SERI/SP-253-1790

SERI

RECOMMENDED SUBELEMENT COST GOALS FOR ADVANCED GENERATION HELIOSTATS

October 1982

L. M. Murphy

file 3-1

OBJECTIVE

RECOMMEND COST GOALS FOR THE NEXT GENERATION OF ADVANCED HELIOSTATS AT THE SUBELEMENT LEVEL, CONSISTANT WITH THE RECENTLY COMPLETED DOE VALUE BASED COST GOAL ANALYSIS. THE GOAL BASED ON THIS ANALYSIS* WHICH IS CONSISTENT WITH MAKING SOLAR THERMAL SYSTEMS COMPETITIVE WITH A WIDE RANGE OF FUELS, AND IN MANY REGIONS OF THE COUNTRY IS $\$50\text{-}60/m^2$ AND A DELIVERED ENERGY COST OF $5-6/GJ.

---

*SEE NOTE 1

APPROACH

- o COMPARE FIRST AND SECOND GENERATION HELIOSTAT COST BREAKDOWNS TO ESTABLISH RELATIVE IMPORTANCE AND COST IMPACT OF CURRENT SUB-COMPONENT ELEMENTS.

- o ESTABLISH FEASIBILITY AND POTENTIAL OF REDUCING SUBELEMENT COSTS BASED ON CURRENT STUDIES AND RESEARCH DIRECTIONS. PROVIDE ESTIMATES OF COSTS ASSOCIATED WITH NEW INNOVATIONS WHERE POSSIBLE TO SUPPORT POTENTIAL PROJECTIONS AND FEASIBILITY.

- o RECOMMEND THE REQUIRED RESEARCH TO ATTAIN THE SUBELEMENT COST GOALS.

Heliostat Subelement Cost Breakdown,* $/m² (1982 $)

Component	Barstow First Generation		Second** Generation		Recommended Third Generation Cost Goals	
	$/m²	Fraction of Total Cost	$/m²	Fraction of Total Cost	$/m²	Fraction of Total Cost
Reflector Assembly	72.4	.364 } .462	39.6	.314 } .432	25***	.463
Support Structure	19.5	.098 }	14.9	.118 }	--	--
Drive Assembly	58.6	.295	36.2	.286	12	.222
Controls	27.6	.139	17.2	.136	9	.167
Foundation/Pedestal	20.7	.104	18.4	.146	8	.148
Total Installation Price	198.8	1.00	126.4	1.00	54.0	1.00

*Based on first year production estimates of 50,000 heliostats per year, first and second generation numbers taken from Ref. [1]. Values given in reference [1] are in 1980 $; a factor of 1.149 is used to shift these values to 1982 $.

**Second generation numbers represent an average of the two lowest cost designs; in 1980 $ the Martin Marietta concept (@$109/m²) and the McDonnel Douglas design (@$111/m²).

***Includes support structure.

REFLECTOR MODULES AND SUPPORT STRUCTURES

RECOMMENDATION: REDUCE CURRENT COSTS FOR REFLECTOR MODULES ($39.6/m^2$) AND SUPPORT STRUCTURES ($14.90/m^2$) TO $25/m^2$ FOR THE COMBINED MODULE AND SUPPORT STRUCTURE.

BACKGROUND AND RATIONALE: A NUMBER OF INNOVATIVE APPROACHES AND REFINEMENTS TO CURRENT TECHNOLOGY APPEAR TO PROVIDE SIGNIFICANT OPPORTUNITIES TO REDUCE REFLECTOR MODULE AND SUPPORT STRUCTURE COSTS.

ALTHOUGH LIMITED EFFORT ON INNOVATIVE CONCEPTS HAS BEEN EXTENDED TO DATE, A NUMBER OF APPROACHES HAVE BEEN IDENTIFIED WITH SIGNIFICANT POTENTIAL. AS A SPECIFIC EXAMPLE, STRETCHED MEMBRANE CONCEPTS UNDER DEVELOPMENT AT SERI [2] INDICATE A POTENTIAL WEIGHT SAVINGS FACTOR OF MORE THAN TWO FOR THE COMBINED REFLECTOR MODULE AND SUPPORT STRUCTURE AND THE RESULTING COST IS ESTIMATED TO BE LESS THAN $20/m^2$ IN MASS PRODUCTION FOR THE COMBINATION.* OTHER COST REDUCING INNOVATIONS INCLUDE POLYMER MIRRORS, AND INTEGRATED REFLECTIVE MODULES WHERE A GLASS REFLECTIVE SURFACE IS EMPLOYED. POLYMER MIRRORS OBVIATE THE NEED FOR STIFFNESS AIMED AT PROTECTING GLASS SURFACES, THUS ALLOWING THE USE OF LIGHTER WEIGHT, MOVE COMPLIANT SUPPORT STRUCTURES. INTEGRATED REFLECTIVE MODULES, WHERE GLASS IS EMPLOYED AND IS ALSO USED AS AN INTEGRAL STRUCTURAL ELEMENT IN THE STACK HAS POTENTIAL OF REDUCING MODULE WEIGHT AND COST WHILE STILL LIMITING PEAK STRESS IN THE GLASS BY PROPER DESIGN [9]. REFLECTIVE MODULE STACKS MIGHT BE REDUCED IN WEIGHT BY MORE THAN A FACTOR OF THREE WITH THIS APPROACH.

