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December 1979

Heliostat Production Evaluation and Cost Analysis

Executive Summary

Prepared by
General Motors Corporation
Warren, Michigan

MASTER

SERI

Solar Energy Research Institute

A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

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HELIOSTAT PRODUCTION EVALUATION
AND COST ANALYSIS

EXECUTIVE SUMMARY

DECEMBER 1979

GM TRANSPORTATION SYSTEMS CENTER
GENERAL MOTORS CORPORATION
GENERAL MOTORS TECHNICAL CENTER
WARREN, MICHIGAN

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FOR THE
Solar Energy Research Institute

A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

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U.S. Department of Energy
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FOREWORD

This report was prepared under subcontract AH-9-8052-1 as a part of SERI Task 5121.11, the Supply Task of the Repowering Strategy Analysis. The purpose of the Supply Task is to determine the installed cost of solar systems and components in a repowering program and outline the manufacturing investment required to achieve those costs.

The central problem facing solar energy technologies is the cost of supplying the equipment needed to collect the diffuse solar flux. Since solar thermal collectors resemble certain low cost mass produced durable goods, many claims have been made for assumed benefits of mass production for the reduction of the cost of solar thermal hardware. The objective of this cost study was to quantify the benefits of mass producing the current generation of heliostats.

The methodology used to determine the cost was a detailed production cost analysis. Processes were developed for the manufacture of each component of the heliostat. The tooling, labor, and facilities requirements were defined and costed for each of the processes, and vendor quotations were obtained to determine the cost of purchased material. Finally, indirect factory expenses were added to the direct costs to produce the factory cost.

This type of study is expensive because the level of detail needed to assure the accuracy of the cost estimates requires extensive design information and manufacturing detail. Consequently, this type of study is not appropriate for every design, but it is particularly suitable for the SERI repowering study, since the production suitability and cost of current heliostat technology are critical parameters in determining the value of repowering for advancing the commercial prospects of central receiver systems.

Several interesting results emerge from this study. First: the factory cost of the McDonnell-Douglas Prototype Heliostat is estimated to be less than \$96/m² at a production rate of 25,000 units per year. This cost is between one-half and one-third of the cost estimates for the same product in custom production and clearly shows the benefits of mass production. However, the favorable factory cost estimate is dependent on a projected \$87 million investment in facilities and tooling. Second: 81 percent of the factory cost is purchased material.

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This result implies that heliostat manufacture can be a relatively low value added industry, which is a necessary condition for meeting U.S. Department of Energy program cost goals. The high materials fraction also implies that the estimated cost is relatively insensitive to the cost of processing and that the most important area of heliostat development will be the reduction of materials cost.

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Project Manager

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TABLE OF CONTENTS

	<u>Page</u>
Summary and Conclusion	1
Introduction	3
Manufacturing	11
Cost Summaries	15
Manufacturing Design Improvement Possibilities	20
References	24

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	McDonnell Douglas Prototype Heliostat	5
2	McDonnell Douglas Prototype Heliostat - Exploded View	7
3	Documents Used to Establish Cost Estimates	8
4	Plant Layout 25,000 Annual Volume	12
5	Azimuth Drive Housing	13
6	Azimuth Drive Housing Machining - 250,000 Annual Volume	14

LIST OF TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
1	Heliostat Cost Summary - 25,000 Unit Annual Volume (Material, Labor and Burden)	16
2	Burden Costs Per Heliostat Unit	17
3	Total Cost Per Heliostat Unit	18
4	Investment Per Heliostat Unit	19
5	Outside Tooling and Plant Costs	19
6	Welding and Casting Cost Estimates	23

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SUMMARY AND CONCLUSION

A SERI PERSPECTIVE

This study takes a conservative approach to the estimation of heliostat costs by examining the current generation of DOE heliostats from the perspective of contemporary manufacturing technology. The intent of this study is to provide a calibration of the current state of the technology and to suggest directions for near term engineering development. The major findings are summarized in the following paragraphs.

