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ADVANCED SOLAR CONCENTRATOR MASS PRODUCTION, OPERATION, AND MAINTENANCE COST ASSESSMENT

January 1981

Acurex Project 7740
Contract 955477
DRL 015
DRD SE003

For

California Institute of Technology
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103

By

W. A. Niemeyer, R. J. Bedard and D. M. Bell
Acurex Corporation
Alternate Energy Division
485 Clyde Avenue
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SECTION 1

INTRODUCTION AND SUMMARY

This report presents the results of a mass production and maintenance cost assessment of an Advanced Solar Concentrator. This effort was performed by Acurex Corporation under contract to the Jet Propulsion Laboratory (JPL).

The object of this assessment was to estimate the production, installation, operations and maintenance costs of the Advanced Solar Concentrator preliminary design at:

- Production rates of 10^2, 10^3, 10^4, 10^5 and 10^6 concentrators per year
- Concentrator aperture diameters of 5, 10, 11, and 15 meters
- Various receiver/power conversion package weights.

The design of the cellular glass substrate Advanced Solar Concentrator is shown in Figure 1-1. This preliminary design is based on an advanced concentrator concept developed by JPL. The concentrator is an 11 meter diameter, two-axis tracking, parabolic dish solar concentrator. The reflective surface of this design consists of inner and outer groups of mirror glass/cellular glass gores. The gores are attached as simply supported overhung beams to a ring truss support structure to form a complete but physically discontinuous reflective surface. There are five structural support subsystems; the gore support, a quadripod receiver