CURRENT HELIOSTAT CONCEPTS MIGHT BE IMPROVED BY FURTHER REFINEMENTS IN BOTH DESIGN APPROACHES AND IN THE SPECIFICATION AND PERFORMANCE REQUIREMENTS IMPOSED ON THE DESIGNS. FOR INSTANCE, RECENT CONTRACTOR STUDIES [3,4] HAVE SHOWN THAT STRUCTURAL FLEXIBILITY CAN BE INCREASED SIGNIFICANTLY WITH VERY LITTLE LOSS IN DELIVERED ENERGY. IN ONE EXAMPLE STRUCTURAL [3] FLEXIBILITY WAS INCREASED BY A FACTOR OF TWO ACCOMPANIED BY AN ENERGY SPILLAGE OF LESS THAN ONE HALF OF ONE PERCENT. ALSO THESE SAME STUDIES [3,4] INDICATE A POTENTIAL

---

*TO PUT THIS IN PERSPECTIVE THE GENERAL ELECTRIC CO. HAS ESTIMATED THAT THEIR PROPOSED REFLECTOR AND SUBSTRUCTURE IN THEIR POLYMER ENCLOSURED CONCEPT WOULD COST LESS THAN $10/m^2$ IN MASS PRODUCTION.

SAVINGS BY DESIGNING FOR SURVIVAL RATHER THAN POINTING ACCURACY. THIS APPROACH HAS NOT YET BEEN FULLY EXPLOITED. THE ENERGY SPILLAGE RESULTS ARE CONSISTENT WITH A CURSORY SERI STUDY [6] ON ENERGY SPILLAGE DUE TO WIND LOADING.

DRIVE ASSEMBLY

Recommendation: Establish a goal of reducing costs for the drive assembly from \$36.2/m^2 to \$12/m^2.

Background and Rationale: Again, number of new concepts and refinements to existing designs appear to provide significant potential to reduce costs.

In terms of new design approaches, hydraulic rotary activators may provide a cost effective substitute for the current motor/gear drive systems. Preliminary analysis of such approaches based on currently available hardware and their specifications indicate a potential drive system cost of \$10/m^2 [7].* Other new approaches, such as rim drive concepts may also provide significant cost reduction opportunities; though only limited development of alternative approaches has been pursued. However, analysis and testing of one related rim drive concept applied to line focus troughs demonstrated significant cost/performance improvement potential [8].

Modifications to existing approaches leading to enhanced cost performance of drives, and which appear to have potential include: the reduction of operational wind drive requirements through wind reduction schemes; stowing at lower cut off wind levels; unloading the drive in stowage and survival conditions, and allowing more flexibility in stowage procedures.

---

*ARCO is currently looking at this approach.

CONTROL COSTS

RECOMMENDATION: REDUCE CURRENT ESTIMATED COSTS FOR CONTROLS FROM $17.2/M^2 TO $9/M^2.

BACKGROUND AND RATIONALE: RECENT WORK BY TWO SUMMER VISITING PROFESSORS AT SERI [11] INDICATES A SIGNIFICANT POTENTIAL TO REDUCE CONTROL COSTS BY EMPLOYING RF FIELD CONTROL COUPLED WITH STATE-OF-THE-ART PAGING CIRCUITRY, MICROCIRCUITS AND MICROCOMPUTERS AT EACH HELIOSTAT. THEIR EVALUATION OF SIX APPROACHES AND COST ESTIMATES INDICATE A POTENTIAL OF ROUGHLY $9/M^2 FOR RF CONTROL BY ELIMINATING CABLING AND ENHANCING THE CAPABILITIES OF THE CENTRAL COMPUTER (BY DOING A SIGNIFICANT AMOUNT OF COMPUTING AT THE HELIOSTAT). A GREAT DEAL OF THE POTENTIAL APPEARS TO RESULT FROM THE DRAMATIC REDUCTION OF MICROPROCESSOR AND MICROCOMPUTER COSTS IN THE LAST DECADE.

FOUNDATION AND PEDASTAL

RECOMMENDATION: REDUCE FOUNDATION AND PEDASTAL COSTS FROM $18.4/$m^2$ TO $8/$m^2$.

BACKGROUND AND RATIONALE: CURRENT STUDIES ON OPTIMIZED SECOND GENERATION CONCEPTS BY MCDONNEL DOUGLAS [4] SHOW ESTIMATED COSTS FOR THE FOUNDATION AND PEDASTAL WHICH ARE LESS THAN $9/$m^2$ (CORRESPONDING TO THEIR 95 m^2, INCREASED AREA DESIGN). ALSO, IT IS INTERESTING TO NOTE THAT OPTIMIZED FOUNDATION COSTS FOR TROUGHS HAVE BEEN SHOWN TO BE ABOUT $8.00/$m^2$ OF APERTURE [13], AND THAT ONE MIGHT EXPECT SINGLE PEDASTAL COSTS (ON A PER APERTURE AREA BASIS) TO BE SOMEWHAT LESS. FURTHER, DETAILED STUDIES OF DRILLED PIER CONCEPTS FOR HELIOSTATS [12] SHOW SIGNIFICANT OPPORTUNITY FOR REDUCED VOLUME AND PIER DEPTH (AND HENCE REDUCED COSTS) CORRESPONDING TO GOOD SOIL CONDITIONS, AND/OR REDUCED LOADING CONDITIONS; THEREFORE, OPPORTUNITIES FOR REDUCED WIND LOADING IF EXPOITED WILL ASSIST IN REDUCING FOUNDATION AND PEDASTAL COSTS BELOW THAT PREDICTED FOR OPTIMIZED SECOND GENERATION CONCEPTS.

