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High Temperature Line
Focus Central Receiver
System Cost and Performance Objectives

16 November 1978

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FOREWORD

This report is written as a partial account of work performed for the Department of Energy, on the Advanced Central Power Project, under Letter Contract Number EY-76-C-03-1101 (PA 14).

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1.0 INTRODUCTION

The Department of Energy's (DOE) Division of Solar Energy is engaged in an effort to develop the technology for economic conversion of sunlight to electricity. DOE made an early decision to emphasize the development of point focus systems (PFS). DOE's first generation PFS plant includes a large collector field of two-axis driven heliostats providing power to a tower mounted water boiler receiver which, in turn, provides steam to a conventional nonreheat Rankine conversion system. Second generation plants would incorporate a separate primary loop which provides energy to a more efficient reheat Rankine Conversion cycle.

DOE is currently funding a study to determine if recent advances in line focus technology provide this solar concept with an economic potential comparable to the first generation Point Focus central receiver system for generation of electricity. This report was prepared in support of this effort and has the following specific objectives:

1. Determine the High Temperature Line Focus System (HTLFS) performance and cost goals required for the system to be economically competitive with first generation PFS.
2. Identify HTLFS plant physical and operational characteristics.
3. Determine HTLFS sensitivities to capital equipment cost and subsystem efficiencies.

A simplified analytical model was developed to determine the annual electrical energy generating capabilities and the plant capacity factor while accounting for both the daily and annual variation in solar position. The PFS performance data was based on recent DOE studies, while the HTLFS performance was obtained from sources at the Jet Propulsion Laboratories and at the Stanford Research Institute. The performance models were combined with the standard DOE economic model to generate the annual cost of electricity in terms of mills/kw-hr.

Both the PFS and HTLFS were analyzed with this model using identical performance, operational and economic groundrules. The

performance and cost characteristics of both systems were determined and judgements are made on their comparative merits.

2.0 ANALYTICAL PROCEDURES

This section describes the Line Focus System design, performance and cost models, and the analytical procedures used for solar electrical power plant cost-of-service calculation.

2.1 Line Focus Concept Overview

The Line Focus Central Power System concept, described in Reference 1, utilizes a line cavity-type central receiver system. Figure 1 shows a system configuration utilizing a number of linear arrays. Each array consists of several 60-m long receiver modules, each of approximately 1 MWe power rating. The heliostats have variable-focus mirrors and track the sun in elevation only. The receiver modules are mounted on steel truss towers at an aperture height of 60 m.

The storage, steam turbine, and the remaining subsystems and equipment are assumed to be of the same type as those defined for the system being studied by McDonnell Douglas Astronautics Company for DOE's 100 MWe Central Receiver Studies (Ref. 2). The thermal storage system is a rock-HT43 caloria sensible heat type. The steam cycle is a conventional non-reheat Rankine power plant with steam conditions of 950°F and 1465 psia.

2.2 Analytical Procedures

The analytical procedures used in this study are summarized in Figure 2. The analysis is designed to calculate the annual electrical energy generation including the effects of variation in the sun position throughout the day and the year.

The analysis is based on clear day Barstow, California insolation data. Power generation characterizations are based on three days of the year, summer and winter solstice and spring equinox (Figure 2a). Due to the symmetry of the sun position, only one-half of the year need be calculated since output characteristics would be identical for both halves. The symmetry of sun positions about noon is also used to simplify daily energy calculations. The calculated energy generation for the three days are then extended to other days, in proportion to the known daily insolation levels throughout the year.

FIGURE 1 100-MW_e HIGH-TEMPERATURE, LINE-FOCUS, CENTRAL-RECEIVER SOLAR POWER SYSTEM

Figure 2. Flow Diagram for Analysis

The calculation is performed for a 100 MWe rated plant in which the collector field glass area is varied from 0.75 to 2.0 million square meters (Figure 2b). Excess glass area is used to increase energy storage and therefore plant capacity. The plant subsystem performance models used to convert insolation into electrical power to the utility grid is based on the models identified in Section 2.3 and shown schematically in Figure 2c.