This study projects the factory cost of heliostats to lie between \$68/m² and \$96/m².

The factory cost computed by this study is projected to be \$96/m² when produced in quantities of 25,000 units per year and is projected to decline to \$68/m² at volumes of 250,000 units per year. The installed price derived for this study using profit computed by SERI and installation costs from Battelle is \$122/m² at volumes of 25,000 units per year, and \$89/m² at volumes of 250,000 units per year. Heliostats which have been bought to date have been purchased for research purposes in custom quantities, and as a result are substantially more expensive than the prices given in this report. Estimates have been made for the cost of heliostats using low volume production techniques which are likely to be used by an expanding industry (as for a government demonstration program), and those estimates are approximately twice the values given here.¹ In addition to the cost estimates, the present study also suggested ways to modify the design using current technology to make it more suitable for mass production; changes which could reduce the cost below the estimates given here. In this sense the study may be interpreted optimistically, since with design modifications heliostats would not be expected to cost more than the prices given here.

The results of this study lead to the conclusion that the value of central receiver systems is potentially greater than their cost.

The DOE goal for heliostats is \$72/m² of reflective area, a value which is based on estimates of the cost of electricity from imported oil. A recent study by SERI indicates that heliostat based systems could be competitive for the production of electric power at heliostat prices between \$80 and \$130/m², depending upon the cost of competing energy sources.² However, the study assumed that the central receiver technology would be improved beyond that used in the Barstow pilot plant, that the plants would be located in areas of good insolation in the southwest, and that the cost of oil would continue to inflate more rapidly than inflation for the next few years. While these assumptions appear prudent in

light of recent events, they indicate the potential of central receiver technology and not current economic viability. The present study leads to estimates of installed prices for the MDAC prototype heliostat of \$90 to \$122/m² depending on the volume of production. This result shows a broad range of overlap between achievable prices and those needed for economic break even.

The costs derived by this study represent potential costs and are not current market costs.

The costs quoted are significantly less than the costs which have been observed in actual purchases of heliostats by the government and thus requires interpretation. The cost estimates produced by this study are predicated on substantial levels of capital investment by a heliostat supplier who is convinced of the soundness of his product and in the stability of the market. An \$87 million investment was estimated as a requirement to build a 25,000 unit per year factory, and the market must be stable enough and large enough to justify this investment. The reader is cautioned not to assume that the cost estimates are achievable today, but rather they represent what can be achieved if the market conditions are appropriate. This study has identified attractive possibilities for heliostat cost reduction but these possibilities are not yet realities. The technical performance of central receiver systems must be satisfactorily demonstrated before these favorable economic results can be achieved.

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INTRODUCTION

In support of the Repowering Strategy Analysis SERI asked the GM Transportation Systems Center to conduct a production evaluation and manufacturing cost analysis of a prototype DOE heliostat designed by the McDonnell Douglas Astronautics Company (MDAC).⁴ The results of that study are contained in the "Heliostat Production Evaluation and Cost Analysis" Final Report, SERI/TR-8052-1, December 1979.

The ground rules for this study were developed using the principle that standard mass production industry practice would be used throughout the study. Advanced manufacturing or assembly technology (such as robotics) was not used for this study. The cost collection techniques used followed practices similar to those used for the costing of other durable goods and included amortization schedules and other accounting practices. The factories defined by this study were required to meet the same environmental, safety, and engineering requirements as other factories performing similar functions. All material prices used for this study were based on quotations from suppliers who currently supply similar products to other industries. This approach was deliberately conservative in order to produce a cost estimate based on the current state of the manufacturing art.

This study developed a "factory cost" for the manufacture of heliostats from the ground up without reference to a target figure or cost limit. It is important that the definition of this term is clear and explicit. Factory cost is the sum of all costs necessary to place a finished product on the factory dock ready to ship. The data below shows the factory cost for each of the two production rates studied.

