott Brine Lake. The Pacific Northwest Laboratory reviewed the overall technical feasibility of solar salt pond technology, and the U.S. Army Corps of Engineers investigated site-specific factors affecting a solar pond installation at Truscott Brine Lake.

The review of solar pond technology investigated the status of solar pond research and development. The results indicated that small solar ponds have been successfully operated in the United States, Israel, and several other countries. Israel's experience includes the operation of a 150-kWe generator receiving thermal energy from a 0.75-hectare pond. Based on their experience, Israel is proceeding with a much larger power-producing pond with a surface area of ~20 hectares (50 acres). Any questions on the intrinsic technical feasibility of power from salt-gradient solar ponds have been essentially eliminated by the successful operation of the 0.75-hectare pond in Israel. The technology involved in construction of solar ponds and the accompanying power generation equipment does not require any technical breakthroughs to obtain technical feasibility; indeed, the required technology is essentially state-of-the-art. The areas of technical uncertainty that must be addressed in a parallel R&D program cover the following engineering and technical problems:

- thickness of the upper convecting zone
- maintainable thickness of the gradient zone
- pond clarity
- heat loss to the ground
- requirements for maintaining gradient zone thickness
- heat extraction from the pond

- wind effects on large ponds
- heat exchanger design and cost
- soil-brine interactions in unlined ponds

The U.S. Army Corps of Engineers has considered three aspects of the Truscott Brine Lake. The Ohio Agricultural Research and Development Center (OARDC) has studied the characteristics of the brine and indicated that the brine was suitable for use in solar ponds and that it had excellent optical properties. OARDC also tested soil permeability; though the results were inconclusive, there is no reason to believe that a liner will be necessary to achieve acceptable seepage rates. In addition, OARDC conducted a preliminary investigation of brine/soil chemical interaction which showed no detrimental effects due to brine/soil reactions. The USACE has had a series of model tests run on diffuser designs by the USACE Hydraulics Laboratory located at Vicksburg, Mississippi. The results showed that, from a fluid dynamic point of view, acceptable flow characteristics for both inflow and outflow could be achieved with proper diffuser design. Based on these studies, there do not appear to be any specific characteristics which would prevent a successful solar pond facility at Truscott Brine Lake. Studies that include the coupled effects of energy extraction on the diffuser design are not expected to present any problems.

6.2 STATUS OF POND TECHNOLOGY

While questions of intrinsic technical feasibility have been answered by existing power generating solar salt ponds, it must be acknowledged that uncertainties do exist in the design and performance of the pond. Most uncertainties result from a desire to operate with an economically optimum pond design and from a lack of operating experience with large solar salt ponds. A complete discussion of pond technical uncertainties is provided by the Desert Research Institute (1980). This section will discuss the technical uncertainties with specific reference to the Truscott Brine Lake design. To provide a quantitative measure of the impact of some of these uncertainties, a sensitivity study was conducted at PNL using the SOLPOND computer code developed at SERI. The study involved comparing the specific pond output of a base case with the output of a similar pond with one variable changed. A summary of the

results of the sensitivity study is given in Table 6.1. It should also be remembered that the design for the Truscott Brine Lake is the first of its kind in the United States. Consequently, the design tends to be conservative yet considerable risks remain due to the uncertainties listed in Section 6.1. When many of the areas of uncertainty discussed in that section are resolved by the R&D program, the result may be to increase pond output above that predicted by the designers.

6.2.1 Thickness of Upper Convecting Zone

The thickness of the upper convecting zone has been recognized as having a significant impact on pond performance. Previous reviews of solar pond research needs have emphasized the importance of maintaining the thinnest possible upper convecting zone (Nielsen 1979). It would be desirable to be able to predict the thickness of the upper convecting zone, but the current state of our knowledge does not allow a reliable estimate of the upper convecting zone thickness. The design of the Salton Sea solar salt pond developed by ORMAT assumes an upper convecting zone thickness of 25 cm. This value is apparently based on ORMAT's experience in operating a 2-acre pond located at the Dead Sea. The Truscott Lake design assumes a conservative upper convecting

TABLE 6.1. Results of Pond Performance Sensitivity Analysis

<u>Case</u>	<u>Upper Convecting Zone Thickness (m)</u>	<u>Gradient Zone Thickness (m)</u>	<u>Brine Optical Quality</u>	<u>Conductivity of Soil (W/m · °C)</u>	<u>Pond Specific Output (kw hr/m² · yr)</u>	<u>Variation (%)</u>
1	0.3	1.5	Truscott	1.0	43.72	-
2	0.2	1.5	Truscott	1.0	49.96	+14
3	0.4	1.5	Truscott	1.0	37.43	-14
4	0.3	1.0	Truscott	1.0	40.33	-8
5	0.3	2.0	Truscott	1.0	27.45	-37
6	0.3	1.5	Salton Sea	1.0	23.78	-46
7	0.3	1.5	Truscott	5.0	26.34	-40

zone thickness of 40 cm. If the solar salt pond located at Truscott Brine Lake proves capable of maintaining a thinner upper convecting zone, then an increase in pond output can be expected. If a 20-cm upper convecting zone thickness is assumed (rather than the 30-cm thickness), the thermal output of the pond would be increased by 14 percent.

6.2.2 Maintainable Thickness of Gradient Zone

The maintainable thickness of the gradient zone is a major factor in determining pond performance. Previous research has shown that the stability of the gradient zone is not a serious problem, but there is less certainty on the maintainable average annual thickness of the gradient zone. Research has shown that the unmaintained average annual thickness of the gradient zone is much thinner than the optimum thickness. The maximum thickness of a maintained gradient zone in a large pond is not well defined. The Salton Sea salt pond design by ORMAT uses a gradient zone thickness of 1.3 m, while the Truscott Brine Lake design includes a gradient zone thickness of 1.5 m.