The analysis begins by calculating the power absorbed into steam in the receiver for three key days of the year, accounting for the collector field and receiver thermal losses (Figure 2d). The thermal energy absorbed in the steam is converted into electrical energy using the following technique: when the power absorbed by the receiver in transforming water into steam is equal to or greater than 300 MWt, corresponding to the energy required for the turbine-generator set to provide 100 MWe net to the utility grid, 300 MWt is delivered to the turbine to generate the 100 MWe; any absorbed power above 300 MWt is diverted to the Thermal Storage Subsystem for subsequent production of electrical power at 70 MWe net to the utility grid; absorbed power below 300 MWt is used to charge the Thermal Storage Subsystems.

The electrical energy generated each day is plotted on an annual basis (Figure 2e) based on the three key days and the insolation symmetry. This curve is integrated to yield the total annual energy generation and the plant capacity factor (Figure 2f). The plant capital and operating costs are based on the economic models described in Section 2-4 (Figure 2g) with the key assumptions that the indirect and operational and maintenance costs are proportional to capital costs.

The performance and cost models are then combined to yield the plant operating costs for the range of conditions of interest.

2.3 Performance Assumptions

Performance assumptions are based primarily on data available in the literature. Central receiver point focus data are based on the McDonnell Douglas final report (Reference 2). The central receiver line focus data are less defined and are based primarily on data reported by SRI and the recent work by JPL (Reference 3). The HTLFS data will come under further scrutiny in the current 100 MWe LFS studies.

The solar insolation data were obtained from The Southern California Edison Company and processed by The Aerospace Corporation.

TABLE 1
PERFORMANCE ASSUMPTIONS

	Point Focus		Line Focus	
	Value	Reference	Value	Reference
<u>Collector Efficiencies</u>				
Cosine	Variable (Fig. 4)	Reference 6	Variable (Fig. 5)	Reference 3
Reflectivity	.91	Reference 2	Variable (Fig. 5)	Reference 3
Blocking	Variable (Table 2)	Reference 6	Variable (Fig. 5)	Reference 3
Shading	Variable (Table 2)	Reference 6	Variable (Fig. 5)	Reference 3
Atm. Atten.	0.953	Reference 2	0.98	Reference 3
Rec. Intercept Factor	0.958	Reference 2	Figure 5	Reference 3
<u>Receiver Efficiency</u>				
Rec. Absorption	0.95	Reference 2	Figure 6	Reference 7
Rec. Radiation & Conv.	0.952	Reference 2	Figure 6	Reference 7
<u>Heat Transport</u>				
Thermal Loss	.994	Reference 2	.95	Estimated
<u>EPGS</u>				
<u>Direct</u>				
Gross Cycle Efficiency	0.337	Reference 2	0.337	Reference 2
Parasitic Power	0.89	Reference 2	0.89	Reference 2
<u>From Thermal Storage</u>				
Gross Cycle Efficiency	0.268	Reference 2	0.268	Reference 2
Parasitic Power	0.92	Reference 2	0.92	Reference 2

TABLE 2

ADDITIONAL HELIOSTAT FIELD VARIABLE POWER LOSS FACTORS

Day	Time	% Spillage (mirror waviness, tracking errors)		% Shading	% Blocking
21 December	Noon,		1.68	1.87	0.09
	11:00 A.M.	1:00 P.M.	1.77	2.52	0.17
	10:00 A.M.	2:00 P.M.	1.83	5.25	0.09
	9:00 A.M.	3:00 P.M.	2.10	15.05	0.06
	8:00 A.M.	4:00 P.M.	2.38	34.22	0.11
21 March	Noon,		1.71	0	0.05
	11:00 A.M.	1:00 P.M.	1.77	0.01	0.11
	10:00 A.M.	2:00 P.M.	1.77	0.04	0.09
	9:00 A.M.	3:00 P.M.	1.85	0.94	0.11
	8:00 A.M.	4:00 P.M.	1.86	6.66	0.09
	7:00 A.M.	5:00 P.M.	2.31	25.41	0.07
24 June	Noon,		1.65	0	0.01
	11:00 A.M.	1:00 P.M.	1.61	0	0.06
	10:00 A.M.	2:00 P.M.	1.71	0	0.17
	9:00 A.M.	3:00 P.M.	1.98	0.04	0.07
	8:00 A.M.	4:00 P.M.	1.91	0.81	0.08
	7:00 A.M.	5:00 P.M.	2.06	6.08	0.12
	6:00 P.M.	6:00 P.M.	2.59	23.75	0.10

(Reference 4 and 5). The data are based on Barstow, California measurements for the best insolation day (24 June 1976, representative of summer solstice), worst solar insolation day (21 December 1976) and spring equinox (21 March 1976). See Figure 3.