Annual heliostat production rate	25,000	250,000
Plant size in square feet	304,384	682,240
Investment required	\$87,330,250	\$392,805,000

Factory cost per heliostat	\$ 4,699.07	\$ 3,301.87
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Factory cost per square meter	\$ 95.80	\$ 67.31
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Further cost breakdowns are given in Tables 1 through 5 of this report.

Due to the specialized nature of the heliostat production scenario, certain suppliers were reluctant to include investment and/or tooling costs in their material and part quotations. These are real costs that must be considered if heliostat production is to begin at mass production levels.

These additional investments required but not included in the factory cost are given below. These numbers were developed by vendors.

Annual heliostat production rate	25,000	250,000
Investment required	\$1,230,730	\$41,000,000

With typical depreciation allowances, these investment costs would add less than \$1/m² to the factory cost.

The Policy Analysis Branch of the Solar Energy Research Institute developed a profit figure and applied it together with an installation cost from a study done for SERI by Battelle Pacific Northwest Laboratory.³ This allowed a comparison to be made of heliostat installed costs. The results follow.

Annual heliostat production rate	25,000	250,000
Factory cost	\$ 4,699.07	\$ 3,301.87
Profit	\$ 350.86	\$ 207.96
Factory price F.O.B.	\$ 5,049.93	\$ 3,509.83
Installation cost per unit	\$ 940.38	\$ 879.52

The GM installed costs are:

Installed cost per unit	\$ 5,990.31	\$ 4,389.35
Installed cost per square meter	\$ 122.12	\$ 89.48

The Battelle installed costs are:

Installed cost per unit	\$ 4,507.01	\$ 3,948.35
Installed cost per square meter	\$ 91.88	\$ 80.49

The heliostat design considered in this report was developed by the McDonnell Douglas Astronautics Company as a part of the U.S. Department of Energy Prototype Heliostat Program which was managed by Sandia Laboratories (Livermore). Design detail for this baseline heliostat is contained in the MDAC final report.⁴ For this project, design details were collected directly from MDAC in meetings held with the contractor. These meetings produced advanced design drawings which were current as of June 1979. Although the MDAC design continues to evolve, the design detail used in this study contains only information obtained from the contractor through July, 1979. The prototype heliostat considered is shown in Figure 1.

The MDAC heliostat units are large structures with mirrored reflecting surfaces which are mounted on a steel pedestal that reaches about fourteen feet above the ground. The reflecting surface occupies a square area about 24 feet on a side, i.e., the top of the heliostat is nearly 26 feet high. This heliostat has two sections each of which supports six 4 ft by 11 ft panels of specially constructed glass mirrors. These massive sections

Figure 1. MCDONNELL DOUGLAS PROTOTYPE HELIOSTAT

are motor driven to track the sun and reflect it to a central receiver. A central computer determines and transmits the angle necessary for receiving maximum sunlight and a drive unit rotates the sections into proper position. The heliostat is designed to rotate from the sun-catching position to a face-down position for storage at night or during bad weather.

While the operation and design of the heliostat appears to be simple, producing them in volume requires substantial amounts of steel, glass and manufacturing equipment. To obtain a mass production cost estimate, it was necessary to develop special processing, to design special machines, and to establish special procedures for handling the large components. The determination of an accurate cost of producing a single heliostat at production levels of 25,000 and 250,000 annually required a part-by-part cost analysis. This meant performing a detail study from acquisition of raw materials or purchased parts through machine, tooling, and labor requirements to the design of a plant facility and the determination of its location. Figure 2, an exploded view of the heliostat, illustrates the basic components cost estimated in the study.