TABLE I. SYSTEM AND ECONOMIC PARAMETERS (1982)*

PLANT DESCRIPTION; 30 MW_{TH} - IPH
PLANT LIFE; 20 YR.
FINANCING; 100% EQUITY
DISCOUNT RATE; 10% (REAL)
TAX CREDIT; 10% INVESTMENT
LAND COST; $3000/ACRE.
O&M AND INSURANCE; 4%.
HELIOSTAT ENERGY DELIVERY PERFORMANCE; 5.57 GJ/M^2-YR.
BALANCE OF PLANT COSTS; $35/$M^2$ + $48000.

*THE DELIVERED ENERGY COST BASED ON AN ANNUAL REQUIRED REVENUE APPROACH IS USED.

FIGURE 1. CAPITAL COST ALLOCATIONS AMONG SUBELEMENTS FOR FIRST, SECOND, AND RECOMMENDED THIRD GENERATION HELIOSTAT COLLECTOR CONCEPTS (INSTALLED).

FIGURE 2. DELIVERED ENERGY COST VS. INSTALLED COLLECTOR COST CORRESPONDING TO SECOND GENERATION HELIOSTAT PERFORMANCE, SHOWING COST ALLOCATIONS FOR MAJOR SYSTEM COMPONENTS (SEE SYSTEM/ECONOMIC ASSUMPTIONS IN TABLE 1).

FIGURE 3. DELIVERED ENERGY COST ALLOCATED TO THE COLLECTOR ONLY VS. INSTALLED COLLECTOR COST CORRESPONDING TO SECOND GENERATION HELIOSTAT PERFORMANCE, SHOWING COST ALLOCATION AMONG COLLECTOR SUBELEMENTS (SEE SYSTEM/ECONOMIC ASSUMPTIONS IN TABLE 1).

FIGURE 4. THE SENSITIVITY OF PERCENT OF DELIVERED ENERGY COST ALLOCATED TO COLLECTORS ONLY TO CHANGES IN COLLECTOR COST ONLY.

FIGURE 5. PERFORMANCE/COST BREAKEVEN RELATIONSHIP SHOWING THE ALLOWABLE DECREASE IN ANNUAL ENERGY PRODUCTION (PER UNIT AREA OF HELIOSTAT CORRESPONDING TO A $1.00 DECREASE IN COLLECTOR COST/PER UNIT AREA OF HELIOSTAT). AS AN EXAMPLE CONSIDER A COLLECTOR COST OF 100/M^2 AND ASSUME THAT THE DELIVERED ENERGY COST REMAINS CONSTANT AT $8.5/GJ (FIGURE 2); THEN A DECREASE IN COLLECTOR COST OF $1/$M^2$ WOULD BE EXACTLY OFFSET BY A DECREASE IN ANNUAL ENERGY DELIVERED OF AMOUNT 0.043 GJ/M^2. THUS IF THE ENERGY DECREASE CAN BE HELD BELOW 0.043 GJ/M^2, THEN THERE WILL BE A NET DROP IN THE DELIVERED ENERGY COST.

Figure 1
(1982 $)