2.3.1 Optical Performance

Optical performance assumptions and sources are summarized in Table 1. The line focus data were based on work by JPL (Reference 3). The point focus data were based on McDonnell-Douglas results for time invariant properties, and on Aerospace work for data dependent on sun angle (Reference 6).

A comparison of point focus and line focus optical performance is shown in Figure 5. The HTLFS optical efficiency is superior at noon but drops rapidly in the early morning and late afternoon, while the point focus efficiency is more uniform throughout the day.

It is assumed that none of the solar energy is useful for sun elevations below 15° since there is no sun tracking requirement on the collector field below that angle. It was also assumed that linear scaling of the energy collected by the collector fields as a function of the size of the heliostat glass area is valid.

2.3.2 Receiver Performance

The source of receiver efficiency data is also identified in Table 1. The HTLFS efficiency is based on a constant loss of 6 kwt per meter of receiver length, independent of sun angle. This loss is uniform throughout the day since the receiver feedwater boiling temperature is proportional to pressure which remains constant. The comparison of point focus and line focus of receiver efficiencies as shown in Figure 6. The drop in SRI receiver efficiency in the early morning and late afternoon is due to constant thermal losses due to constant receiver temperature, while the input power levels are dropping.

2.3.3 Heat Transport Subsystem Performance

The heat transport losses shown in Table 1 are considered speculative at this time. The HTLFS losses, however, should be substantially larger than those of the point focus systems due to the distributed nature of the multiple receivers.

Figure 3: DIRECT SOLAR INSOLATION

-10-

Figure 4.
AVERAGE COSINE VARIATION

Figure 5. Comparison of Collector Field Optical Efficiency

Efficiency Includes:
Shading & Blocking
Cosine
Reflectivity
Atmospheric Attenuation
Receiver Intercept Factor

Figure 6. Comparison of Receiver Efficiency

2.3.4 Electrical Power Generation System (EPGS) Performance

The EPGS for both systems are identical. The performance is based on the steam conditions (temperature/pressure) used by MDAC in their preliminary design report (Reference 2). The EPGS efficiencies noted in Table 1 are based on the following conditions:

- (a) Rated receiver steam (950°F and 1465 psia) at the turbine stop valve.
 - 1. feedwater inlet conditions - 2600 psia, 425°F and enthalpy of 405 BTU/lb.
 - 2. receiver exit conditions - 1465 psia, 950°F , and an enthalpy of 1461 BTU/lb.
 - 3. steam flow rate - 960,415 lb/hr.
- (b) Thermal storage steam.
 - 1. feedwater inlet conditions - 2600 psia, 250°F , and enthalpy of 219 BTU/lb.
 - 2. steam generator exit conditions at the turbine admission port-- 385 psia, 525°F , and enthalpy of 1263 BTU/lb.
 - 3. steam flow rate - 905,593 lb/hr.
 - 4. generator output - 76.1 MWe

2.3.5 Thermal Storage Subsystem (TSS) Performance

The TSS performance assumptions are summarized below:

- (a) thermal storage media - Caloria HT-43 + rock
- (b) storage conditions - 232° to 316°F
(450° to 600°F)
 - charge: 950°F /1450 psig (480°F condensate out)
 - discharge: 525°F /385 psia (250°F feedwater in)
- (c) warm turbine startup (daily) requires 100 MWt-hr. extraction from TSS
- (d) turbine seal steam (daily) requires 5.04 MWt-hr. extraction from TSS.
- (e) thermal storage subsystem daily convective energy losses equal 2% of maximum TSS capacity.