The step by step procedure of the manufacturing study traced each part from fabrication to readiness for site delivery. The documents needed to establish cost estimates included the bill of materials, material purchase request sheets, and tool and labor routing sheets. The bill of materials listed every item, part or raw material required to complete the manufacture and assembly of the heliostat and described it by part number, material specification, weight, shape and size. In addition to this information the material purchase request sheets supplied the price of each part needed. This input was further expanded on the tool and labor routing sheets where each step of the manufacturing process and tools required were defined or developed and recorded. Shown in Figure 3 are samples of these three documents.

Once the material and processing needs were determined it was also necessary to configure a plant facility for heliostat production. After factory layouts were completed for the high and low production volumes, the next task was labor development. Since large scale heliostat production is untried, this study considered typical labor development based on the requirements generated from the tool and labor costing sheets. These led to cost extension, a necessary step to determine burden costs. All costs were collected on product cost estimate sheets to show the total manufacturing cost.

Factory Cost

It is important for the reader to understand that from its inception this study of heliostat production costs intended to develop what is known as "factory cost".

Figure 2. MCDONNELL DOUGLAS PROTOTYPE HELIOSTAT - EXPLODED VIEW

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Factory cost is:

the sum of all costs necessary to place a finished product on the factory dock ready to ship.

Factory cost does not include:

shipping, field installation, profit, return on investment, distributed general and administrative expenses, state or local product or inventory taxes, general commercial expense, sales and advertising costs, public relations costs, or any other profit and loss items.

Facility design requirements defined by the ground rules of the study also included a site selection. This selection was influenced by the need to be close to the major potential market area for repowering sites. This limited site location considerations to the southwest.

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MANUFACTURING

Costing ground rules were established to determine the cost of producing a single heliostat unit based on the design detail provided. The areas considered included production volumes, equipment and processing, heliostat design requirements, facility design requirements and the costing methods to be used.

In addition to an analysis of the design, manufacturing processes were developed for each component and plant layouts were configured for both the 25,000 and 250,000 unit annual volumes. The plants for both the 25,000 and 250,000 unit annual volume heliostat production are single-story slab construction of high-bay design. The low volume plant floor area is approximately 300,000 square feet and the high volume plant occupies approximately 680,000 square feet.

To illustrate the nature of heliostat production, the plant layout for the 25,000 unit annual volume is shown in Figure 4. The letters identify processes that take place in the various areas of the plant.

• Mirror Module Assembly	A
• Mirror Support	B
• Reflector Panel Assembly	C
• Azimuth Drive Housing Machining	D
• Drag Link Machining	E
• Torque Tube Machining	F
• Flex Spline Machining	G
• Circular Spline Machining	H
• Wave Generator Machining	I
• Bearing Retainer Machining	J
• Electronics Assembly	K
• Azimuth Drive Assembly	L
• Elevation Drive Assembly	M
• Drive/Pedestal Assembly	N

Additional processes occurring in the plant designed for the 250,000 unit annual volume heliostat production include:

- Fabricating and galvanizing for the azimuth drive housing, torque tube and drag link
- Forming, welding and galvanizing for the pedestal and tapered pipe.

Figure 4. PLANT LAYOUT 25,000 ANNUAL VOLUME

As an example of the approach used throughout this study, the processing of a representative part, the azimuth drive housing, will be discussed. The azimuth drive housing is the structural part which transmits the loads from the mirror panels to the pedestal and the foundation. It contains the azimuth drive assembly and the elevation drive and the control system are attached to it. The azimuth drive housing, shown in Figure 5 weighs 275 lb. It is fabricated from steel pieces which are purchased from an outside supplier and welded on automatic lines in the manufacturing plant. The rough weldment is then moved to the transfer line where all of the surfaces and holes are machined. These machined surfaces accommodate the bearings and mounting hardware. In order to produce the housings at the high volume of 250,000 heliostats a year, an automated transfer machine was designed especially for this application.

