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LINE-FOCUS SOLAR CENTRAL POWER SYSTEMS

Phase I

Monthly Technical Progress Report
for the Period 1 August 1979 to 31 August 1979

Prepared by: Arthur J. Slemmons

September 1979

Work performed under Contract EY-76-C-03-0115
WO 3-78-482 PA#140

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ABSTRACT

This report summarizes the work performed during the eleventh month of the Phase I study of the Line-Focus Solar Central Power System. The conceptual design of a 100 MW_e system was completed during the reporting period. Annual levelized busbar energy costs of 61 mills/kWh are projected for the 80th plant at an average daily capacity factor of 0.6, making the Line-Focus Central Power System plant competitive with nuclear and coal fired plants.

Depending on a coal price escalation rate of 8%, it is estimated that there could be as many as 440 100-megawatt solar thermal power plants built in the Western United States by the year 2010. Even higher coal prices could mean a market penetration into other less sunny parts of the United States. Further cost reduction studies proposed should accelerate the realization of electric energy from the sun.

1.0 Introduction

In accordance with the reporting instructions in Contract EY-76-C-0115, SRI International submits this report of project technical progress for the month of August 1979, the eleventh month of the project.

2.0 General

The Department of Energy, through its Division of Solar Technology, is engaged in an effort to develop the technology for the practical and economic conversion of sunlight into electricity. The Solar Thermal Power Program presently being conducted by the Division of Solar Technology includes several contracts with industrial teams for the conceptual design, development, testing, and demonstration of a variety of Solar Thermal Power System concepts and applications. Efforts have been expended in two areas, central power applications and dispersed power applications. This contract falls into the central power applications area.

As prime contractor, SRI is analyzing the Line Focus Central Power System, the complement to the other three generic solar thermal power systems being studied by Department of Energy contractors (see Figure 1). The SRI team includes Bechtel National, Incorporated, the Foster Wheeler Development Corporation, and the Acurex Corporation. The Pacific Gas and Electric Company is acting as consultant to the team. The team has completed a system and subsystem parametric analysis, and is now completing a 100 MW_e commercial plant conceptual design, power cost analysis and commercial assessment.

3.0 Parametric Analysis

3.1 General

The parametric Analysis of the Line-Focus Solar Thermal Power Plant has been completed.

THE FOUR GENERIC TYPES OF SOLAR THERMAL POWER SYSTEMS
BEING STUDIED BY THE U.S. DEPARTMENT OF ENERGY

Figure 1

4.0 Commercial Plant Conceptual Design

Table 1 shows the specifications of the conceptual design for a 100 MW_e line-focus solar central power system.

5.0 Commercial Plant Cost and Performance Estimate

Table 2 shows the estimates for the 1st and 80th commercial plant costs. The collector costs are based on tooling for a production rate of 62,500 heliostats per year. Salt cost is based on 15¢/lb.

6.0 Subsystem Experiment

A report covering this task will soon be issued.

7.0 Commercial Assessment

The High-Temperature Line-Focus (HTLF) central power system applied to intermediate load service operates in an economically competitive range in the year 2000 for most of the western and a very small fraction of the eastern United States, if the cost of coal escalates at an average rate of 8% per year (3% above the assumed general inflation). Depending on whether the initial coal price is taken to be closer to \$1.00 or \$1.40/MMBtu, a potential total of 250 to over 400 units is estimated for installation by 2010. These totals will be limited by the reluctance of utilities to commit large fractions of installed capacity to an insolation dependent source. At a lower escalation rate (6%), the HTLF could capture a small share of the intermediate load market. This would mean introduction of as many as 42 units concentrated in the most favorable locations by 2010. Significant penetration of eastern United States markets, characterized by relatively low solar insolation levels, would require extremely high coal price, escalation rates of more than 12% per year (7% per year greater than the assumed general inflation rate), or capital costs for the HTLF dropping into the neighborhood of \$1,000/kW.