The capacity of the Thermal Storage Subsystem is a free parameter, and the assumption is made that any receiver steam bypassing the turbine can be accommodated by the Thermal Storage Subsystem at any

charging rate. The physical sizes (and, hence, cost of equipment, such as charging heat exchangers, steam generators, pumps, piping, and Thermal Storage Unit - Caloria Storage Tank), are expected to be affected by this assumption, but it should not lead to insurmountable design problems.

2.3.6 Performance Assumptions Summary

All of the estimates used in this analysis should be considered approximate, even though they are based on the latest available information. Also, effects caused by detailed component characteristics (such as startup/shutdown limitations and turndown ratios) on the operating modes used in this analysis were ignored. The data will be updated by the HTLFS integrating contractor in the design definition phase of the program.

2.4 Solar Power Plant Economic Model

The following procedures and cost data are used to generate capital cost and operating costs for both the line and point focus power plant concepts.

2.4.1 Baseline Capital Costs

Table 3 displays the capital costs for all the subsystems of the point focus and line focus plants for both the first plant and the 80th plant. The cost groundrules are identified in the Table and are applied equally for both plants.

The line focus collector/receiver/tower costs are varied parametrically to determine the operating cost sensitivity to this key variable. Of special note for this analysis is that both the indirect costs identified in Table 3 and the operations and maintenance costs are assumed proportional to capital cost.

TABLE 3
BASELINE CAPITAL COSTS

Item	Capital Costs \$/kwe			
	Strawman Point Focus		Line Focus Plant	
	1st Plant	80th Plant	1st Plant	80th Plant
Land, Yardwork ⁽²⁾	5.	6.	Variable ⁽²⁾	Variable ⁽¹⁰⁾
Structures & Improvements	51.	39. ⁽³⁾	51	39 ⁽³⁾
Turbine Plant	242.	187. ⁽³⁾	242	187 ⁽³⁾
Electric Plant	88.	68. ⁽³⁾	88	68 ⁽³⁾
Collectors	695. ⁽⁴⁾	504. ⁽³⁾	Variable	Variable ⁽³⁾
Receiver	185.	108. ⁽⁵⁾	Variable	Variable ⁽³⁾
Tower	124.	124.	Variable	Variable
Thermal Storage	215.	156. ⁽³⁾	Variable	Variable ⁽¹¹⁾
Distributables ⁽⁹⁾	86.	36. ⁽⁶⁾	86	36 ⁽¹⁶⁾
BOP	53.	38. ⁽³⁾	53	38 ⁽³⁾
Direct Cost	1744.	1262.	TBD	TBD
Indirect Cost ⁽⁸⁾	348. ⁽⁷⁾	136. ⁽⁶⁾	TBD ⁽⁷⁾	TBD ⁽⁶⁾
Total	2092.	1398.	TBD	TBD

(1) Taken from Reference 5, increased by 6% from 1977 dollars.
Costs include burden, contingency and fee.

(2) Based on 900 acres @ \$500/acre.

(3) 0.95 Learning curve.

(4) Based on \$80/m²

(5) 0.90 Learning Curve

(6) 69% Reduction from 1 unit due to larger cost base for 80 units, Reference 5, p. 169.

(7) 20% of Direct Costs.

(8) Indirect Costs include A&E services, construction management, solar integrator, and plant startup.

(9) Distributables include contractor field office, insurance (project and equipment) construction equipment, spares, taxes.

(10) 20% cost growth from 1978 dollars.

(11) Set equal to 80th plant Point Focus specific costs of \$9.28/kwt-hr.

2.4.2 Cost of Service Calculation

The cost of service calculation determines the specific cost of electricity (mills/kw-hr) using normal private utility estimating procedures. The following are data input for the cost of service calculation:

1. Planning Factors

Plant = 80th unit

System Lifetime, (N) = 30 years

First Year of Operations (y_{co}) = 1990

Site = Barstow, Ca.