Figure 5. AZIMUTH DRIVE HOUSING

The machine shown in Figure 6 can produce up to 100 parts per hour. An average rate of 65 pieces per hour is required to meet production in a two-shift operation. One operator is required for parts loading/unloading and monitoring of the operation. The housings move through the machine on transfer pallets and the machinery operations are performed simultaneously. The machine occupies approximately 4000 square feet of floor space and has a capital cost of approximately \$4,000,000. Similar detail was developed for each of the components processed in the heliostat plant. When the processing for each of these components was complete, costs could be developed. When these costs were collected, as discussed in the next section, the total factory cost of the heliostat could be determined.

FIGURE 6. AZIMUTH DRIVE HOUSING MACHINING -
250,000 ANNUAL VOLUME

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COST SUMMARIES

This section contains factory cost summary information for the production of a single heliostat unit at both the low (25,000) and high (250,000) production volumes. The cost summaries represent the collection of the following cost factors:

1. Direct Labor - The labor applied to each element of the heliostat unit as it is processed in the manufacturing plant. Labor for assembly and shipping are also collected in this category.
2. Material - The purchased materials (or components) that are used in the heliostat assembly. Material costs include delivery costs and are applied to the proper element of the heliostat assembly.
3. Variable Burden - The overhead costs which are sensitive to the production volume. These costs are allocated on the basis of direct labor content in the particular heliostat component.
4. Fixed Burden - The overhead costs which are insensitive to the productive volume. These costs are allocated on the basis of direct labor content.
5. Variable Fringe - The fringe benefits for employees which are sensitive to labor content.
6. Fixed Fringe - The fringe benefits for employees insensitive to labor content.
7. Overtime, Night Shift, Cost of Living Allowance - Labor costs which are in addition to the basic rate paid to the hourly employees involved in direct labor.
8. Special Tools - The overhead costs which result from those tools which depreciate over a shorter period than the plant equipment.
9. Plant Engineering - The overhead costs which result from on-going engineering to update the plant.
10. Outside Tooling and Plant Costs - These costs represent payments to suppliers for special tooling or plant facilities.

A summary of the allocation of material, labor and burden expense for each component of the heliostat is shown in Table 1. Direct material and labor costs are allocated to each component of the heliostat. All burden expense for the plant operation is totaled and then allocated to the component cost on the basis of the direct labor content.

To illustrate how these detail costs are determined, the cost for one subassembly -- the reflective surface -- is discussed in the following paragraphs.

Material costs are collected from the material price request sheets which are prepared for every part of the heliostat. In this case, the reflective surface costs include glass, mirroring and adhesives. These costs total \$1,065.17 and are entered in Table 1.

Table 1. HELIOSTAT COST SUMMARY - 25,000 UNIT ANNUAL VOLUME
(MATERIAL, LABOR AND BURDEN)

	Material \$	Labor \$	Burden \$	Total \$
4411 - Reflective Surface	1,065.17	7.55	95.35	1,168.07
4412 - Support Structure	286.20	2.40	30.26	318.86
4413 - Assembly	1.13	3.23	40.81	45.17
4410 - Reflective Unit	1,352.50	13.18	166.42	1,532.10
4421 - Azimuth Drive	766.38	23.90	301.80	1,092.08
4422 - Elevation Drive	656.00	8.74	110.39	775.13
4423 - Motors	145.65	1.92	24.28	171.86
4424 - P/L Indicator	93.98	1.79	22.61	118.38
4425 - Power Sup./Dist.	162.56	7.32	92.40	262.27
4420 - Drive & Controls	1,824.57	43.67	551.48	2,419.72
4433 - Control/Sig. - Equip.	145.70	2.95	37.28	185.93
4451 - Structure & Tapered Pipe	358.00	0.08	0.99	359.07
Materials Shipping	116.93	-	-	116.93
Final Assembly	1.67	3.30	41.70	46.67
Total	3,799.37	63.18	797.87	4,660.42

Direct labor costs are collected from the tool and labor routing sheets and represent the direct labor applied to reflector assembly, bonding, curing and handling operations. These costs total \$7.55 and are entered on Table 1. The labor costs are represented by a time factor of 7.984 hours per 100 reflector panels. Since each heliostat requires 12 panels, the total time is 95.808 hours per 100 heliostats. Based on the \$7.88 hourly rate, with fringes, the \$7.55 cost figure is obtained by multiplying by the total time and dividing by 100.