Table 1

LINE-FOCUS SOLAR CENTRAL POWER SYSTEM
100 MW_e Conceptual Design

Collector

40,000 linear feet
24 rows of heliostats
10-foot width
~ 18-foot row pitch

Receiver

44,200 linear feet $\alpha_{\text{sun}} = 0.90$
10 rows
4-foot aperture $\epsilon = 0.06$
6-foot diameter
450°-550° F salt in
1050° F salt out
350 lb/ft

Towers

200 feet high
150 feet between towers

Heat Storage Subsystem

7.5 h storage @ 100 MW_e
3 tanks, for hot or cold salt
Tank thermal loss
Hot: 0.33 MW_{th}
Cold: 0.17 MW_{th}

Electric Power Generation Subsystem

1050° F salt in
550° F salt out
450° F, 2000-psi feedwater
1000° F steam inlet
520-psi, 1000° F steam reheat

40.0% efficiency including pumping and auxiliary losses

System Average Daily Capacity Factor

0.6

Table 2

LINE-FOCUS SOLAR CENTRAL POWER SYSTEM
80th Plant Cost

		Costs \$ millions	
		<u>1st Plant</u>	<u>80th Plant</u>
Design basis, 100 MW _c , 0.6 average daily capacity factor			
Collector			
44,050-ft length			
24 rows			
10-ft length	@ \$5.05/ft ²	52.55	52.55
Receiver			
48,643-ft length total in 10 rows			
(extends beyond heliostats	@ \$750/ft (1st)		
approximately 210 ft)	@ \$542/ft (80th)	36.48	26.36
Towers and trusses			
200 ft high	@ \$208/ft (1st)		
150-ft span	@ \$132/ft (80th)	10.12	6.42
Heat transport system		13.53	13.53
Heat storage system			
6 tanks			
7.5 hrs storage		11.07	11.07
Steam generator		3.91	3.91
Turbine-generator		22.40	22.40
Land, 752 acres @ \$500/acre		0.38	0.38
Structures and improvement		3.90	3.90
Distributables		3.60	3.60
BOP		<u>3.80</u>	<u>3.80</u>
Total Direct Cost		161.74	147.92

The projected BBEC depending on heliostats costs are:

<u>1st Plant</u> <u>(mil/kWh)</u>	<u>80th Plant</u> <u>(mil/kWh)</u>
66.07	60.40

Summary

The markets for intermediate load electric generating capacity were estimated to the year 2000 by careful estimation of the requirements of 61 major electric utilities representing approximately 75% of the total generating capacity of the western United States, and an estimated 90% of the total market. The markets to 2000 were derived from analyses of data collected from analyses of data collected as part of a former SRI study.* The markets beyond 2000 were estimated by conservatively assuming power demand growth rates in the range of 2.0 to 2.5% per year in the regions most suited to HTLF market penetration.

Demand in the eastern United States is roughly estimated at 1.5 times that in the western United States. However, almost all of this demand is in regions with low direct normal insolation, averaging 4.5 kWh/m^2 per day or less. As the economics of the HTLF system generally do not favor its use unless it is located in higher insolation regions (5.5 kWh/m^2 per day or above), the eastern United States is not likely to be an important market and no detailed analysis of this potential market was performed.

When the relatively small HTLF system is considered for base load application, it must be compared with nuclear units or large scale coal fired units. Nuclear plants are likely to produce electricity at more favorable rates under all conditions. The large scale coal units will generally produce electricity more cheaply than the HTLF units unless the coal escalation rate is several percentage points above the general inflation rate.

SRI studies indicate that if production or cost is not restrained by U.S. policy, coal prices will remain constant or change only slightly in constant dollar terms. The lower inflation rates of 6 and 8% are therefore considered much more likely and SRI has concentrated on assessing the markets

*Fuel and Energy Price Forecasts; Quantities and Long Term Marginal Prices. EPRI EA 433. Electric Power Research Institute. Palo Alto, CA (1977).

for intermediate load units based in the western United States. The assessment indicates a good potential for application. Table 3 provides a summary of the HTLF market penetration results for the western United States under a variety of concerning coal prices.

8.0 Development Plan

Although the task to provide a development plan was deleted from the scope of work, the following program elements for the short range and long range development of the line-focus central power system are presented to assist DOE in its implementation of low cost electricity from solar thermal central power plants.