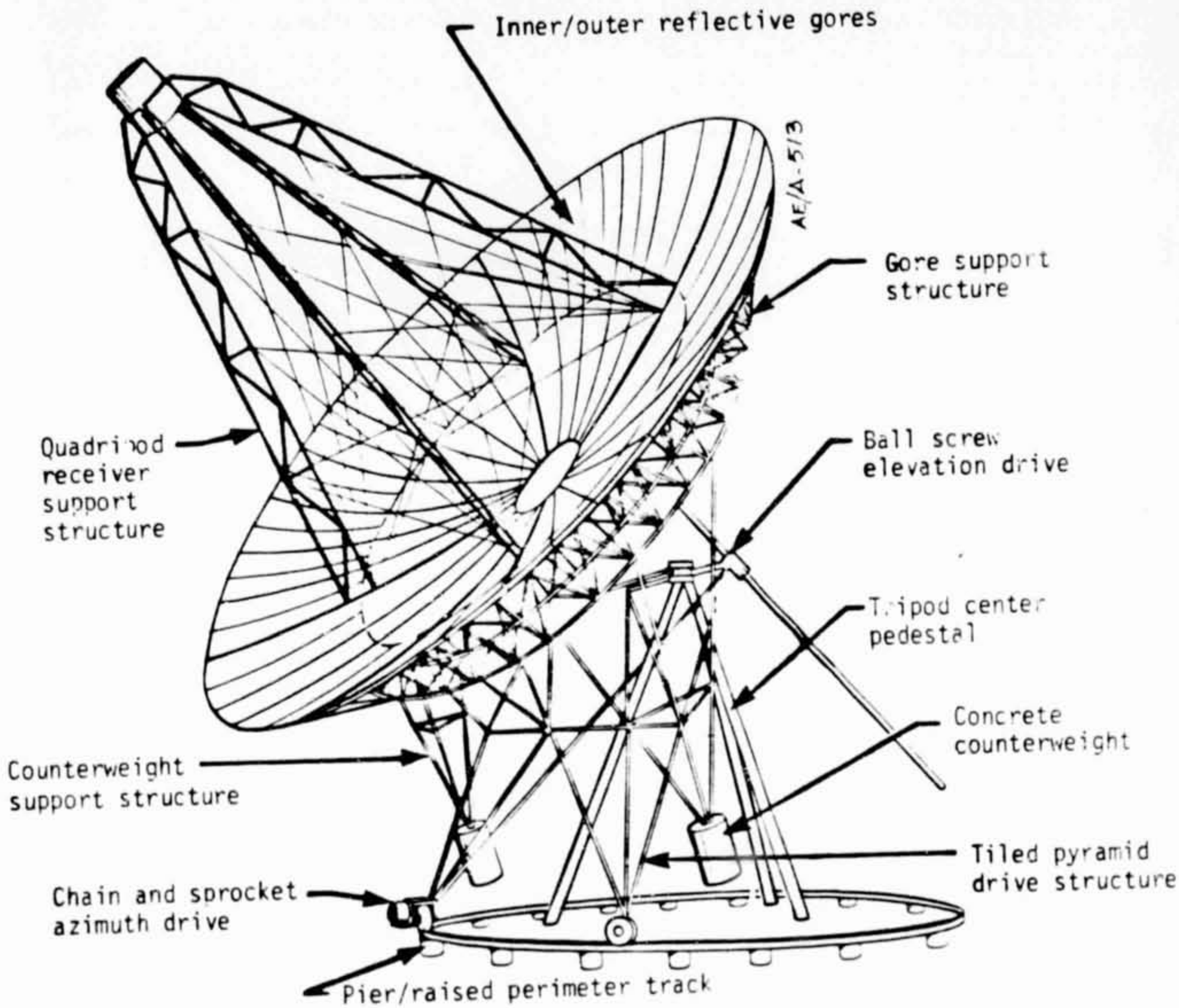

Figure 1-1. Design Description

support, a counterweight support, a tripod center pedestal and a tilted pyramid drive structure. Elevation motion is produced by a ball screw and azimuth motion by a chain and sprocket perimeter drive. The foundation consists of contrete piers for the center pedestal and a raised steel track also on concrete piers.

A complete preliminary design description of the Advanced Solar Concentrator is contained in Reference 1.

The objective of this cost assessment effort was accomplished using a "bottom up" or detailed costing approach. The cost elements making up the total installed concentrator cost and operations and maintenance costs were broken down in detail. This costing approach, as described in the cost methodology section, provides a high level of accuracy as each estimate is made for a detailed cost element of the concentrator.

A key part of the cost analysis approach was using qualified subcontractors to provide "real-world" cost estimates for those elements of the concentrator for which there existed related experience. Pioneer Engineering and Manufacturing Company provided the cost estimates for production of the structure and drive components. Pioneer has extensive related experience in costing high production rate manufactured parts. Newbery Constructors Inc. provided the cost estimates for installation of the concentrator. Newbery has extensive general site work and construction experience with specific related experience in the field erection of transmission towers which are large space frame structures like point focus solar concentrators are.

For purposes of this mass production cost analysis, cost is defined as the cost of merchandise plus the amortized cost of capital equipment. Typical business expenses which are not included as cost in this assessment are selling, research and development, general and administrative, interest, and income tax expenses. Profit is also not included. Detailed cost estimates were made in 1980 dollars and scaled back to 1978 and 1975 dollars, using appropriate scaling factors at the summary level only.

Caution must be emphasized about comparing cost estimates made different analysts whether they are for identical or different system designs -- they cannot be compared with any certainty -- underlying cost assumptions made by the cost analyst may totally dictate the quantitative cost estimate. Comparison of cost estimates of competing designs, for example, should only be made when a single unbiased analyst has performed a side-by-side cost analysis employing a totally consistent set of assumptions.

The total installed cost for the Advanced Solar Concentrator in 1978 dollars is estimated at $12,662 or $133.3 per square meter of gross aperture area. A summary of the cost by major cost breakdown element is presented in Table 1-1.

These costs have been developed based on conceptual level production, shipping, and installation plans as described in the following paragraphs.

The conceptual production approach developed for the Advanced Solar Concentrator at the 100,000 per year production rate is described in Section 3. In summary, the production approach is as follows:

- Reflective Panels -- The reflective panels are assembled from purchased glass components. This is accomplished in a single plant located adjacent to a glass manufacturing plant. The finished panels are shipped to regional final assembly

Table 1-1. Advanced Concentrator Cost Summary
(per concentrator @ 10^5 units/yr, 11 m aperture)