6.2.3 Pond Water Clarity

The impact of pond water clarity on pond performance is well documented (Desert Research Institute 1980). In the case of Truscott Brine Lake, a water sampling program has helped to reduce the uncertainty associated with pond optical properties, but the complicated nature of the problem and the extreme sensitivity of pond output to water optical properties do raise several concerns. Techniques for clarity measurements have several problems, particularly in underestimating the amount of light reaching the storage zone. In addition, the relationship between laboratory clarity measurements, when compared to in-pond measurements, is not clear. A second area of concern is the change of pond water clarity with time. The buildup of wind-blown dusts, organic matter, and debris may reduce the clarity of the pond. Currently, there is no method of estimating or measuring long-term changes in pond optical properties. As an indication of the impact of clarity on pond performance, two cases were considered in the sensitivity study: 1) the base case where 31 percent of the solar radiation is transmitted to the storage zone, and 2) an alternative case where 25 percent of the solar radiation is transmitted to the storage zone. The decrease in pond clarity results in a decrease of 46 percent in pond output.

6.2.4 Heat Loss to the Ground

The loss of heat from the storage zone to the ground below the pond can have a substantial impact on pond performance. The PNL sensitivity study showed that an increase in the thermal conductivity of the ground from a base case of $1 \text{ W/m}\cdot^{\circ}\text{C}$ to $5 \text{ W/m}\cdot^{\circ}\text{C}$ results in a reduction in pond output of 40 percent. The base case thermal conductivity used in the Truscott Brine Lake performance calculations was based on field measurements. The second number corresponds to the thermal conductivity of moist soil and was included to give some idea of the sensitivity of pond performance to variations in soil heat transfer characteristics. Currently, it is difficult to predict the long-term thermal conductivity of the ground, the ultimate ground temperature, or the impact of thermal energy storage in the ground. These uncertainties will affect both the pond performance and the pond warm-up period.

6.2.5 Maintenance Requirements of the Nonconvecting Zone

Assuming that a gradient zone of the desired thickness can be established and maintained, the magnitude of the maintenance effort is uncertain. Gradient zone maintenance will require capital equipment, labor, make-up brine, and make-up fresh water. It appears that a gradient zone with a thickness greater than the equilibrium thickness can be maintained by increased injection of brine into the gradient zone and increased flushing of the pond surface. The impact of the increased requirements for brine, fresh water, and labor above that required to compensate for diffusion is not well defined.

6.2.6 Heat Extraction From the Pond

The techniques for extracting heat from large ponds are not well defined. the uncertainties associated with equipment and pond design introduce substantial risk in the design of a solar pond system. Particular areas of uncertainty include:

- Diffuser Design--The actual design of the diffuser can influence the fraction of the pond which is effectively utilized, but the design being used at Truscott Lake has been model-tested using prototypic conditions, including brine and density gradients, by the U.S. Army Corps of Engineers, which substantially decreases the technical risks

associated with the design. Further research that addresses the coupled effects due to energy extraction are expected to support these preliminary tests. In addition, experience obtained at the Miamisburg pond, the SERI heat-extraction experiment, and the TVA pond should further substantiate these measurements.

- Pond Size Limits--There is some experience with the extraction of brine from small ponds, but the impact of increasing pond size is not clear. There may be some maximum pond size that is limited by heat extraction considerations required to prevent the disruption of the gradient zone. The use of a single large pond reduces dike and piping costs, resulting in a reduced pond capital cost.
- Stratified Flow--The ability to stratify flow in the storage zone would benefit pond performance and might allow inlet and outlet piping to be located on the same side of the pond. The Truscott Lake design is based on the conservative assumption that the storage zone would be mixed rather than stratified. If stratified flow can be achieved, the capital cost of the pond can be reduced.

6.2.7 Wind Effects on Large Ponds

Wind can adversely affect the performance of a solar salt pond by causing the growth of the upper convecting zone. The suppression of wind-induced wave action has been demonstrated in a small pond, but there is currently no opportunity to investigate suppression of wind-induced waves in large ponds. A second area of concern is large-scale flows induced by wind action, which would be more important for large ponds than for small ponds because of the impact of long distances exposed to wind shear. If effective wave suppression can be demonstrated, then a single pond design with substantially lower capital costs can be used with greater confidence.

6.2.8 Heat Exchanger Design

The heat exchangers are the dominant cost components in many solar pond designs, but it is difficult to size the vaporizers and condensers with a high degree of confidence. Further development is required in this area. The calculation of the heat transfer coefficient in these components is complicated

by having unusual working fluids and the need to operate with relatively low temperature differences for reasonable cycle efficiency. Good heat transfer correlations do not exist for these situations, and those that do exist give a wide variation in heat transfer coefficients. The problem is further complicated by the availability of advanced heat exchanger designs developed for Ocean Thermal Energy Conversion (OTEC) and geothermal applications. These heat exchangers may substantially improve performance. The direct contact heat exchanger is of particular interest because of the potential for a dramatic reduction in cost and improvement in cycle efficiency. The Truscott Brine Lake design has taken the conservative approach of using conventional shell-tube heat exchangers.

6.3 CONCLUSIONS ON POND TECHNICAL FEASIBILITY

Based on the results of our evaluation, we conclude that a solar pond at Truscott Brine Lake is technically feasible. We base this conclusion on the following points:

- A small solar pond power plant has been operated successfully in Israel.
- A large-scale solar pond power plant is under construction in Israel. Technology transfer from privately-owned companies in Israel has not been successful, thus, the U.S. must develop its own solar pond technology via the parallel R&D program to insure a reliable source.
- Areas of uncertainty do exist. They pertain to the risks in scaling up pond designs and to the ability to operate with economically optimum design parameters, rather than to questions about intrinsic technical feasibility.
- No fundamental breakthroughs are required in solar pond technology.
- No site-specific factors have been identified that would prevent successful operation of a solar pond power plant at Truscott Brine Lake.