Burden expenses are collected for all other items of factory cost. The total yearly burden expense is first determined for the heliostat plant. This figure is divided by the total direct labor cost to arrive at a burden factor for the plant. The result is a burden rate for each hour of direct labor. In the case of the heliostat plant for this volume level, the rate is 12.63 percent. This rate, times the direct labor cost is used to arrive at the burden cost figures shown in Table 1 for each heliostat component. For the reflective surface, this cost is \$95.35. In some large plant operations, burden costs may be established on a departmental basis. This degree of precision is not warranted for the size of the heliostat processing plant. However, this is not a serious problem for the purposes of generating overall heliostat manufacturing costs.

The following table shows the breakdown of the heliostat fixed and variable burden. Note that taxes and depreciation on the building and equipment make up the greatest share of these costs.

Table 2. BURDEN COSTS PER HELIOSTAT UNIT

	25,000 Volume		250,000 Volume	
	Variable	Fixed	Variable	Fixed
Hourly	5.34	1.26	4.81	1.13
Salary	21.10	29.49	6.87	9.60
Supplies	8.33	-	8.33	-
Tools	9.67	24.79	4.88	12.86
Utilities	12.25	18.42	4.74	7.14
Maintenance	14.88	1.53	12.70	1.31
Scrap	98.01	-	81.20	-
Taxes and Depreciation	-	463.92	-	228.21
Sundry	9.24	1.19	8.40	1.19
Total	\$178.82	\$540.60	\$131.93	\$261.44

The cost summary shown in Table 1 does not represent the total factory costs. To these costs are added the items for special tools, plant engineering and outside tooling/plant costs. These factors are shown in Table 3. For the 25,000 volume at the 100 percent capacity level, these costs add \$48 to unit cost and bring the factory cost up to \$4,708.42 which is \$95.99/m². Table 3 also shows the factory cost for the 250,000 production level. This cost is \$3,333.03 per heliostat (\$67.95/m²). In addition the factory cost is shown at production rates of 75 percent and 125 percent of the standard volume.

Table 3. TOTAL COST PER HELIOSTAT UNIT

	75% of Plant Capacity		100% of Plant Capacity		125% of Plant Capacity	
	18,750 Volume	187,500 Volume	25,000 Volume	250,000 Volume	31,250 Volume	312,250 Volume
Direct Labor	63.18	46.65	63.18	46.65	63.18	46.65
Material	3,799.37	2,798.67	3,799.37	2,798.67	3,799.37	2,798.67
Variable Burden	178.82	131.93	178.82	131.93	178.82	131.93
Fixed Burden	720.80	348.59	540.60	261.44	432.48	209.15
Variable Fringe	40.29	24.92	40.29	24.92	40.29	24.92
Fixed Fringe	31.96	19.77	23.97	14.83	19.18	11.86
Overtime	3.35	2.08	3.35	2.08	3.35	2.08
Night Shift	3.10	1.92	3.10	1.92	3.10	1.92
C.O.L.A.	7.74	4.79	7.74	4.79	7.74	4.79
Subtotal	4,848.61	3,379.32	4,660.42	3,287.23	4,547.51	3,231.97
Special Tools	40.37	10.69	30.28	8.02	24.22	6.42
Plant Engineering	8.37	6.62	8.37	6.62	8.37	6.62
Total Factory Cost	\$4,897.41	\$3,396.63	\$4,699.07	\$3,301.87	\$4,580.10	\$3,245.01
Outside Tooling and Plant Costs	11.72	41.59	8.79	31.19	7.03	24.95
Grand Total	\$4,909.13	\$3,438.14	\$4,707.86	\$3,333.06	\$4,587.13	\$3,269.96
\$/m ²	\$ 100.08	\$ 70.09	\$ 95.98	\$ 67.95	\$ 93.51	\$ 66.66