Cost Element	1980 $	1978 $		1975 $	
	$/conc	$/conc	$/m²	$/conc	$/m²
Production Costs					
1000 Reflective Panels	3,905	3,254	34.3	2,616	27.5
2000 Drives	1,353	1,127	11.9	907	9.5
3000 Electrical and Control	917	764	8.0	614	6.5
4000 Structure	2,868	2,390	25.2	1,922	20.2
5000 Factory Assembly	228	190	2.0	153	1.6
Total Factory Costs	9,271	7,725	81.3	6,212	65.3
6000 Shipping	962	801	8.4	645	6.8
Installation Costs					
7000 Installation					
7100 Site Preparation	1,762	1,265	13.3	1,181	12.4
7200 Foundation Installation	2,870	2,061	21.7	1,923	20.2
7300 Site Assembly	1,098	809	8.5	736	7.7
	5,730	4,135	43.5	3,840	40.[illegible]
Total Installed Costs	$15,963	$12,661	$133.3	$10,697	$112.4
Operations and Maintenance Costs					
8000 Operations and Maintenance					
8100 Operations	8/yr	7/yr	0.07/yr	5/yr	0.05/yr
8200 Scheduled Maintenance	159/yr	133/yr	1.40/yr	107/yr	1.13/yr
8300 Unscheduled Maintenance	32/yr	27/yr	0.28/yr	21/yr	0.22/yr
Total O&M Costs	$199/yr	$167/yr	$1.75/yr	$133/yr	$1.40/yr

facilities located near the solar energy system installation sites.

- Drives, Electrical, and Control -- These components are purchased parts. They are shipped by the vendors to the regional final assembly facilities. In actual implementation, these parts may be made in-house, but within the scope of this study, it was decided to re on vendor quotes to provide cost estimates. It is anticipated that the economics would not be significantly different for in-house manufacture at the 100,000 units per year production rate.
- Structure -- The structure subassemblies of the concentrator are fabricated at regional plants of approximately 20,000 units per year capacity. These plants are to be located close to the areas in which the concentrators will be installed. These regional structural steel fabrication plants are colocated with the concentrator final assembly facilities.
- Final Assembly -- The various elements of the concentrator are assembled at the regional final assembly plant, located next to the structure fabrication facility. In this facility the concentrator is virtually fully assembled, before airshipping to the installation site. All elements which attach to the pedestal (structure, reflective panels, drives, controls) are assembled in the factory to save on expensive field labor.

The shipping approach described in Section 4 is shipping fully assembled concentrators (except for the pedestal and track) to the site by air (airship or heliocopter). By using airshipping, field assembly labor is kept to a minimum and total installed cost is reduced.

The installation plan described in Section 5 addresses site preparation, foundation installation and site assembly costs. With the airshipping approach, installation costs are 33 percent of the total installed concentrator cost. With common carrier shipping and site assembly of piece parts, the installation cost element would be approximately 50 percent of the total installed cost. Airshipping was selected because it provided the lowest total installed concentrator cost.

The operations and maintenance costs as described in Section 6 are estimated to be $167 per concentrator per year.

Costs were scaled as a function of production rate, aperture diameter, and receiver weight from the cost estimates developed in the detailed effort (at 11 meter diameter, 10^5 units per year and 1350 kg receiver/power conversion weight). The scaling is discussed in Section 7. The results quantify the cost reductions possible through the economics of high production rates and show that 11 meters is the minimum cost aperture size for this particular design concept. Significant changes in receiver/power conversion weights had only a small impact on installed concentrator costs.

The preliminary design is only one iteration in the evolution of an Advanced Solar Concentrator; therefore, the cost analysis presented in this report only indicates where effort should be expanded to achieve cost reductions rather than providing absolute and nonchanging values. Over the course of our design and cost analysis efforts we have identified a number of potential cost reduction areas. Recommendations relative to each area are discussed in Section 8. The major cost reductions can be categorized as follows:

- Specification Requirements -- Operational and survival wind loads are major drivers in the design of virtually all components of the concentrator. The probability of encountering the governing wind loads is extremely low, and can be reduced by using wind screens and accounting for mutual wind blocking.
- Concept Redesign -- Two areas of redesign that can significantly reduce the installed cost of the system are the mount and foundation assembly and the counterweight assembly. While the wide base perimeter mount system provides the lightest weight concentrator, it requires significant site preparation and foundation installation labor. A more material intensive design using a single pedestal mount allows for low cost site preparation and foundation installation and would most likely result in a lower total installed cost. Counterweight systems, although allowing for reduced elevation drive motor requirements and low parasitic operating power, result in higher life cycle cost concentrators than noncounterweighted systems.
- Materials Technology -- Two areas of material technology development have the potential for reducing the cost of the critical reflective panel component. A full size monolithic cellular glass core, formed to rough contour would eliminate the 50 percent of the material required and the labor operations of bonding and trimming multiple small size cellular glass blocks. The development of large, high strength temperable mirror glass sheets would allow wider reflective

panels, and therefore, fewer panels per concentrator with the attendant reductions in attachment hardware, supporting structure and the number of individual alignment operations.