8.1 Short Range Development Plan

8.1.1 Reduction of Heliostat Cost

About two dollars of the estimated five dollars per square foot of the heliostat cost is represented by the cost of the mirror and mirror plastic substrate. Most of this cost is in the material cost for the plastic. It is proposed to analyze the use of glass reinforced cement (GRC), a much lower cost material, for the mirror substrate. The following tasks should be performed during this analysis:

- a) Stress and deflection analysis of GRC substrate.
- b) Mirror/GRC adhesives analysis.
- c) GRC weight and material cost estimate.
- d) GRC production technique analysis.
- e) Substrate experiment: experiment design and cost estimate.
- f) Revised heliostat cost estimate.
- g) Letter report.

8.1.2 Reduction of Receiver Cost

Performance and design requirements for the line-focus receiver will be reviewed. These requirements will include minimum and maximum salt flowrates per linear foot of receiver, inlet and outlet salt temperatures, inlet pressures, allowable pressure drops, insolation fluxes, and methods for applying optical coatings to the receiver panels.

Table 3

SUMMARY OF PROJECTED HTLF
MARKET PENETRATION IN WESTERN U.S. MARKETS*
(IN CUMULATIVE NUMBER OF 100 MW UNITS)

YEAR	\$1.00/MMBTU COAL PRICE		\$1.40/MMBTU COAL PRICE	
	COAL PRICE ESCALATION RATE		COAL PRICE ESCALATION RATE	
	6%/YEAR	8%/YEAR	6%/YEAR	8%/YEAR
1990	0	0	0	0
1995	0	11	2	22
2000	1	67	14	123
2010	3	260	42	441

* BASED ON 55 UTILITIES REPRESENTING 75% OF INSTALLED
CAPACITY IN WESTERN UNITED STATES, 1977.
(DOES NOT ASSUME INCREMENTAL STARTUP.)

Based on the design requirements outlined above, a number of potential heat exchanger panel designs will be prepared. The assessment will include material and manufacturing technique selections. The materials considered will include carbon and austenitic stainless steels. The manufacturing techniques will include embossed and welded construction and welded and hydraulically expanded construction. From this assessment, the panel material and construction technique will be selected.

From the above results, a conceptual design will be prepared for the heat exchanger panel. The design will include specifications of the materials, flow patterns, pressure drops, heat transfer coefficients, and required heat transfer area. Once the panel design has been finalized, the impact of the design on the receiver length and the salt pump power requirements will be addressed. Automated techniques for producing large quantities of the receiver panels will be considered. The study will focus on conceptualizing a manufacturing facility dedicated to the mass production of the panels.

Capital costs of the receiver panels will be developed. Costs will be developed for small quantities available from an established manufacturer. Costs will also be developed for large quantities, based on the capital cost of the dedicated manufacturing facility and the purchase of the heat exchanger material in large quantities. Installation costs for the receiver panels will also be estimated.

8.1.3 Further Wind Tunnel Tests of Receiver Model

Since the purpose of the cryogenic wind tunnel was to more nearly approximate natural convection heat losses, and the cryogenic wind tunnel tests showed natural convection heat losses to be very low, it is proposed that further testing of receiver models can now be done in air. It is proposed to measure heat losses with a larger scale model in a wind tunnel with and without wind diverting panels. The air velocities inside the cavity and the reduction of heat losses using these wind diverting panels can be measured. A proposal for a test in the Ames Research Center's 7' x 10' tunnel has been submitted to DOE-SAN.

The following tasks will be performed during the proposed wind tunnel model tests:

- a) Experiment design and test plan.
- b) Equipment design and construction.
- c) Tests of unbaflled receiver model.
- d) Tests of baffled receiver model.
- e) Test data reduction and analysis.
- f) Letter reports and final report.

8.2 Long Range Technology Development Program

Certain technologies necessary to the economic success of the line-focus central power system are now concurrently being developed as part of the central tower central power system program. These are:

- Molten salt storage techniques
- Molten salt related metallurgy
- Low cost reflective surfaces
- Efficient reflective surfaces

These and other technolobies are common to both point focus and line-focus central power systems. The line-focus central power system will also benefit from the advancements already being made in the point focus central solar thermal power program.