Further illumination of the cost structure for the heliostat units is provided in Table 4. This table shows the magnitude of the investment for the manufacturing operations at the two production volumes. The investment is presented in terms of the amount required to produce a single heliostat unit and shows that buildings and equipment are the major cost factors. When expressed as total investment, they represent \$87,300,000 and \$392,800,000 for the 25,000 and 250,000 production levels, respectively. They also show the very significant reduction in unit burden expense as volume is increased.

Table 4. INVESTMENT REQUIRED TO MANUFACTURE HELIOSTATS

ANNUAL VOLUME	25,000	250,000
PLANT SIZE	304,384 sq.ft.	682,240 sq.ft.
LAND REQUIRED	50 Acres	100 Acres
INVESTMENT		
Building	\$37,000,000	\$ 75,000,000
Land & Improvements	900,000	1,600,000
Machinery & Equipment	43,300,000	292,000,000
Tools	3,800,000	10,000,000
Operations	2,300,000	14,200,000
TOTAL	\$87,300,000	\$392,800,000

Because of the specialized nature of heliostat production, investments were required by outside suppliers in addition to that required in the heliostat factory. These costs, collected in Table 5, are added into the vendor price quotes for heliostat components.

Table 5. OUTSIDE TOOLING AND PLANT COSTS

	25,000 Volume	250,000 Volume
Rolling Mill Tools	104,000.00	2,600,000.00
Rolling Mill Building	--	4,000,000.00
Mirroring Equipment	1,000,000.00	3,000,000.00
Glass Making Equipment	--	32,000,000.00
Gear Equipment (tooling)	44,000.00	44,000.00
Junction Box Tooling	8,500.00	--
Total	\$1,156,500.00	\$41,044,000.00
Annual Cost	\$ 219,735.00	\$ 7,798,360.00
Per Unit Heliostat Cost	\$ 8.79	\$ 31.19
Cost per square meter	\$ 0.18	\$ 0.64

MANUFACTURING DESIGN IMPROVEMENT POSSIBILITIES

One of the study tasks required identification of design improvement possibilities that could reduce heliostat production costs. The suggestions for improvement included changes in the design or in the materials selection which would allow the heliostat to be fabricated and assembled more efficiently, and would have the potential to reduce cost. Design improvements were identified in the following areas:

- Glass
- Mirror surface protection and line capacity
- Adhesive curing
- Design and/or cost effectiveness factors of the harmonic drive, flex spline shear bolts, wire-race bearing
- Weldment - support structure
- Control system cabling
- Galvanizing
- Plant construction: new/existing

Glass Problems

Two problems affect glass processing: size and source.

The sole source for the low-iron fusion glass used in the front lite of the heliostat panels is the Corning Glass Plant in Blacksburg, Virginia. This plant can meet production requirements at the 25,000 unit volume level but is not large enough for the 250,000 unit volume level.

The additional capacity requirements would require an estimated \$3.25 million investment that once amortized, would contribute \$0.52/m² to the cost of a heliostat.

Fusion Glass Front Lite Size. The 4 ft x 11 ft size selected for the reflective surfaces increases the glass cost since the facility used to produce the fusion glass is designed to produce glass panels which are 6 feet wide and 10 feet long.

The modifications necessary to the glass making facility increase the cost of the front lite. Selection of panel dimensions which are closer to the 6 ft x 10 ft capacity of the present facility would yield a lower price for the front lite. However, since a 6 ft wide mirror panel may require double curvature to maintain acceptable image quality, a trade-off study should be performed.

Fusion Versus Float Glass. The current specification of fusion glass for use in the front lite could be substituted by use of a less costly float glass. Since some transmissivity might be sacrificed, a trade-off study should be performed.