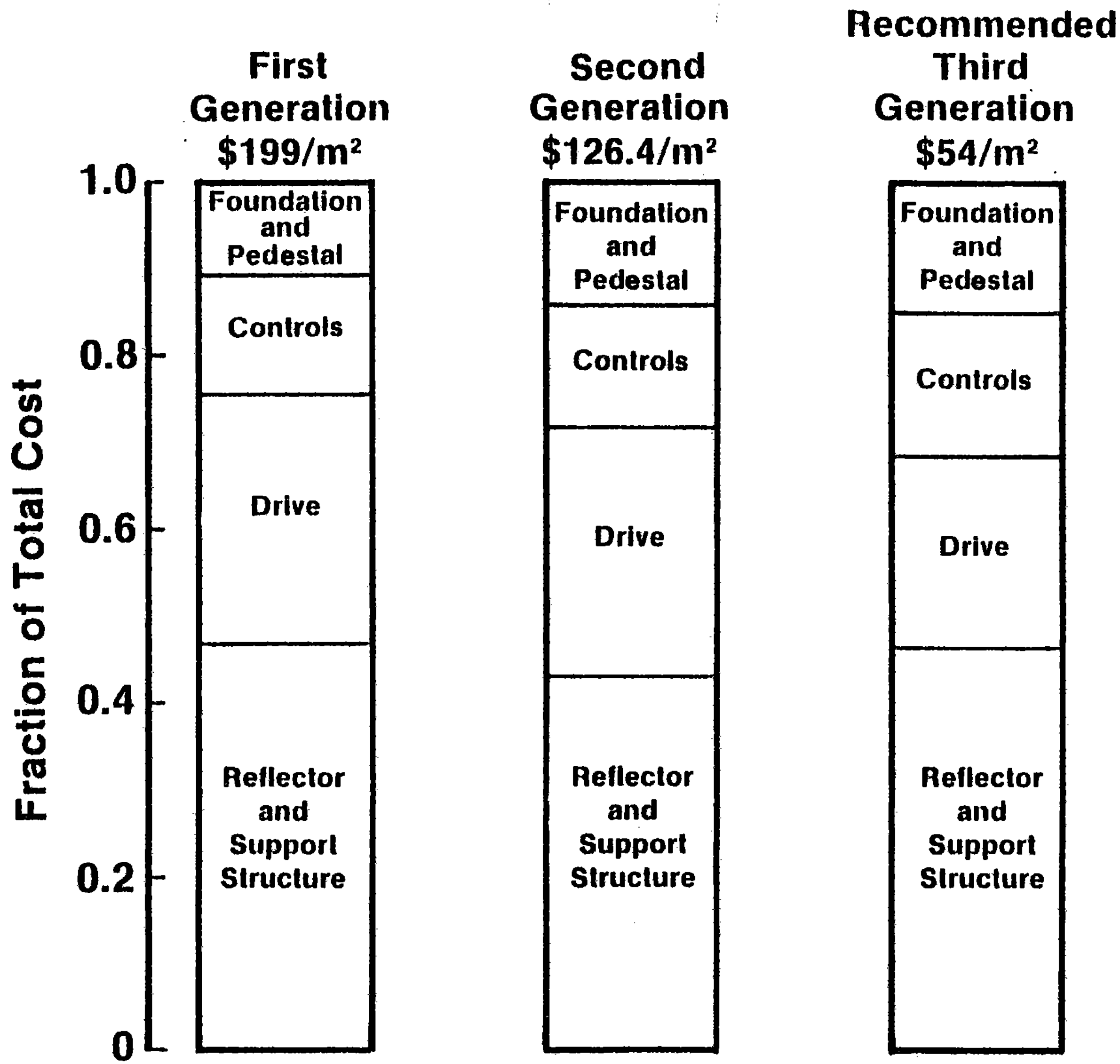


Figure 2.
Second Generation Performances
(1982 $)

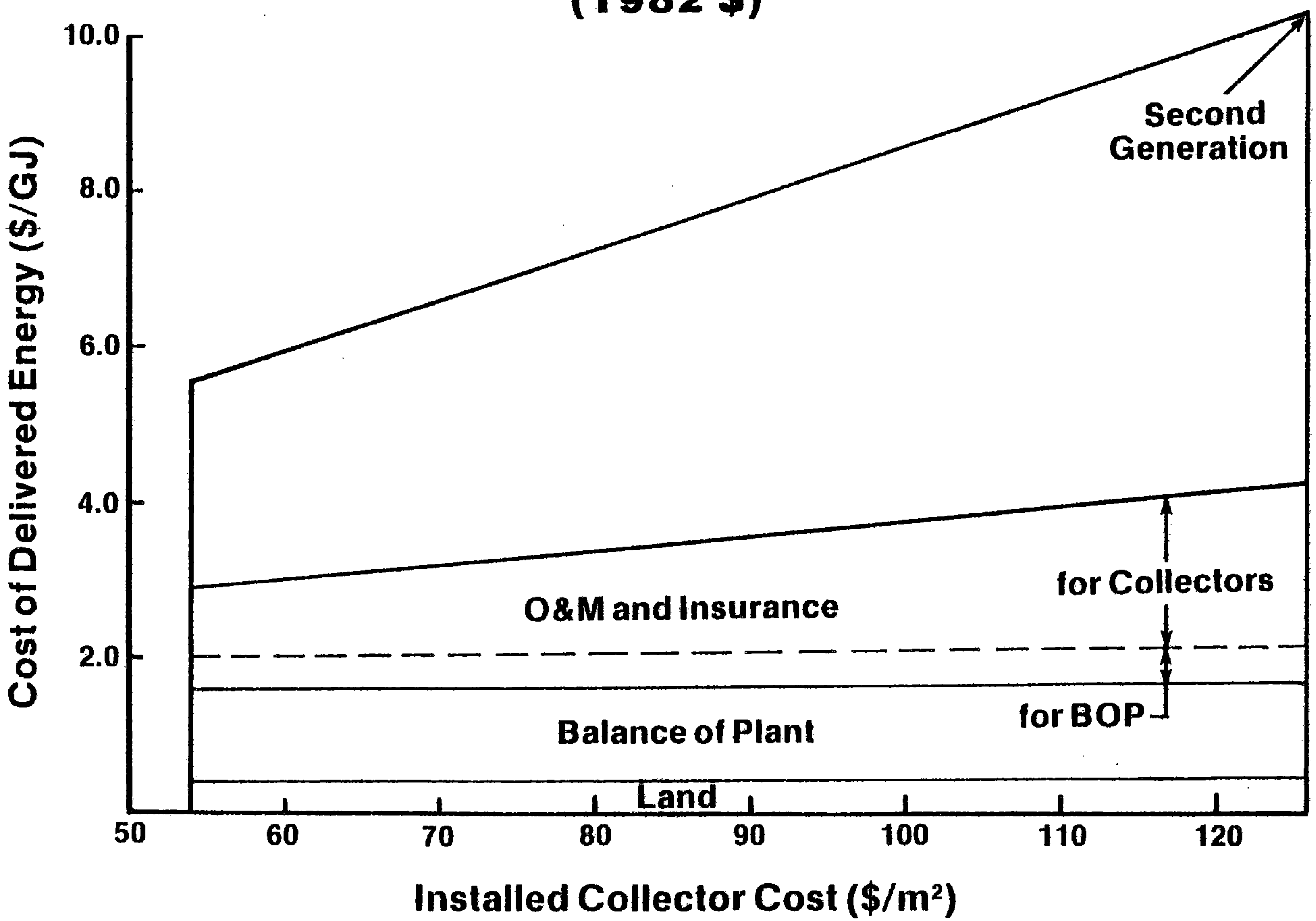


Figure 3.
Second Generation Performance
(1982 $)