To implement low cost electricity from line-focus solar thermal central power systems in the 80s, it is necessary to reduce to practice several technologies more specifically important to the economic success of the line-focus central power system. These are:

- 1) Low cost single-axis heliostats
- 2) Low cost line cavity receiver
- 3) Receiver selective surfaces production capability
- 4) Proof of concept experiment
- 5) Low cost cleaning of single-axis heliostats.

It should be pointed out that, although these are important to the economic success of the line-focus central power system, the technology will also be useful to other solar technologies, e.g., glass reinforced cement materials for 2-axis heliostats, and selective surfaces for flat-plate and parabolic-trough collectors.

On the basis of these advantages, it is proposed that DOE plan for the following long range technology development program:

8.2.1 Low Cost Single-Axis Heliostat

- Glass reinforced cement (GRC) technology

Make test pieces of GRC for measurement of properties, durability, and manufacturing techniques (1 year).

- Heliostat construction

Build a heliostat module with GRC for measurement of properties, durability, and study of manufacturing techniques (2 years).

- Reflective surface construction

Build reflective surface with GRC substrates for measurement of properties, durability, and study of manufacturing techniques (2 years).

- Heliostat module construction

Build and test at HTTF a heliostat module for measurement of performance, durability, and study of manufacturing techniques (2 years).

- Further heliostat cost reduction

Perform studies of further manufacturing cost reduction techniques and performance/cost tradeoffs (1 year).

8.2.2 Low Cost Line Cavity Receiver

- Panel construction

Make expanded metal type heat transfer panel and test with molten salt with radiant lamps under thermal cycling and freezing regimes (1 year).

- Receiver test

Test production prototype receiver with solar energy at HTTF, Sandia, Albuquerque (2 years).

- Panel cost reduction

Make manufacturing process and tooling studies for complete automation of panel manufacturing (1 year).

8.2.3 Receiver Selective Surfaces Oven

- CVD oven design

Based on the proposed preliminary studies on the current project, design and detail an atmospheric pressure CVD oven capable of thin film selective surface deposition on line-focus cavity receiver panels (1 year).

- CVD oven construction and test

Build the CVD selective surface oven and coat line-focus receiver panels with high solar absorptance/low infra-red emissivity surfaces (2 years).

- CVD oven modification

Modify CVD oven to coat other solar thermal absorbers, e.g., parabolic trough receivers and flat panel collectors (2 years).

8.2.4 Proof of Concept Experiment

- Receiver experiment

Build and test a receiver row 60 meters long on 60-meter tall towers in front of the HTTS tower. Test performance with extant 2-axis heliostats, simulating calculated 1-axis heliostat field solar concentration at the receiver aperture (2 years).

- Proof of concept

Move test receiver to Barstow, add additional receivers and test with prototype single-axis heliostat field (3 years).

8.2.5 Low Cost Cleaning of Single-Axis Heliostat

- Design and build self-propelled single-axis heliostat washing machine. This requires no technological breakthroughs, but no such machine is commercially available. This development can be done in conjunction with the proof of concept experiment (2 years).

8.2.6 10 MW_e Experiment (3 years)

This experiment will be similar in scope and purpose to the power tower Barstow experiment.

8.2.7 The long range DOE development program for line-focus central receiver solar thermal power system is shown graphically in Figure 11.

9.0 Phase II Plan and Proposal

This task has been deleted by DOE-SAN.

10.0 Management

The final report is written and is being edited. The final quarterly review will be held on 18 September 1979 at SRI.

Program Elements	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Low Cost 1-axis Heliostat											
GRC Technology											
Heliostat Construction											
Reflective Surface Construction											
Heliostat Module Construction											
Further Cost Reduction Studies											
Low Cost Line Cavity Receiver											
Panel Construction											
Receiver Test											
Further Cost Reduction Studies											
Receiver Selective Surface CVD Oven											
CVD Oven Design											
CVD Oven Construction and Test											
CVD Oven Modification											
Proof of Concept Experiment											
Receiver Experiment											
Concept Experiment											
Low Cost Cleaning of 1-axis Heliostat											
Design, Build and Test											
10 MW _e Experiment											

Figure 11 Long Range Development Program for
Line-Focus Central Solar Thermal
Power System