Type of Ownership = Investor Owned

2. Operation and Maintenance Cost

Assume Operations and Maintenance (X_o) = 1% of CI_t

3. Utility Descriptive Data

Annual "Other Taxes" as a fraction of CI_{pv} , (β_1) = 0.02

Annual insurance premiums as a fraction of CI_{pv} , (β_2) = 0.0025

Income tax rate, (τ_1) = 0.50

Ratio of debt to total capitalization, (D/V) = 0.55

Ratio of common stock to total capitalization, (C/V) = 0.27

Ratio of preferred stock to total capitalization (P/V) = 0.18

Debt interest rate, (k_d) = 0.09

Annual rate of return on common stock, (k_c) = 0.15

Annual rate of return on preferred stock, (k_p) = 0.11

Investment tax credit, (α) = 0.10

Depreciation ($DPF_{m,k,n}$) = Straight Line ($DPF_{SL_{k,n}}$)

4. General Economic Conditions

Rate of general inflation, (g) = 0.050

Escalation plus inflation rate for capital costs, (g_c) = 0.65

Escalation plus inflation rate for operating costs, (g_o) = 0.065

Escalation plus inflation rate for maintenance cost, (g_m) = 0.065

Base year for constant dollars, (y_b) = 1978

The following equations are used for the cost of service calculation for all the power systems. The analysis is based on a JPL model and is the current standard for the DOE/SAN funded solar thermal central power

system cost of energy calculation. (Reference 8). All values are in 1978 dollars.

Cost of Capital (k)

$$k = (1 - \tau) k_d \frac{D}{V} + k_c \frac{C}{V} = k_p \frac{P}{V}$$

Capital Recovery Factor (CRF_{k, N})

$$CRF_{k, N} = \frac{k}{1 - (1+k)^{-N}}$$

Annualized Fixed Charge Rate (FCR)

$$\overline{FCR} = CRF_{k, N} \left(\frac{1 - (\tau)(n \ CRF_{k, N})^{-1} - a}{1 - \tau} \right) + \beta_1 + \beta_2$$

Present Value of Capital Investment (Cl_{pv})

$$Cl_{pv} = (1+g_c)^{y_{co}-y_p} \sum_t Cl_t \left(\frac{1+g_c}{1+k} \right)^{y_t-y_{co}+1}$$

Present Value of Recurrent Costs (X_{pv})

$$X_{pv} = (1+g_x)^{y_{co}-y_p} (X_o) \left(\frac{1+g_x}{k-g_x} \right) \left[1 - \left(\frac{1+g_x}{1+k} \right)^N \right]$$

Annualized System - Resultant Cost (AC)

$$\overline{AC} = (1+g)^{y_{co}+y_b} \left[\overline{FCR} (Cl_{pv}) + (CRF_{k, N}) (X_{pv}) \right]$$

Levelized Bus Bar Energy Cost (BBEC)

$$\overline{BBEC} = \frac{AC}{MW_e h} = \frac{AC}{(MW_c)(PCF)(8760)}$$

3.0 ANALYTICAL RESULTS

This section details the analytical techniques and results used in the process of developing the LFS plant performance comparison to point focus plants.

3.1 Power Absorbed into Steam

The analysis begins by applying the collector field and receiver loss factors identified in Section 2 to the Barstow, California measured insolation data to determine the steam thermal power rate of the receiver. The plant rating was fixed at 100 MWe, but the collector field glass area was varied parametrically from a range of 0.75 to 2.0 million square meters. The significant power loss factors for both the collectors and the receiver were varied with the time of day.

Figure 7 a-e show the power absorbed into steam in the receiver for the 100 MWe point focus system after accounting for the aforementioned losses for the summer solstice (June 24), Equinox (March 21) and winter solstice (December 21) days. The shaded area in the curves of Figure 7 correspond to the unused solar insolation for sun elevations less than 15% above the horizon. Figure 8 a-e show the similar data for the line focus system using JPL performance representative data and Figure 9 a-e show the thermal power absorbed using performance data recommended by SRI.

Figure 10 shows the comparative absorbed power for the three concepts for equal glass area. The point focus power level is flatter due to its uniform efficiency throughout the day. The line focus system power levels peak around the noon characteristic high collector efficiency and high insolation point. This high peak power level will lead to higher TSS and Receiver ratings requirements for the HTLFS systems. On a full day basis June 21 the point focus system can produce 53% more thermal energy per glass area than the HTLFS and on December 21 the plant outputs are approximately the same.