SECTION 2

COST METHODOLOGY

The methodology used to estimate the costs for mass implementation of the Advanced Concentrator is described in this section. Five key elements were developed to establish a structure for organizing, conducting, and reporting this cost analysis task.

These elements are described in the following paragraphs:

Section 2.1	Cost Analysis Approach
Section 2.2	Assumptions
Section 2.3	Cost Breakdown Structure
Section 2.4	Costing "Flow"
Section 2.5	Cost Definitions

2.1 COST ANALYSIS APPROACH

Because the accuracy of the cost estimates depends on the level of detail used in developing them, it is important to be as detailed as is reasonable. Therefore, to obtain an accurate cost estimate, yet remain within a reasonable scope, detailed costing was performed at a single production rate (100,000 units per year), aperture size (11 meter diameter), and receiver/power conversion weight (1350 kg). Scaling relationships were used to develop costs at other productions rates, aperture sizes, and receiver/power conversion package weights. All detailed cost estimates were made in 1980 dollars and were scaled back, using appropriate inflation factors to 1978 and 1975 dollars at the summary level only. The detailed costing is based on the preliminary design developed for the concentrator except for the design for the reflective gore "blank" which is taken from the detailed design. A complete description of the Advanced Solar Concentrator is contained in Reference 1.

A key part of the cost analysis approach used in conducting this study was to use the services of qualified subcontractors. The intent was to obtain real world cost estimates for elements of the concentrator for which related experience existed. The two elements of the concentrator for which present day experience could be related were production of the structure and drives and the installation activities.

The subcontractors selected to conduct the cost analyses of these two elements were:

- Structures and Drives Production Cost Estimates -- Pioneer Engineering and Manufacturing Co. Pioneer has extensive related experience in the costing of high production rate manufactured parts and familiarity with solar energy technologies. Pioneer has performed many manufacturing engineering and cost studies for customers such as Ford, Chrysler, General Motors, the Department of Transportation, and others. Their related solar experience was gained in a manufacturing cost analysis for Boeing for their heliostat design and a detailed mass production cost analysis for JPL of the Test Bed Concentrator prototypes installed at the Edwards test site.
- Installation Cost Estimates -- Newbery Constructors, Inc. Newbery has extensive general site work and construction

experience. Their Phoenix, Arizona location gives them familiarity with costs in the geographical area in which the concentrators would likely be installed. Their experience with field erection of transmission towers gives them experience with the unions most likely to be installing solar concentrators and a present day knowledge of construction activities comparable to erection of large parabolic dish concentrators. Transmission towers are large space frame structures and have a great deal of similarity to solar concentrators as far as handling, foundation installation, and assembly requirements are concerned.

2.2 ASSUMPTIONS

The basic assumptions used in conducting this study were:

- Structure fabrication and final concentrator assembly plant(s) located in U.S. Southwest
- 100 mile maximum shipping radius from final assembly plant to field site (implications regarding plant capacity are discussed in the production plan)
- 100 concentrators per field, 10 rows of 10 on 80 foot centers

The inflation factors used to scale the costs in 1980 dollars to 1978 dollars are as follows:

- Production, shipping, operations and maintenance -- 9.5 percent per year
- Installation -- 18 percent per year

The inflation factors used to scale the costs in 1980 dollars to 1975 dollars are as follows:

- Production, shipping, operation and maintenance -- 49 percent over the period (8.3 percent annual average)

- Installation -- 50 percent over the period (8.3 percent annual average)

The rate for production, shipping, operations, and maintenance is based on data in the U.S. Department of Labor Bureau of Labor Statistics Producer Price Index (Reference 2). The inflation rate for installation is based on our experience for installation costs of parabolic trough solar collector systems over the past 2 years.