Whenever a technology is scaled up from a small research facility to a larger-scale engineering test facility, there are technological risks, and these must be acknowledged. If the technological risks are minimized by maintaining a comprehensive R&D program in parallel with the Truscott Lake Solar Pond Project to remove the previously mentioned uncertainties and to insure timely solution of unforeseen problems, we feel justified in concluding that the risks associated with proceeding with the Truscott Lake design are not great enough to inhibit the project. This is particularly true in the light of the concomitant benefits of the project as discussed in Section 8.

7.0 ECONOMIC FEASIBILITY

Two factors determine the economic feasibility of a solar salt pond (SSP) constructed in conjunction with the Truscott Brine Lake project; the value of the power produced and the cost of the power from the facility.

The projected value of the power that would be produced depends on the "avoided cost" of power, i.e., the cost of power that would have to be obtained from other conventional sources if the solar pond power facility is not built. Several assumptions can be made as to the alternative conventional sources. The assumptions depend on the projected power requirements of the region and the way they will be met by the existing power production infrastructure.

To project the cost of power from the facility, one must not only have an estimate of the raw cost of construction and operation, but also must make assumptions as to the financial arrangement under which the plant will be constructed and operated. Several such assumptions can be made based on the same existing power production infrastructure, and they materially influence the projected cost of power.

7.1 REGIONAL POWER REQUIREMENTS

An analysis was made of the requirements for additional power in the region in which the Truscott SSP would operate. The analysis:

- established the applicable power market area for the analysis.
- projected the future demand for power within the market area.
- determined the anticipated or scheduled availability of resources to meet power needs.
- estimated the nature of power generation from a solar pond power plant which would best serve to meet the future market area power requirements.

7.1.1 Market Region

The assumed market areas, based on the location of existing electric utility service areas and generating plants, and the extent and nature of the electrical transmission system, are shown in Figure 7.1. The combined market area

FIGURE 7.1. Market Area for Power From the Truscott Brine Lake

is approximately 171,000 km² (66,000 mi²) in size, with the proposed SPPP site located in the approximate geographic center of the area. The study area is serviced by four investor-owned utilities, two power generating electric cooperatives, 21 distribution-only electric cooperatives, and 25 municipal systems. Of the 61 generating plants owned by the utilities serving the area, 45 are located within the boundaries of the designated market area. The area is presently well-interconnected electrically. The transmission lines crossing the area near the Truscott site are adequate to permit wheeling of power from the site, with a minimum of additional cost for construction of transmission facilities.

7.1.2 Power Demand and Growth

The market area, like most of the Southwest, is a summer peak load region. This is a result primarily of heavy air conditioning and irrigation energy use during the summer months of June, July and August. Summer peak load requirements in excess of 90 percent of the daily peak commonly prevail for a 10-to 11-hr period. The area's winter peak demand normally averages only 67 percent of the summer peak. Therefore, the magnitude and duration of the winter load

are generally not important utility planning criteria, except with respect to the scheduling of plant maintenance activities.

The area peak load grew 5.95 percent annually during the 1970-1980 period, from 6,185 MWe to 10,526 MWe. However, the effects of conservation programs, economic constraints, and the probable implementation of load management practices have resulted in the projection of a lower annual peak load growth rate of 3.56 percent from 1981-1989 to a total peak demand of 16,550 MWe.

7.1.3 Generation Resources

The 1980 installed capacity by fuel type for the utilities serving the market area are shown in Table 7.1. Of the total installed capacity of 15,672 MWe, 82.7 percent of the capacity was fired by natural gas. It would appear, on the basis of comparing the current installed capacity of the area utilities relative to the expected peak loads over the 1981-1989 period, that existing capacity would be adequate to meet system requirements. However, to insure that the system is able to reliably meet projected loads, a certain percentage of the installed capacity is placed in reserve to meet emergency situations. The projected mix of capacity in the region has resulted in the establishment of a target level of 25 percent reserve capacity over the 1981-1989 planning horizon. This reserve requirement, coupled with forced (unplanned) outages and maintenance requirements, results in a need for an installed generating capability well in excess of projected peak loads. Scheduled additions to meet these needs are shown in Table 7.2.

TABLE 7.1. Area Utilities Installed Capacity by Fuel Type--1980 (MWe)

<u>Utility</u>	<u>Gas</u>	<u>Oil</u>	<u>Coal</u>	<u>Total</u>
Southwestern Public Service	2,098.1	18.4	1,080.0	3,196.5
West Texas Utilities	1,084.8	--	--	1,084.8
Public Service of Oklahoma	3,239.6	201.2	500.0	3,940.8
Texas Electric Service	5,298.2	--	911.5	6,209.7
Western Farmers Elec. Coop.	738.0	--	--	738.0
Brazos Elec. Coop.	503.0	--	--	503.0
Total	<u>12,961.7</u>	<u>219.6</u>	<u>2,491.5</u>	<u>15,672.8</u>
Percent	82.7	1.4	15.9	100

TABLE 7.2. Scheduled Generating Capacity Additions and Retirements--1980-1989

Fuel Type	Additions		Retirements (MW)	Net Increased Capacity (MW)
	Number	MWe		
Coal	15	4450	--	4450
Natural Gas	--	--	765	(765)
Nuclear	2	814	--	814
Oil	--	--	6	(6)
TOTAL	17	5264	771	4493

The relevant factor with regard to the ability of the utility to meet system loads is the extent to which the utility's dependable capacity (installed capacity less a provision for forced outage and maintenance) exceeds the required reserve capacity. This capacity is the capacity actually available for dispatch to meet load requirements. Table 7.3 shows the relationship of planned dependable capacity, projected peak demand, and required reserves for 1980-1989. With consideration of current data for utility capacity expansion, it is evident that there is a substantial shortfall in capacity to meet system requirements after 1984.