3.2 Daily Electrical Output

Figures 11 a-e show the daily electrical power generating capability for the three conceptual plants, for each of the candidate field sizes, under the groundrules previously discussed. The HTLFS generates power

Figure 7a. Net Power Absorbed into Steam
Point Focus Plant of $0.75 \times 10^6 \text{ M}^2$ Collector Area
(Barstow Insolation Data)

Figure 7b. Net Power Absorbed into Steam
Point Focus Plant of $0.87 \times 10^6 \text{ M}^2$ Collector Area
(Barstow Insolation Data)

Figure 7c. Net Power Absorbed into Steam
Point Focus Plant of $1.0 \times 10^6 \text{ M}^2$ Collector Area
(Barstow Insolation Data)

Figure 7d. Net Absorbed Power into Steam
Point Focus Plant of $1.5 \times 10^6 \text{ M}^2$ Collector Area
(Barstow Insolation Data)

Figure 7e. Net Absorbed Power into Steam
Point Focus Plant of $2.0 \times 10^6 \text{ M}^2$ Collector Area
(Barstow Insolation Data)

.75/10⁶ m²

Figure 8a. Net Power Absorbed into Steam
Line Focus Plant of $0.75 \times 10^6 \text{ M}^2$ Collector Area
JPL Data Base
Barstow Insolation Data

82

Figure 8b. Net Power Absorbed into Steam
Line Focus Plant of $0.87 \times 10^6 \text{ M}^2$ Collector Area
JPL Data Base
Barstow Insolation Data

27

Figure 8c. Net Power Absorbed into Steam
Line Focus Plant of $1.0 \times 10^6 \text{ m}^2$ Collector Area
JPL Data Base
Barstow Insolation Data

2
2

Figure 8d. Net Power Absorbed into Steam
Line Focus Plant of $1.5 \times 10^6 \text{ m}^2$ Collector Area
JPL Data Base
Barstow Insolation Data

Figure 8e. Net Power Absorbed into Steam
Line Focus Plant of $2.0 \times 10^6 \text{ m}^2$ Collector Area
JPL Data Base
Barstow Insolation Data

Figure 9a. Net Absorbed Power into Steam
Line Focus Plant of $0.75 \times 10^6 \text{ M}^2$ Collector Area
SRI Data Base
Barstow Insolation Data

Figure 9b. Net Absorbed Power into Steam
Line Focus Plant of $0.87 \times 10^6 \text{ M}^2$ Collector Area
SRI Data Base
Barstow Insolation Data

Figure 9c. Net Absorbed Power into Steam
Line Focus Plant of $1.0 \times 10^6 \text{ M}^2$ Collector Area
SRI Data Base
Barstow Insolation Data

SRI 1.5

2

Figure 9d. Net Absorbed Power into Steam
Line Focus Plant of $1.5 \times 10^6 \text{ M}^2$ Collector Area
SRI Data Base
Barstow Insolation Data

SRI = 2.0

92

Figure 9e. Net Absorbed Power into Steam
Line Focus Plant of $2.0 \times 10^6 \text{ M}^2$ Collector Area

Figure 10. Thermal Power Available From Receiver
($0.87 \times 10^6 \text{ m}^2$ Collector Field Glass Area)

Figure 1la. Daily Electrical Energy Generation Capability
($0.75 \times 10^6 \text{ m}^2$ Collector Glass Area)

Figure 11b. Daily Electrical Energy Generation Capability
($0.87 \times 10^6 \text{ m}^2$ Collector Glass Area)

Figure 11c. Daily Electrical Energy Generation Capability
($1.0 \times 10^6 \text{ m}^2$ Collector Area)

Figure 11d. Daily Electrical Energy Generation Capability
($1.5 \times 10^6 \text{ m}^2$ Collector Glass Area)

2.0

11e

Figure 11e. Daily Electrical Energy Generation Capability
($2.0 \times 10^6 \text{ m}^2$ Collector Glass Area)

more uniformly throughout the year while the point focus power levels peak heavily in the summer months. The point focus plant generates more electrical energy per day even in the winter solstice period even though as noted previously the line focus plant generates more thermal power from the receiver. This results because a larger percentage of the LFS thermal energy is directed to the turbine via thermal storage and this causes a lower overall thermal to electrical conversion efficiency than for LFS plants.