Mirror Surface Protection

In the current design, the mirrored surface is subject to chemical attack during shipment. Protection could be provided by applying a plastic film or a mirror backing paint. Determining the best alternative would require further study and a cost comparison.

Mirror Line Capacity

Current mirror line designs are not sized for the high production level. Efficiency is also lost in shipping and scrappage operations.

Expanding the size of the glass lines and locating them in the fusion glass production facility improves efficiency and is an alternative the fusion glass manufacturer, Corning Glass, is willing to consider.

Adhesive Cure Time

The polyurethane adhesives specified in the design require large and expensive ovens for curing. Cost improvements could be made by reducing cure time. To achieve this, a different or modified adhesive might be developed. Also, experimenting with cure times to determine an acceptable minimum would be useful.

In the previous listing, several components were selected as candidates for design improvement as cost effectiveness possibilities.

Harmonic Drive

The numerous components of the harmonic drive require extensive fabrication and machining. A cost reduction could be possible with a design change that substitutes other mechanisms for the intricate harmonic drive.

Flex Spline Shear Bolts

To effect a savings over the costly aircraft-quality shear bolts specified in the current design, commercial grade fasteners available for this application should be considered.

Wire-Race Bearing

The wire-race bearing requires stringent manufacturing tolerances for proper operation. Special tooling and increased quality control operations could be reduced if a conventional bearing design could be used.

Support Structure Weldment

The support structure weldment is a "K" frame design and requires numerous spot welds. The structures are large, bulky, and difficult to work on. Significant labor is required to process this part, and because the welding is concentrated in a single area the cost is high. Design changes to reduce the number of components and/or relieve the concentration of welding in the joint area should be considered.

Control System Cabling

The heliostat was designed using fiber optic control cable. Copper cable may well be less costly for this application. To determine the cost effectiveness of fiber optics versus copper cable, a trade-off study should be done that includes quality of application as well as cost.

Galvanizing

The heliostat design specified in this study is galvanized to provide a protective coating for exterior corrosion resistance.

The galvanizing process is expensive, occupies substantial factory floor area, and requires the disposal of toxic wastes. In fact, galvanizing may not be required to the extent designed for applications used in the southwest.

One possible alternative is the use of acrylic resin paints which may have lower cost and fewer environmental problems than galvanizing.

Existing Versus New Plant Construction

Plant costs for this study were based on the construction of a dedicated facility on sufficient acreage to allow for normally expected business growth. Half the plant area requires 12-1/2 lbs of structural steel per square foot and the other half

requires 18 lbs of structural steel per square foot. The 8 inch concrete floor requires 3 lbs of rebar steel per square foot. These requirements were dictated by the manufacturing sequence and plant layout configured in the Final Report.

A change in the plant layout or some redefinition of the manufacturing process might allow the use of an existing plant or facility for heliostat production at a lower investment cost than required for new construction.

A cost/manufacturing process trade-off study is recommended in order to weigh the desirability of converting an existing plant versus constructing a new one.

Weldment Versus Casting

The following table compares the cost of welded construction of the azimuth drive housing and drag link components (as designed) and the consideration of casting the units in a single piece as estimated during the study.

TABLE 6. WELDING AND CASTING COST ESTIMATES

	25,000 Unit Annual Volume		250,000 Unit Annual Volume	
	Purchased Weldment	Casting	Processed Weldment	Casting
Azimuth Drive Housing	\$370.00	\$180.48	\$223.53	\$180.48
Drag Link	\$ 72.00	\$ 42.48	\$ 59.52	\$ 42.48

Although this limited study of weldment versus casting costs includes only gross estimates of comparative costs, it does indicate generally lower costs for the cast parts. Therefore, it is recommended that investigations be pursued to determine if cost benefits can be achieved through substitution of castings for weldments in the MDAC heliostat design.

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