TABLE 7.3. Area Utilities--Total Capabilities, Peak Demand, Reserves, and Needed Capacity (1980-1989)

Year	Dependable Capacity (MWe)	Peak Demand (MWe)	25 Percent Reserves (MWe)	Capacity Needed But Unscheduled (MWe)
1980	14,402	11,662	2,915	175
1981	15,427	11,780	2,945	--
1982	16,300	12,423	3,106	--
1983	16,298	12,989	3,247	--
1984	16,529	13,579	3,395	445
1985	17,447	14,175	3,544	245
1986	17,272	14,767	3,692	1,187
1987	17,957	15,361	3,840	1,244
1988	18,006	15,955	3,989	1,938
1989	19,181	16,550	4,137	1,506

7.1.4 Potential for SSP Contribution to System Requirements

While Table 7.3 shows that the area utilities face a potential shortfall in needed generating capacity, the utilities will revise their scheduled capacity additions in future years to meet these needs. The utility planning horizon is sufficiently long, 5 to 10 years, to accommodate additional capacity from a renewable energy source such as an SSP. The major opportunity for expansion into the market area appears to be in the provision of peaking power. As was discussed above it is as a result of the impact of the system's projected large summer peak loads that the majority of the planned capacity additions have been scheduled. Consequently, it is likely that oil-fired, gas-turbine-powered generating units will be used for those planned capacity additions. Any SSP peak power generating facility which can compete economically with this type of power plant and meet the reliability standards required by the utility industry could be readily integrated into the area power market.

7.2 ECONOMIC AND FINANCIAL COMPARISON OF SOLAR SALT POND POWER VIS-A-VIS A CONVENTIONAL POWER PLANT

Based on the foregoing discussion, the value of power from a solar pond will be based on the avoided cost of installing a combustion turbine power plant to meet peaking power requirements of the region. However, the projected cost of power from the conventional plant will depend on whether it is calculated based on the assumptions used in the federal power marketing scenario, or on the assumption that it is owned and operated by an investor-owned utility (IOU) or a rural generation and transmission cooperative utility. Similarly, the cost of power from a solar salt pond will depend on not only the construction and operating cost of the facility, but also on the economic scenario under which the plant is evaluated. The economic scenario includes such information as the type of ownership of the pond, how the pond will be financed, and appropriate economic assumptions for the economy as a whole, such as interest rates. Investigating several economic scenarios is important because, even when pond performance and costs are held constant, a solar pond may be economically attractive under some economic scenarios and unattractive under others.

Economic factors affecting the national economy are, of course, beyond the control of parties potentially interested in constructing a solar pond. However, pond ownership and financing are factors which can be varied to find the most economically feasible method for pond construction and operation. The economic scenarios considered in this analysis investigated three ownership options and two alternative construction financing options, giving rise to five solar pond cases. The first ownership scenario investigated was that of federal ownership and operation of the pond by the USACE. The remaining scenarios examined nonfederal ownership and potential joint federal and nonfederal ownership. An economic analysis of a combustion turbine was also conducted for each of the ownership options to serve as a benchmark for the solar pond comparison.

The economic calculations were based on a 1.9-MWe plant operating with a 0.15 capacity factor. This represents a specific pond output of $30.8 \text{ KWh/m}^2\text{-yr}$. The heat engine design operates with an efficiency of 9% which is ~65% of the Carnot efficiency.

7.2.1 Method of Economic Analysis for Federally Owned and Operated Facility

The federal evaluation criteria include the following assumptions:

1. 100-year project life
2. cost of capital based on the federal interest rate of 7-5/8% per annum
3. Project benefits would be established by the cost of power from the most likely alternative to the solar pond power plant, as indicated by the generalized power values provided by the Federal Energy Regulatory Commission (FERC), Fort Worth Regional Office. Figure 5.2 displays the FERC power values applicable to the Truscott project.
4. 1990 on-line date.

In order to develop the annualized cost of power from the solar pond power plant under federal criteria, it is necessary to develop the schedule of expenditures necessary to construct the plant, including a provision for major replacements, for a 100-year life. The total list cost plus major replacements and interest during construction is summed and multiplied by the capital

recovery factor of 7.63 percent to give the average annual cost. To this is added an assumed operations and maintenance cost to yield the total average annual cost.

The cost of power from the plant in mills per kilowatt-hour (kWh) is then computed by dividing the average annual total cost of operating the plant by the plant's average annual output. This yields an average annual cost of power for the power plant. The cost of power from the solar pond plant can then be compared to that of the FERC combustion turbine alternative at the appropriate capacity factor as shown in Figure 5.2.

7.2.2 Method of Financial Analysis for Non-Federal Ownership and Operation

The method used for assessing the relative economics of the alternative cases is based on life-cycle cost analysis. This approach considers all costs associated with the solar pond, including capital construction costs, interest during construction, financing costs, annual operating and maintenance costs, and taxes and a return on investment for IOUs. A key concept in life-cycle costing is discounting of future cash flows, a technique which quantifies the time value of money. Applying a discounted cash flow approach allows for a direct comparison between alternatives which may have cash flows of different magnitudes occurring at different periods of the project's lifetime.