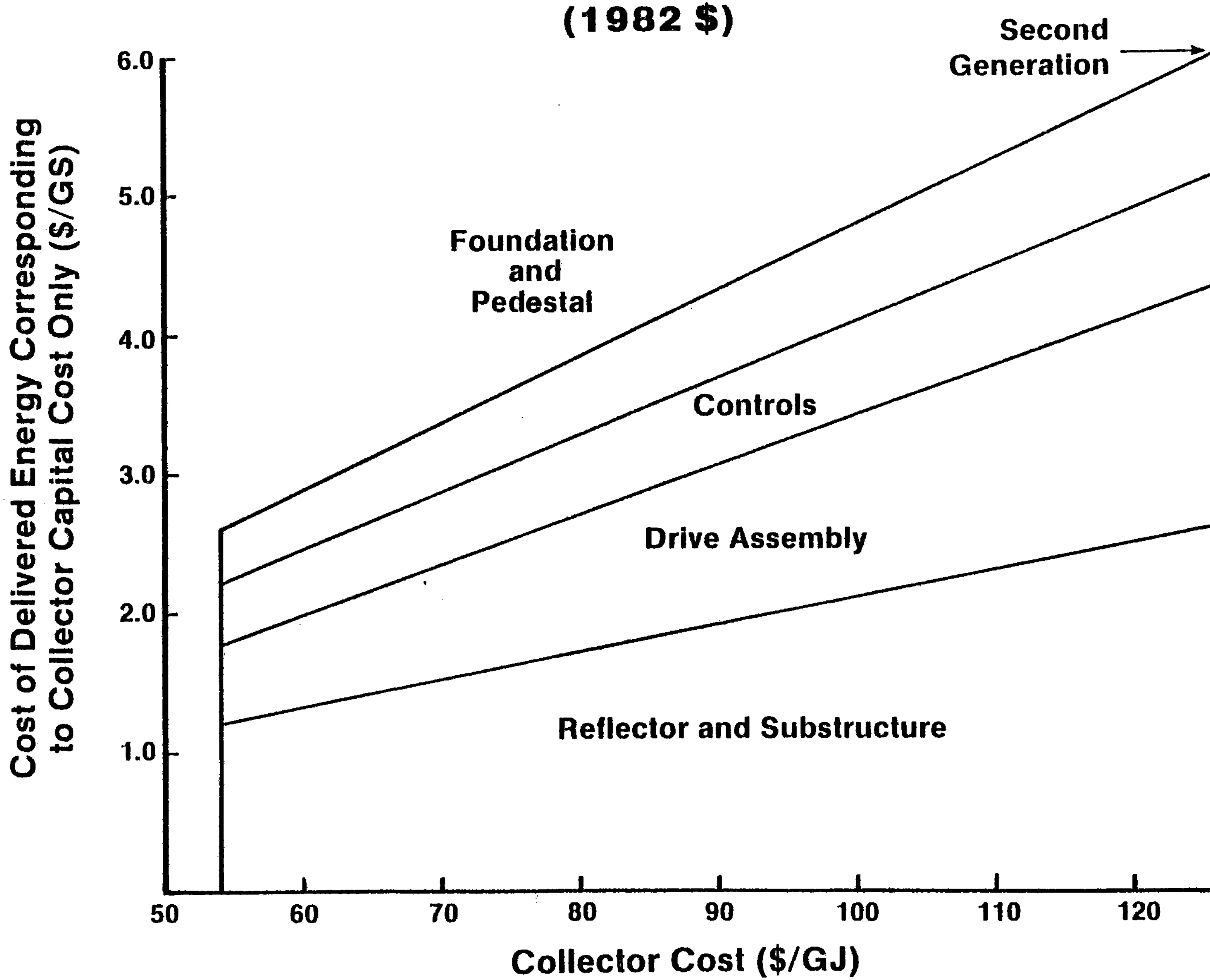


Figure 4.
Second Generation Performance
(1982 $)