2.3 COST BREAKDOWN STRUCTURE

A cost breakdown structure (CBS) was developed to organize the detailed cost estimate elements. A numerical index was assigned to each cost element of the concentrator. This CBS presented in Table 2-1 serves as the basis for all detailed costing reported here.

2.4 COSTING FLOW

A flowchart of the cost estimate buildup is illustrated in Figure 2-1. As the chart shows, this is a bottom up costing approach, in which requirements and costs for materials, labor, equipment, and overhead are estimated for each element of the CBS and summarized upwards to yield costs at the various levels of breakdown and ultimately at the overall summary level. Only the summary cost estimate has been scaled using the appropriate scaling relationships to obtain cost estimates at the various production rates, aperture sizes, and receiver weights.

2.5 COST DEFINITIONS

For purposes of this mass production cost assessment, cost is defined as the cost of merchandise plus the amortized cost of capital equipment. Typical business expenses which are not included as cost in this assessment are selling, research and development, general and

Table 2-1. Cost Breakdown Structure

Subsystem	Assembly	Subassembly
1000 Reflective panels	1100 outer gores (40) 1100A inner gores (24)	1110 Cellular glass 1120 Reflective surface 1130 Spar cap 1140 Attachment hardware 1150 Adhesive 1160 Coating 1170 Protective covering 1180 Shipping container
2000 Drives	2100 Azimuth	2110 Motor 2120 Gear reduction 2130 Sprocket assembly 2140 Wheels 2150 Chain Ass'y
	2200 Elevation	2210 Motor 2220 Gear reduction 2230 Ball screw jack
3000 Electrical and control	3100 Tracker (control)	3110 Microcomputer 3120 Photodetector assembly 3130 Shaft encoders 3140 Cabling
	3200 Electrical	3210 Receiver generator Fused disconnects 3220 Drive motor controls 3230 Distribution panel 3240 Cabinet 3250 Cabling 3260 Lightning protection
4000 Structure	4100 Gore Support Ring 4200 Drive Structure	4110 Structure assembly 4210 Structure assembly 4220 Azimuth bearing
	4300 Counterweight Structure	4310 Structure assembly
	4400 Receiver/Engine Support	4410 Quadripod legs (4) 4420 Receiver/engine mount
	4500 Pedestal	4510 Pedestal structure
	4600 Track	4610 Track 4620 Chain guard
5000 Factory assembly	5100 Gores Mounting/Aligning 5200 Final Assembly	
6000 Shipping		
7000 Installation	7100 Site preparation 7200 Foundation installation 7300 concentrator assembly	
8000 Operations and maintenance	8100 Operations 8200 Scheduled Maint.	8210 Reflective panels (cleaning) 8220 Drive system 8230 Elect., I&C 8240 Structure
	8300 Unscheduled maint.	8310 Reflective panels 8320 Drive system 8330 Elect., I&C 8340 Structure