There are several different methods of applying life-cycle cost analysis, such as calculating a net present value, or a discounted payback period. The method used in this analysis is that of calculating a levelized cost of energy. This approach calculates the present value of all costs associated with the plant, and converts this present value to an annualized cost which, over the lifetime of the plant, has exactly the same present value. Dividing this annualized cost by the annual energy output of the plant produces an energy cost which is constant, or levelized, over the plant's operating lifetime. One interpretation of the levelized energy cost (LEC) is that it is the price (at which the plant energy output could be sold) which, over the plant's lifetime, would exactly recover all costs associated with the plant. An alternative expression of the same concept is that the present value of all energy sold at the LEC would exactly equal the present value of all plant costs. The use of an LEC to compare alternatives is a powerful tool because it condenses

the required revenue to recover all project costs into a single unit cost of energy. If all other factors of consideration (such as operating characteristics, capacity factor, risk, etc.) between two alternative plants are identical, the plant with the lowest LEC can be clearly judged to be the most economic alternative.

It is important to note that the LEC calculated for a plant has no direct connection with the price the utility would actually charge for the electricity from the plant. By definition, the LEC is a fixed unit cost for electricity over the plant's operating lifetime. In actual practice, utilities do not fix electricity prices for the lifetime of a plant, but allow them to increase to cover increases in operating costs. Another important point is that the LEC is not necessarily equivalent to the worth of the energy to the utility. The actual value to the utility of the energy from any plant is determined both by the cost of producing energy from the plant, and how operating the plant interfaces with the rest of the generating grid. Power plants which can reduce the need to operate expensive peak generation plants have a higher value to a utility than plants which would primarily replace energy generated from less expensive base-loaded plants.

Economic assumptions were developed in conjunction with the USACE for a base case and a sensitivity analysis. The sensitivity analysis was conducted to examine the impact of current high interest rates on the economics of pond construction. The base case economic assumptions assume that by the time the solar pond construction begins (in the mid-1980s) interest rates and rates of return on common and preferred stock will have a relationship to the rate of inflation similar to that which has historically existed.

7.2.3 Ownership Scenarios

The ownership scenarios considered included three options (federal, investor-owned, and cooperative utilities-owned) and two alternative construction financing options (involving joint federal/nonfederal participation), which resulted in a total of five cases for the solar pond and three for the combustion turbine.

7.2.3.1 Federal Ownership and Operation

Under this scenario, the Truscott solar pond power facility would be built, owned, and operated by a federal agency, presumably the USACE. Comparison of power cost would be with the FERC power values at the appropriate plant factor as shown in Figure 5.2.

7.2.3.2 Nonfederal Ownership and Operation

The two totally nonfederal ownership options that were investigated were ownership of the power plant by either an investor-owned utility (IOU) or a rural generation and transmission cooperative utility (COOP). Investor-owned utilities are privately held and finance the construction of new power plants through the sale of common stock, preferred stock, and bonds. As with other privately-held corporations, IOUs are required to pay income tax on their earnings. Rural cooperative utilities are publicly owned and are not required to pay federal income taxes. Power plant construction for COOPs is financed through borrowing from the Cooperative Financing Corporation, which normally provides capital at interest rates below current market rates for utility bonds. An additional factor which makes financing costs higher for IOUs than COOPs is that rates of return on common and preferred stock have traditionally been somewhat higher than the return required for bonds. In these scenarios the entire pond and power plant would be built and operated by either an IOU or a utility COOP.

7.2.3.3 Joint Federal/Nonfederal Arrangements

In these scenarios, the USACE would construct and own the solar pond, and a utility would construct and own the power plant. The USACE would then lease the use of the pond to the utility for the duration of the power plant's lifetime. These scenarios are more advantageous to the utility than the total ownership of the pond, because the interest rate the USACE is required by law to use in determining the lease payment is lower than current cost of capital for either IOUs or COOPs. Although in the leasing option the utilities would not have actual ownership of the pond, they would have the use of it guaranteed for the lifetime of the power plant at a lower cost than if they constructed it themselves. The essential features of each of these cases are listed in Table 7.4.

TABLE 7.4. Summary of Ownership Scenarios

<u>Case Number</u>	<u>Ownership</u>	<u>Financing/Construction</u>
<u>Solar Pond Cases:</u>		
1	Investor-owned utility	Utility owns complete plant.
2	Investor-owned utility	Utility leases pond from USACE.
3	Rural G&T coop utility	Utility owns complete plant.
4	Rural G&T coop utility	Utility leases pond from USACE.
5	Federal auth. (USACE)	Totally constructed by USACE.
<u>Gas Turbine Cases:</u>		
1	Investor-owned utility	Utility owns plant.
2	Rural G&T coop utility	Utility owns plant.
3	Taken from FERC power value curve (Figure 5.2)	

7.3 POWER COSTS FROM THE TRUSCOTT SOLAR POND

The size of the generating facility and the assumed capacity factor (see Section 5.1.2 for definition) are two factors which generally have a marked effect on the projected cost of power.

A consensus exists among many involved in solar pond development that uncertainties in design parameters and operational characteristics of ponds tend to limit the extent of scale-up from existing experience that designers are willing to consider. This limit was felt to be less than 12 MWe, about the maximum solar pond system that could be sustained by the Area VIII resources. Two other sizes were considered: 1) a system to deliver to the grid the equivalent annual energy requirements of Area VIII (1.6 GWh/yr), and 2) a system equivalent to that planned for demonstration at the Salton Sea in California (~5 MWe). Because of these constraints, these plant sizes represent neither an optimum facility size nor the potential plant size for the total Arkansas-Red River Basin. Consequently the projected costs and the benefit-to-cost ratio that have been determined do not represent the actual potential of solar pond technology.

The decision was made to develop a conceptual design, cost estimate, and economic assessment based on a solar pond system only large enough to meet the Area VIII, Bateman Pump Station power requirements because of the low first

costs. Also, at this stage of development, 1.90 MWe gross output and an 8-hectare (20-acre) solar pond represent the next logical stage in the development of solar pond technology. The net output of the system and the advancement of the solar pond state of the art is large enough to make an attractive offer to the local utilities for a power trade agreement.