3.3 Annual Energy Delivered

Figure 12 shows the annual energy delivered to the grid, and the plant capacity factor as a function of collector glass area. The plant capacity factor is defined as the ratio of annual energy output to the rated power (100 MWe) multiplied by the 8760 hours of the year.

3.4 HTLFS Operating Costs

The LFS operating costs as a function of collector field/receiver/tower specific costs are shown in Figure 13 for three values of capacity factor. The data indicates that the LFS operating costs are relatively insensitive to capacity factor, or TSS size. This phenomenon is the result of the low specific cost of thermal storage used in the study. As capacity factor increases the collector field contribution to the cost of electricity remains relatively constant since it generates approximately constant kilowatts thermal per glass area. The plant EPGS size, however, remains constant at 100 MWe and therefore as it's used more with greater capacity factors, its contribution to the cost of electricity drops. If the TSS Specific Cost is low, its contribution to the cost of electricity as more TSS capacity is used increase in approximate inverse proportion to the EPGS cost and the total cost remains relatively constant until higher capacities are reached.

This result was further investigated by varying the TSS specific cost (\$/kwt-hr). See Figure 14. At higher than the baseline TSS capital cost, the TSS cost contribution to total cost increases more rapidly and the system optimum cost is biased towards less storage.

3.5 HTLFS Cost Sensitivity

The HTLFS operating cost as a function of collector/receiver/tower specific cost and overall conversion efficiency is shown in Figure 15. All the cost data noted is based on 80th plant learning curves. The overall

Figure 12. Comparison of Energy Generation Capability

Figure 13. LFS Operating Costs as a Function of Operating Cost and Collector/Receiver/Tower Specific Costs

Figure 14. Sensitivity of Plant Operating Costs to TSS Specific Costs
Collector/Receiver/Tower Capital Cost of \$100/m²

Figure 15. LFS Cost and Efficiency Sensitivity
(0.4 Capacity Factor)
(80th Plant)

conversion efficiency is defined as the ratio of annual energy generated to the annual insolation energy falling on the collector glass area. The lowest efficiency curve is representative of JPL data. The middle curve is representative of SRI data, and the higher efficiency curve is the SRI data which has been modified to include a higher efficiency reheat power conversion cycle.

The first generation point focus data yields an operating cost of 83 mills/kw-hr using a collector/receiver/tower specific cost of $\$85/\text{m}^2$, of which $\$56/\text{m}^2$ represents the collector system. For the HTLFS to be competitive its specific cost must be $\$~~70~~⁶⁸/\text{m}^2$ based on JPL data, and $\$~~76~~⁸⁰/\text{m}^2$ based on SRI data. Improving system efficiency to 12.2% would make LFS competitive at even $\$~~70~~⁹²/\text{m}^2$. These numbers are representative of 80th plant costs and their associated learning curves. If the cost goals are extrapolated back to the first plant, the cost goals are $\$101/\text{m}^2$ for the JPL data based plant and $\$110/\text{m}^2$ for the SRI data based plant.

4.0 CONCLUSIONS

Based on this preliminary analysis, the following conclusions can be reached on the LFS system economic viability in comparison to the first generation point focus power plant.

- o LFS can be cost competitive with PFS when collector/tower/receiver specific costs are below \$~~12~~¹⁸/m² based on 80th plant learning curves **JPL DATA; 180 M² BASED ON SRI DATA.**
- o LFS of same capacity can operate approximately 5 hours directly from solar insolation as compared to 7 to 10 hours for PFS.
- o LFS are strongly dependent on TSS operation to improve plant capacity factor.
- o TSS cost must be low in order for LFS to be cost competitive.
- o LFS receiver and TSS charging equipment ratings must be larger than those of PFS.
- o LFS operating costs are twice as sensitive to annual efficiency than to capital costs.
- o The shorter direct solar operation time for HTLFS will probably lead to severe startup requirements.

These conclusions are strongly dependent of the assumptions used in this study. Most basic of these assumptions are the assumptions of the proportionality of the O&M and indirect costs to capital costs. The LFS currently underway will serve to verify these and other assumptions used in this study.

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