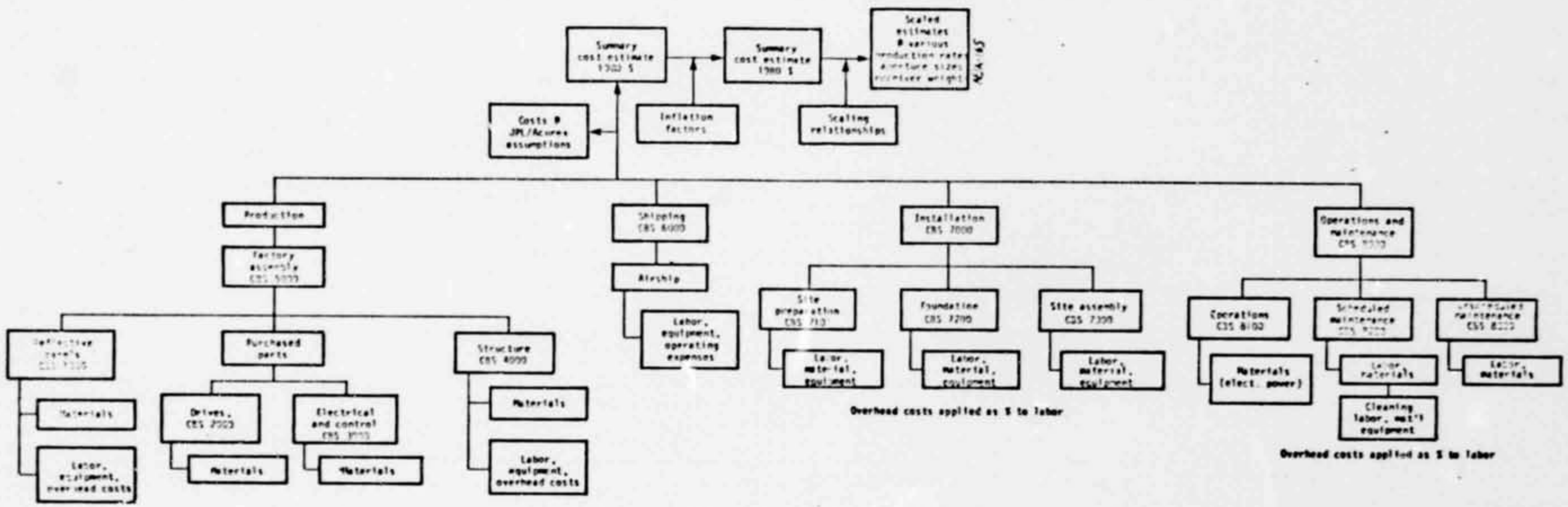

Figure 2-1. Costing Flow Chart

administrative, interest, and income tax expenses; profit is also not incuded.

Each of these items is defined with respect to a typical manufacturing company's income or earning statement as shown in Table 2-2.

The terms are defined as follows:

- Sales -- This revenue represents the total sales of merchandise to customers. It is the selling price of a product times the number of product units sold
- Other revenues -- These may include items such as rental income, interest earned, etc.
- Cost of Merchandise -- This category of expense represents the direct and indirect cost to produce the merchandise. It is composed of compensation including fringes to employees working directly in the manufacturing process, all raw material and purchased parts used to produce the merchandise, and factory overhead. Factory overhead represents all factory costs of an indirect nature; it includes such items as indirect labor, indirect material, facility leasing, and inventory costs. Indirect labor is the compensation paid to supervisory, quality inspection and assurance, manufacturing engineering, planning, expediting and tool and equipment maintenance personnel. Indirect material includes those items purchased by the company that do not end up in the product. For example, manufacturing supplies and other consumables such as light, heat, and power. Facility leasing is the rental cost of the land and building in which the product is manufactured. Inventory cost is the value

Table 2-2. Typical Manufacturing Company Income Statement

REVENUES
- Sales
- Other revenues

EXPENSES
- Cost of merchandise
  - Direct labor
  - Direct material
  - Factory overhead
    - Indirect labor
    - Indirect material
    - Facility leasing cost
    - Inventory cost
- Amortized Capital equipment
- Selling
  - Selling labor
  - Advertising
  - Etc.
- Research and development
  - R&D labor
  - R&D material
- General and administrative
  - Salaries of general managers/administrations
  - Insurance
  - Property taxes
  - Etc.
- Interest

INCOME BEFORE TAXES

INCOME TAX

NET INCOME

of the material that must be kept in stock to allow a smooth manufacturing flow.

- Amortized Capital Equipment -- This is an expense reflecting using up the usefulness of capital equipment which produces the product.
- Selling Expenses -- Those operating expenses which are incurred for the purpose of selling and distributing the product
- Research and Development Expenses -- Those expenses associated with the development of new products
- General Administrative Expenses -- Those expenses associated with the general management of the business
- Interest -- The cost of financing the business
- Income Tax -- The tax that is related to the income reported for the period

SECTION 3

PRODUCTION PLAN

This section discusses production plans and production cost estimates. The overall production approach is presented i ·tion 3.1. Sections 3.2, 3.3, and 3.4 present specific plans and cost ·nates for the reflective panels, purchased parts, and the steel structure, respectively.

3.1 OVERALL PRODUCTION APPROACH

The overall production approach for the Advanced Solar Concentrator at the 100,000 unit per year production rate is:

- Reflective Panels -- The reflective panels are assembled from purchased glass components. This is accomplished in a single plant located adjacent to a glass manufacturing plant. The finished panels are shipped to regional final assembly facilities located near the solar energy system installation sites.
- Drives, Electrical, and Control -- These components are purchased parts. They are shipped by the vendors to the regional final assembly facilities. In actual implementation, these parts may be made in-house, but within the scope of this study, it was decided to rely on vendor quotes to provide cost estimates. It is anticipated that the economics would not be

significantly different for in-house manufacture at the 100,000 unit per year production rate.