The plant was designed to operate at a 15 percent capacity factor because the generalized cost of power, as developed by the FERC (which would be the value of the power displaced by the solar salt pond under a federal power marketing scenario), showed a definite break at a 15 percent capacity factor (see Figure 5.2). In all probability, the comparative cost of solar pond power (vis-a-vis generalized FERC power) would be most favorable at the 15 percent capacity factor as illustrated in Figure 5.2.

The decision to select the smaller plant size was also supported by a SERI study of alternative plant sizes, which showed that the rule of economy of scale does not hold true at Truscott. This is due in part to the large increase in dike cost as the solar ponds are expanded out into the reservoir and a design assumption that the cost of the energy conversion systems would increase linearly with plant size. The design assumption concerning the cost of the energy conversion subsystem was required by the limited time available for the heat engine optimization, but a more detailed evaluation would probably show substantial economies of scale. Past experience has shown that a large reduction in cost normally occurs when Rankine-cycle heat engines increase in size from 1 MWe to 10 MWe (Laity et al. 1979).

7.3.1 Facility Cost Estimate

A summary of the estimated cost for the 1.90 MWe power plant described in Section 5.2 is given in Table 7.5. A detailed breakdown of estimated cost is given in Appendix B. The cost estimate is based on a preliminary design and substantial uncertainties exist in the cost of the heat engine.

7.3.2 Economics and Costs Used for Comparative Assessment

The capital and operating cost assumptions for the solar pond and the combustion turbine used in the levelized energy cost calculations are listed in

TABLE 7.5. Summary of Plant Capital Costs

<u>Cost Element</u>	<u>Cost in \$ (1982)</u>
Dams	744,000
Power Plant	3,811,000
Buildings	138,000
Engineering Design	328,500
Supervision and Administration	<u>234,500</u>
	\$5,256,000

Tables 7.6 and 7.7. The economic assumptions are listed in Tables 7.8 through 7.10. The sensitivity analysis assumptions are based on current rates of return on debt and equity financing derived from a survey of area utilities by the USACE.

TABLE 7.6. Solar Pond and Natural Gas Power Plant Cost Data

	<u>Solar Pond</u>	<u>Natural Gas</u>
Plant size (net)	1.61 MW	270 MW
Capacity factor	0.15	0.15
Capital cost ^(a)	5,646 (1982)	91,923 (1982)
Annual O&M cost ^(a)	150 (1982)	1,949 (1979)
Fuel ^(a)	—	17,000 (1982)

(a) Costs in \$1000s; price year in parentheses

TABLE 7.7. Schedule of Expenditures for Solar Ponds and Gas Turbine Plants^(a)

	<u>1984</u>	<u>1985</u>	<u>1986</u>	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>
Solar pond							
(all built by utility)	480 ^(b)	538	1386	400	1208	1269	355
Solar pond							
(leased from USACE)	--	103	431	93	1081	1269	355
Gas turbine							
(built by utility)	--	--	--	--	--	91,923	--

(a) Expenditures in 1000s of 1982 dollars

(b) Land purchase--390--a nondepreciable capital investment

TABLE 7.8. Economic Assumptions Applicable to All Cases

System operating life	30 years
Capital investment depreciation life	15 years
Method of depreciation	ACRS--1986 service date
Annual property and other taxes as a fraction of capital investment	0.02
Annual insurance premiums as a fraction of capital investment	0.0025
Base year for dollars	1982
Effective income tax rate (for IOUs)	0.50
Investment tax credit fraction (for IOUs)	0.07
Ratio of debt to total capitalization (for IOUs)	0.50
Ratio of debt to total capitalization (for COOPs)	1.00
Ratio of common stock to total capitalization (for IOUs)	0.38
Ratio of preferred stock to total capitalization (for IOUs)	0.12

TABLE 7.9. Base Case Economic Assumptions

General inflation rate	0.06
Capital cost escalation rate	0.06
Operation and maintenance cost escalation rate	0.07
Natural gas escalation rate:	
1981-1985	0.1538
1985-1990	0.0600
1990-	0.0904
Discount Rate (IOUs)	0.0815
Return on debt (IOUs)	0.080
Discount Rate and return on debt (COOPs)	0.070
Return on common stock (IOUs)	0.135
Return on preferred stock (IOUs)	0.085

TABLE 7.10. Sensitivity Analysis Economic Assumptions

General inflation rate	0.08
Capital cost escalation rate	0.08
Operation and maintenance cost escalation rate	0.09
Natural gas escalation rate:	
1981-1985	0.1756
1985-1990	0.0800
1990-	0.1110
Discount Rate (IOUs)	0.1253
Return on debt (IOUs)	0.163
Discount Rate and return on debt (COOPs)	0.140
Return on common stock (IOUs)	0.175
Return on preferred stock (IOUs)	0.150

7.3.3 Comparative Costs

Comparisons of levelized energy cost for the nonfederal base case economic assumptions and comparisons of power costs for the federal case are given in Table 7.11. The results show that the federal case is the most nearly economically attractive and that for both types of nonfederal ownership scenarios examined (IOU and COOP), the Truscott solar pond has an LEC higher than the gas turbine case for both types of land ownership; i.e. utility ownership or the utility lease of the pond from the USACE. With complete federal ownership, the power cost of the solar pond is still somewhat higher

TABLE 7.11. Levelized Energy Costs for Base Case Economic Assumptions

<u>Case</u>	<u>Ownership</u>	<u>Financing/Construction</u>	<u>LEC</u> <u>(mills/kWh)</u>	<u>Cost Ratio</u>
<u>Solar Pond Cases:</u>				
1	IOU	Utility owns complete plant	583	0.41
2	IOU	Utility leases pond from USACE	414	0.58
3	COOP	Utility owns complete plant	463	0.52
4	COOP	Utility leases pond from USACE	351	0.68
5	USACE	Federally financed	300 (power cost)	0.88
<u>Gas Turbine Cases:</u>				
1	IOU		239	
2	COOP		240	
5	USACE		263 (power cost)	

than power from combustion turbines. Utility ownership of the complete plant boosts the LEC by roughly 60 percent compared to the alternative of leasing the pond from the USACE. Overall, the results indicate that the Truscott Brine Lake salt pond at the facility size selected is marginally unattractive economically. The most nearly economically attractive case is federal ownership of the entire facility pond and generating plant. Each of the other alternatives investigated in Cases 1 through 4, with the utilities (IOU or COOP) owning the complete plant, does not appear to be an economically viable option.