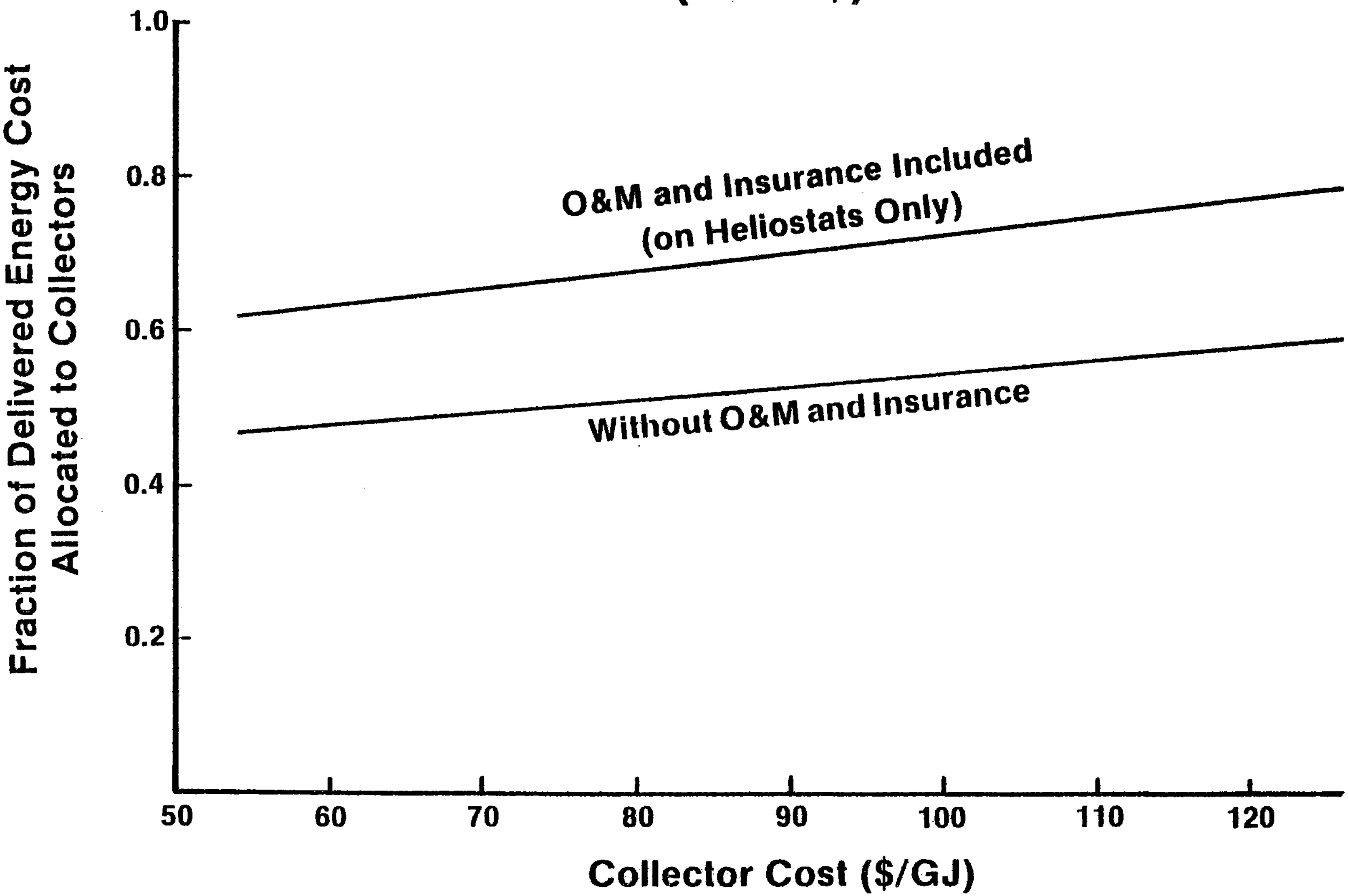
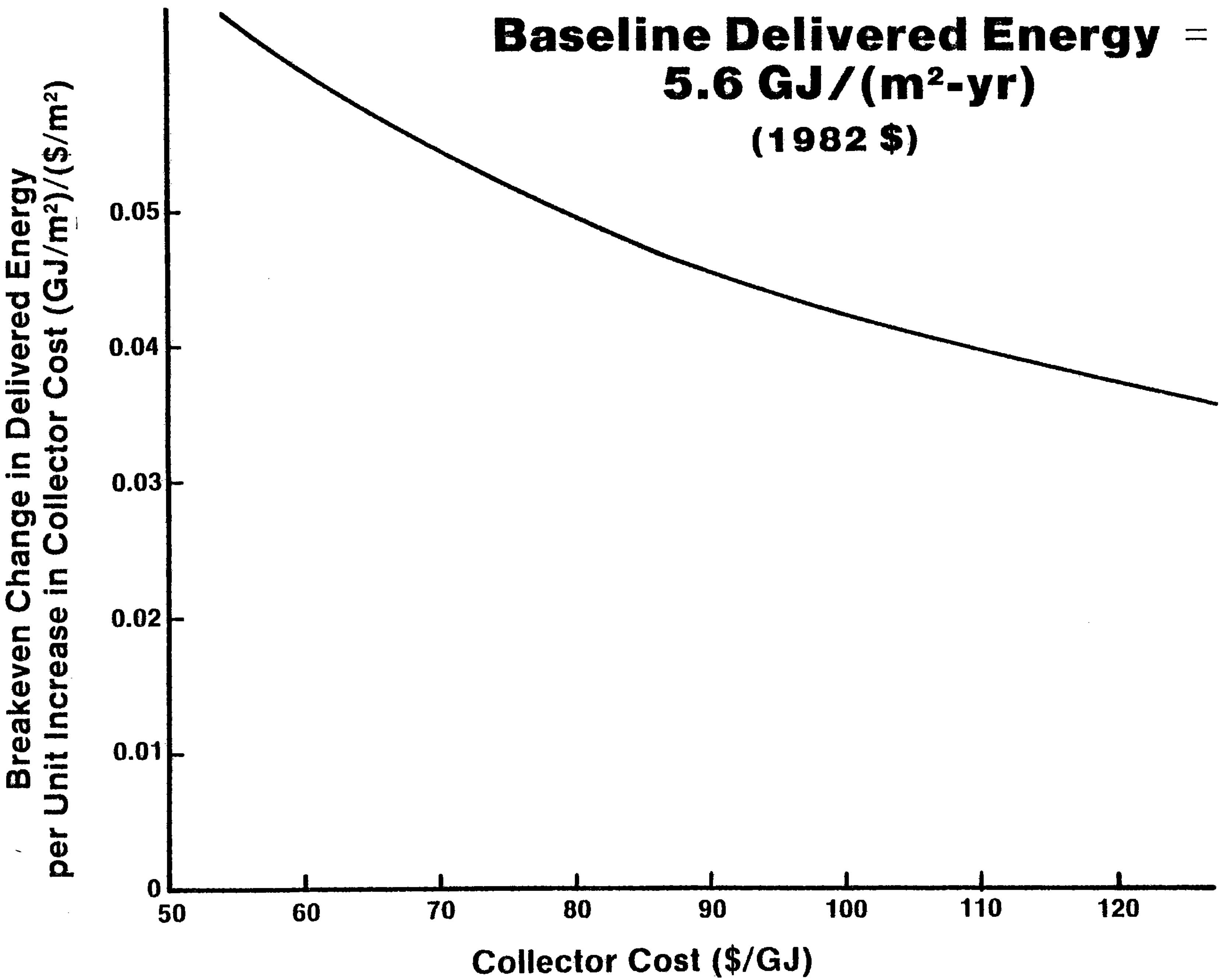


Figure 5.