Levelized energy cost results using the sensitivity analysis economic assumptions are shown in Table 7.12. As for the base case assumptions, the financing/construction alternative of the utilities leasing the use of the pond from the USACE is a preferred alternative to complete utility ownership of the plant. The overall effect of using present-day financing costs in the sensitivity analysis was to significantly increase the LEC of the solar pond options, while having little effect on the gas turbine options. This effect is due to the fact that the solar ponds are very capital intensive, and so are very sensitive toward changes in financing. On the other hand, the driving component of the LEC for the gas turbine cases is the fuel cost, so the gas turbine cases are only marginally sensitive to changes in financing assumptions.

TABLE 7.12. Levelized Energy Costs for Sensitivity
Analysis Economic Assumptions

<u>Case</u>	<u>Ownership</u>	<u>Financing/Construction</u>	<u>LEC (mills/kWh)</u>	<u>Cost Ratio</u>
<u>Solar Pond Cases:</u>				
1	IOU	Utility owns complete plant	770	0.34
2	IOU	Utility leases pond from USACE	495	0.53
3	COOP	Utility owns complete plant	665	0.35
4	COOP	Utility leases pond from USACE	441	0.53
<u>Gas Turbine Cases:</u>				
1	IOU		200	
2	COOP		235	

8.0 OTHER BENEFITS

In addition to the value of the power produced by the solar pond power plant, the Truscott Lake Project would have other benefits which may encourage proceeding with the project. Since the project will be coupled with a comprehensive R&D program, the overall benefit will be to advance the solar pond technology in the U.S. This will have the additional benefits of encouraging local interest in solar ponds, and investigations of pond economics and applications.

The Truscott Brine Lake solar pond project is a logical "part of the U.S. solar pond development. The pond represents a scale-up of a factor of 20 over existing U.S. solar ponds. The energy conversion system is large enough for utility interest and should perform like larger installations. The Truscott Lake project, in conjunction with the R&D activities, will allow the resolution of many of the areas of uncertainty described in Section 5, particularly those factors affected by increasing pond size. In all cases the successful application of solar pond technology at Truscott Brine Lake will reassure potential investors for future solar pond projects.

In addition to clarifying the technical aspects of solar pond power generation, the Truscott Brine Lake project would help define pond economic parameters. Areas of uncertainty include energy conversion system costs, cost of pond maintenance and piping costs. Having one design firmly costed would also simplify the determination of the economies of scale associated with increasing plant size.

The Truscott Brine Lake project will develop solar pond expertise among U.S. participants, which will benefit U.S. commercial interests. As stated in Section 3, the U.S. potential for solar pond power generation is around 3.5 quads. The world potential may be much greater because solar pond technology fits the local requirements of many countries. Without experience in building solar ponds, manufacturing energy conversion equipment, and operating solar pond power plants, the U.S. may be eliminating a potentially attractive market for U.S. services and equipment.

The location of the Truscott Brine Lake project is fortuitous because of the local shortage of generation capacity projected for the late 1980s. When this is coupled with the large potential of the region, it is apparent why the local interest in the project has been quite high. The successful operation of the Truscott Brine Lake power plant would encourage local leadership in future solar pond projects.

In all cases the attractiveness of the Truscott Brine Lake Solar Pond project depends on the ultimate competitiveness of solar pond technology with conventional energy sources. It appears reasonable to assume that solar ponds can ultimately be competitive with other energy sources. Among the most significant reasons for this judgement are:

- If solar ponds exhibit economies of scale as one would expect, then there will be a substantial drop in levelized energy costs if a large plant were built. As indicated on Table 7.7, the ground rules of the study required a comparison between a 1.90-MWe solar pond and a 270-MWe gas turbine. The difference in plant size may significantly affect the results. If a larger solar pond were compared, we would expect an improved benefit-to-cost ratio. In addition, at least four sites existing in the Arkansas-Red River Basin Chloride Control Project could support a 50-MWe solar pond power plant. The four sites have a potential overall capacity of 600 MWe.
- The design of the Truscott Brine Lake solar pond would benefit from a detailed optimization study. Because of time constraints, certain aspects of the design were not rigorously optimized. This is particularly true of the energy conversion system. A more detailed evaluation would produce a design closer to optimum and would likely reduce the cost.
- The cost of power from a solar pond power plant would be substantially reduced if current research on direct contact heat exchangers is successful. The direct contact heat exchanger improve performance by reducing the temperature difference between the working

fluid and brine in the vaporizer and between the working fluid and cooling water in the condenser. In addition, the direct contact heat exchanger should substantially reduce heat exchanger costs. Current research on direct contact heat exchangers is encouraging.

- Other studies have shown that large solar ponds can be economical. The study by JPL discussed in Section 3 (Lin and French 1982) and the results of a preliminary design of a 50-MWe solar pond at Salton Sea (Peelgren 1982) both indicate that large solar ponds are competitive with conventional energy sources.

9.0 CONCLUSIONS

The following conclusions are based on the results of the Truscott Brine Lake solar pond study.

- Given the current state of solar pond technology and the conservative design proposed for Truscott Brine Lake, it is concluded that a solar pond at Truscott Brine Lake is technically feasible. While areas of technical uncertainty do exist, the scale-up from existing small research facilities appears to be justified when coupled to a parallel R&D program.
- As currently proposed, the Truscott Brine Lake solar pond project is marginally uneconomical because of the limitations in size dictated by present lack of experience with large ponds. However, there is good reason to believe that ultimately solar pond power plants can be economical in the Arkansas-Red River Basin.
- A study by Lin and French (1982) of the Jet Propulsion Laboratory concluded that solar ponds have the potential to supply 5.5 quads per year of thermal energy and 3.5 quads per year of electric energy nationally, which represents 7% of the projected energy demand in the year 2000. The Red River Basin has the potential to supply 1.4 quads of thermal energy and 2.0 quads of electric energy.
- Other benefits tend to offset the only-marginal attractiveness of the project when considered strictly from a financial point of view. These benefits include:
 - advancement of solar pond technology
 - resolution of technical uncertainties
 - resolution of economic uncertainties
 - developing solar pond expertise for U.S. manufacturers and designers
 - enhanced local interest in solar ponds.

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APPENDIX A

APPENDIX A

The initial report of Corps of Engineers on the Truscott Lake Study (Matthew, J. L., et al., 1982) included the detailed design information used in developing this report. A summary of the information included in the Appendix of that document is shown below:

- Supplement No. 5 to Design Memorandum No. 3, General Design (design of utility independent scenario developed by SERI).
- Conceptual Design of the Truscott Brine Lake Solar Pond System, Volume II Utility-Dependent Scenario.
- Alternative Operating Strategies and System Sizes for Truscott Brine Lake Solar Pond.
- Conceptual Design of the Truscott Brine Lake System Volume III: Summer Peaking Plant for Area VIII Energy Requirements.
- Truscott Solar Pond Study-Interim Letter Report (results of waterways experiment station model testing).
- Results of Analysis and Investigation of Brine and Soil Samples from Truscott Brine Lake Site.
- Preliminary Evaluation of Power Demand and Marketing of Solar Pond Power Plants Generated Energy in the Red River Chloride Control Authorized Sites: Oklahoma and Texas.

APPENDIX B

DETAILED COST ESTIMATE

APPENDIX B

DETAILED COST ESTIMATE

<u>Cost Account Number</u>	<u>Item</u>	<u>Unit</u>	<u>Quantity</u>	<u>Unit Cost \$</u>	<u>Amount \$</u>
04	Dams				
	Earthmoving	CY	96,700	2.50	241,750
	Clearing and Grubbing	AC	160	500.00	80,000
	3" Gravel Surfacing	FY	590	22.00	12,980
	6" Rock Spalls	CY	12,500	25.00	<u>312,500</u>
	Subtotal				647,230
	Contingencies, ±15%				<u>96,700</u>
	Total Dams				744,000
07	Power Plant				
	Generating Equipment				
	Vaporizer	sq ft	29,600	9.50	281,770
	Preheater	sq ft	4,430	12.00	53,160
	Regenerator	sq ft	34,740	11.00	382,140
	Condenser	sq ft	60,580	14.50	878,410
	Generator (1920 kW avg)	job	--	--	300,000
	Switchgear	job	--	--	80,000
	Electrical Controls	job	--	--	50,000
	Shipping	job	--	--	60,000
	Installation	job	--	--	60,000
	Concrete Slab and	job	--	--	<u>40,000</u>
	Foundation				
	Subtotal				2,185,480
	Contingencies, ±15%				<u>327,520</u>
	Total Generating Equipment				2,513,000
	Piping				
	24" Carbon Steel	ft	450	120.43	54,194

<u>Cost Account Number</u>	<u>Item</u>	<u>Unit</u>	<u>Quantity</u>	<u>Unit Cost \$</u>	<u>Amount \$</u>
	Sch 10, 2" foam insul				
	20" Carbon Steel,	ft	300	98.92	29,676
	Sch 10, 2" foam insul				
	16" Carbon Steel,	ft	500	76.16	38,080
	Sch 10, 2" foam insul				
	24" Carbon Steel,	ft	1080	57.73	62,348
	Sch 10				
	20" Carbon Steel,	ft	850	50.74	43,172
	Sch 10				
	16" Carbon Steel,	ft	680	38.31	26,051
	Sch 10				
	24" Fiberglass	ft	1050	74.86	78,603
	Reinforced Plastic (FRP)				
	20" FRP	ft	5000	63.21	316,050
	8" FRP	ft	200	24.12	4,824
	6" FRP	ft	3300	18.29	60,357
	3" FRP	ft	800	8.38	6,704
	2" FRP	ft	900	6.56	5,904
	Fittings and Transp	job			<u>110,500</u>
	Subtotal				847,850
	Contingencies, ±15%				<u>127,149</u>
	Total Piping				975,000
	Miscellaneous Items				
	Pumps and Motors	job	--	LS	95,650
	Switchyard	job	--	LS	65,000
	Data Acquisition System	job	--	LS	40,000
	Controls	job	--	LS	15,000
	Service Equipment	job	--	LS	25,000
	Wave Suppression	job	--	LS	10,000
	Pump Platforms and Diffusers	job	--	LS	<u>30,000</u>
	Subtotal				280,650

<u>Cost Account Number</u>	<u>Item</u>	<u>Unit</u>	<u>Quantity</u>	<u>Unit Cost \$</u>	<u>Amount \$</u>
	Contingencies, ±15%				42,350
	Total Miscellaneous				323,000
	Total Power Plant				3,811,000
19	Buildings, Grounds, and Utilities				
	Buildings and Repair Shop	job	--	LS	120,000
	Contingencies, ±15%				<u>18,000</u>
	Total Buildings, Grounds, and Utilities				138,000
30	Engineering and Design				328,500
31	Supervision and Administration				<u>234,500</u>
	Total Cost				5,256,000

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