Baseline Delivered Energy = 5.6 GJ/(m^2-yr)

(1982 $)



RECOMMENDATIONS

- o REASSESS DESIGN REQUIREMENTS AND SPECIFICATIONS FOR HELIOSTATS ACROSS THE BOARD. SPECIAL ATTENTION SHOULD BE PAID TO WIND LOADING FOR BOTH SURVIVAL AND OPERATING CONDITIONS ESPECIALLY AS IT RELATES TO THE DRIVE, REFLECTIVE MODULE AND SUPPORT STRUCTURE DESIGN. NEW REQUIREMENTS AND SPECIFICATIONS SHOULD BE EVOLVED IN CONCERT WITH THE ITEMS BELOW. IN GENERAL INNOVATORS SHOULD BE GIVEN MAXIMUM FLEXIBILITY IN PERTURBING REQUIREMENTS AND SPECIFICATIONS TO ARRIVE AT A MINIMUM COST OF DELIVERED ENERGY.

- o DEVELOP INNOVATIVE CONCEPTS WHICH ARE ADAPTIVE RATHER THAN RESISTIVE TO ENVIRONMENTAL LOADS, SPECIFICALLY EXPLORE THE POTENTIAL OF LIGHTWEIGHT COMPLIANT STRUCTURES WITH GOOD HIGH WIND SURVIVAL CAPABILITIES TO HELP ESTABLISH NEW REQUIREMENTS AND GOALS.

- o DEVELOP A HIGHLY REFLECTIVE POLYMER MIRROR FOR USE WITH EITHER ENCLOSED OR UNENCLOSED CONCENTRATOR CONCEPTS.

- o EXPLORE THE POTENTIAL OF "INTEGRATED" REFLECTOR/SUPPORT STRUCTURES WHEN USING GLASS CONCEPTS TO MAKE OPTIMAL USE OF MATERIAL (I.E., CONCEPTS WHICH USE THE GLASS LAYERS AS AN INTEGRAL STRUCTURAL ELEMENT IN THE REFLECTIVE STACK AND SUPPORT PROCEDURE.

- Perform research on wind loading reduction schemes to allow the application less robust structure and support conclusions on potential cost savings through probabilistic failure analysis.

- Focus on lower temperature IPH applications first to take advantage of the less sensitive optical accuracy requirements. This will allow experience in developing lower cost concepts first, and then improving the low cost baseline concepts in terms of performance.

- Perform the joint university/laborabory control experiments recommended by Chen and Pearson to verify the adequacy of their proposed approach.

- Design and test a hydraulic rotary actuator drive system to determine its accuracy and assess the potential leakage problem.

- Research on balance of plant, and system reliability (to reduce O&M costs) is also warranted since these two elements in this analysis total roughly 46% of the delivered energy cost at a collector cost of $\$54/m^2$. Further, the assured balance of plant costs may turn out to be optimistic and further cost reductions may be needed to offset unanticipated losses in anticipated performance levels.

CONCLUSIONS

- o CORRESPONDING TO EACH OF THE COLLECTOR SUB-ELEMENTS, THERE APPEAR TO BE A NUMBER OF COST REDUCING OPPORTUNITIES YET TO BE EXPLOITED. SIGNIFICANT RATIONALE EXISTS TO SUPPORT THE REDUCTION OF CURRENT COLLECTOR COSTS FROM $\$126/M^2$ TO THE RECOMMENDED $\$54/M^2$. HOWEVER THE TRUE VALUE OF SPECIFIC COST IMPROVEMENTS MUST ALSO REFLECT CHANGES IN PERFORMANCE (ON DELIVERED ENERGY COSTS); THE IMPACT ON PERFORMANCE OF VARIOUS IMPROVEMENTS CAN BE ACCURATELY ASSESSED ONLY THROUGH TESTING IN CONCERT WITH ANALYSIS.

- o INNOVATIVE CONCEPTS ARE RELATIVELY UNEXPLORED (EXCEPT FOR POLYMER ENCLOSED HELIOSTATS).

- o AT THE SUB-COMPONENT LEVEL, THE RECOMMENDED COST REDUCTIONS RESULT IN NET COST DISTRIBUTIONS AMONG THE ELEMENTS WHICH ARE FAIRLY SIMILAR WITH THOSE CORRESPONDING TO THE FIRST AND SECOND GENERATION COLLECTORS. THE ONLY SIGNIFICANT DISTRIBUTION CHANGE WHICH OCCURS AS A RESULT OF THE RECOMMENDATIONS IS WITH THE DRIVE SUBSYSTEM. THE FRACTION OF THE INSTALLED COLLECTOR COST CORRESPONDING TO THE DRIVE SUBSYSTEM IS .30, .29, AND 0.22 FOR THE FIRST, SECOND, AND RECOMMENDED THIRD GENERATION CONCEPTS RESPECTIVELY.

- o SPECIFICATIONS AND REQUIREMENTS SHOULD BE SUFFICIENTLY FLEXIBLE SO AS TO PERMIT INNOVATORS TO DEFINE THE APPROPRIATE EMPHASIS ON COST AND PERFORMANCE WHICH WILL RESULT IN OPTIMAL COST/PERFORMANCE FOR THEIR RESPECTIVE SYSTEM.

- o TO BRING THE COST OF DELIVERED ENERGY BY A SOLAR THERMAL CONTROL RECEIVER SYSTEM BELOW \$6.00/GJ, RESEARCH ON COST REDUCTIONS CORRESPONDING TO THE SYSTEM BALANCE OF PLANT AND SYSTEM RELIABILITY WILL BE REQUIRED EVEN IF THE COSTS OF HELIOSTATS IS REDUCED TO $\$54/M^2$.

NOTE 1

o A RECENT DOE STUDY [15,16] ARRIVED AT ESTABLISHING VALUE BASED COST GOALS FOR SOLAR THERMAL SYSTEMS AND COLLECTORS SHOWED THAT AT SYSTEM COSTS BELOW $172/M^2 (1982$) THE POTENTIAL EXISTS FOR SUBSTANTIAL PENETRATION IN THE IPH AND ELECTRIC GENERATION MARKETS. FURTHER FOR SYSTEM COSTS BELOW $115/M^2 (1982$), WHICH CORRESPONDS TO A DELIVERED ENERGY COST OF $5.5/GJ (1982$), SOLAR THERMAL SYSTEMS CAN BE COMPETITIVE WITH A WIDE RANGE OF FUELS IN MANY REGIONS OF THE COUNTRY IN THE 1990-2000 TIME FRAME. MOREOVER, COLLECTOR COSTS HAVE BEEN SHOWN TO REPRESENT ROUGHLY 50% OF MATURE SOLAR THERMAL SYSTEMS COSTS [17]. HENCE COLLECTOR COSTS ON THE ORDER OF $50-60/M^2 ARE NEEDED TO MAKE SOLAR THERMAL SYSTEMS COMPETITIVE, WITH A WIDE RANGE OF FUELS, AND IN MANY REGIONS OF THE COUNTRY. (THIS ASSUMES PERFORMANCE LEVELS OF THE SECOND GENERATION, GLASS METAL HELIOSTATS).

REFERENCES

[1] (Jan. 1982). Second Generation Heliostat Evaluation-Summary Report, SAND 81-8034, Heliostat Development Division, Sandia National Labs, Livermore, CA.

[2] Vineyard, Conrad (Dec. 1981). "SERI Internal Costing Analysis", Solar Energy Research Institute, Golden, CO.

[3] Martin Marietta Corporation, (May 1982). Second Generation Heliostat Optimization Studies, Contractor Report, (MER-82-1700), Sandia Report #SAND 82-8275, prepared for Sandia National Laboratories, Livermore, CA.

[4] McDonnel Douglas Astronautics Co. (May 1982), Optimization of the Second Generation Heliostat and Specification, Contractor Report (MDC 9762, Sandia Report #SAND 82-8181). Prepared for Sandia National Laboratories, Livermore, CA.

[5] Polymer Reflectors.

[6] Murphy, et al. (Jan. 25, 1982). "A Simple Example of Energy Spillage Due to Wind", SERI Internal Memorandum, Solar Energy Research Institute, Golden, CO.

[7] Gee, R. (Aug. 1982). "Low Cost Hydraulic Drive Systems for Heliostats". SERI Internal Memorandum, Solar Energy Research Institute, Golden, CO.

[8] Murphy, L.M. and Gee, R. (June 1982). "Light-Weight Rim Driven Trough" (Briefing Package); Solar Energy Research Institute, Golden, CO.

[9] Murphy, L.M. (March 1981). "Optimum Weight Substructures for Troughs", Internal SERI Memorandum, Solar Energy Research Institute, Golden, CO.

[10] Murphy, L.M. (Feb. 1981). An Assessment of Existing Studies of Wind Loading on Solar Collectors, SERI/TR-632-812, Solar Energy Research Institute, Golden, CO.

[11] Chen, B. and Pearson, J. (Aug. 1982). "Heliostat Control System: 3rd Generation Potential", Internal SERI Memorandum; Solar Energy Research Institute, Golden, CO. (Technical Report in Preparation).

[12] (Jan. 1982). Laterally Loaded Drilled Pier Research. EPRI EL-2197; Vols. 1 and 2; Report Prepared by GAI Consultants. Electric Power Research Institute, Palo Alto, CA.

[13] Auld, H.E. and Lodde, P.F. (Jan. 1979). Study of Low-Cost Foundation/Anchor Designs for Single-Axis Tracking Solar Collector Systems. SAND 78-7048, Sandia National Laboratories, Albuquerque, NM.

[14] (Oct. 1978). Solar Central Receiver Prototype Heliostat, Phase I, Final Technical Report. SAN-1468-1. Schenectady, NY: The General Electric Co.

[15] Edelstein, R; et al. Feb. 1982. Final Presentation of the Solar Thermal Cost Goals Committee. Presented to U.S. Dept. of Energy, Washington, D.C., February 16, 1982.

[16] Edelstein, R. B. Aug. 1981. "Value-Based Costs for Advanced Solar Thermal Systems." Review of Polymer Requirements for Solar Thermal Energy Systems. Proceedings of a workshop sponsored by DOE and SERI. Alexandria, VA. SERI/CP-251-1419. Golden, CO: Solar Energy Research Institute. 75-110.

[17] Thornton, J. June 1981. Comparative Evaluation of Solar Systems for Thermal for Thermal Applications. Draft Report. Golden, CO: Solar Energy Research Institute.