- Structure -- The structure subassemblies of the concentrator are fabricated at regional plants of approximately 20,000 units per year capacity. These plants are to be located close to the areas in which the concentrators will be installed. These regional structural steel fabrication plants are colocated with the concentrator final assembly facilities.
- Final Assembly -- The various elements of the concentrator are brought together at a regional final assembly plant, located next to the structure fabrication facility. In this facility, the concentrator is virtually fully assembled, before airshipping to the site. All elements which attach to the pedestal (structure, reflective panels, drives, controls) are assembled in the factory to save on expensive field labor.
- Shipping -- The fully assembled concentrator (except for pedestal and track) is shipped to the site by airship or helicopter. By using airshipping, field assembly labor is kept to a minimum, and total installed cost is reduced.

Table 3-1 presents a summary of the cost estimates developed for the individual production plans. These plans are presented in the following sections.

3.2 REFLECTIVE PANELS PRODUCTION PLAN

This plan defines the requirements and costs for production of the reflective panels, or gores, for the Advanced Solar Concentrator.

Based on the preliminary concentrator design, 20 inner and 40 outer gores are required per concentrator. Each gore consists of a thin

Table 3-1. Production Cost Summary
(per concentrator @ 10^5 units/yr, 11 m aperture)

Production Costs	1980 $ $/conc
1000 Reflective panels	3905
2000 Drives	1353
3000 Electrical and control	917
4000 Structure	2868
5000 Factory assembly	228
	9271

backsilvered mirror glass reflector flexed to a paraboloidal shape and continuously bonded to a precontoured cellular glass core. An unsilvered sheet glass spar cap is bonded longitudinally along the backside of the gore for added strength. All nonreflective surfaces are protected from environmental damage with a conformal coating applied at the factory.

The cellular glass core is machined to shape from a gore blank. The gore blank is made up of 18 inches x 24 inches x 4 inches cellular glass blocks adhesively bonded together. The preliminary design gore blank was made up of 13 blocks. During detailed design of the reflective panel, a gore blank was designed which required only 7.5 blocks, thereby saving 40 percent in material costs (or approximately $1300 per concentrator). In addition, a 24 inner gore/40 outer gore configuration was shown to be superior. It was therefore decided to use the detailed design gore blank and the 24/40 configuration. However, the overall production plan is based on the preliminary design, as it offers significant cost savings, is the best available design, and does not significantly affect the balance of the concentrator.

The following presents a summary of the production plan for the panels. The panel material requirements and costs, the process flow, the labor requirements and costs, equipment, and factory overhead are each discussed.

Material Requirements and Costs

To develop the material requirements for production of a particular item, a make-or-buy analysis is conducted. This make-or-buy analysis considers the options for purchase or fabrication of components. These considerations relate to the economic and technical feasibility of making components in-house versus purchasing from an outside supplier. Since no company presently manufactures reflective cellular glass panels, it was decided that the gores would be fabricated in-house. The glass components of the panels will be purchased as these materials are supplied by existing suppliers who have the experience and facilities to make them at less cost than would be possible by the concentrator production company.

The material requirements and costs as developed for the reflective panels are listed in Table 3-2. The initial unit requirements per concentrator were derived from the design information. Yield and scrap factors were used where applicable; the yield factor covers expected process waste such as for the adhesive during gore blank bonding; the scrap factor covers breakage, loss, and damage of components during production. These factors were applied to determine the total material required per concentrator produced. Costs per unit were applied to determine the total material cost per concentrator. Unit cellular glass cost estimates were supplied by Pittsburgh Corning Corporation and sheet glass costs by Corning Glass Works.

Process Flow

Having determined which items to buy and which to make, a production process flow was developed to determine requirements for factory labor, equipment, facilities, and factory overhead costs. The panel production facility envisioned for the 100,000 concentrators per year rate is a highly automated facility, making extensive use of robotics to perform the repetitive tasks necessary to manufacture the gores.

The process flow is shown schematically in Figure 3-1. These process steps are based on preliminary assessments for materials whose process technology is still under development. The production process consists of the following steps:

Table 3-2. Reflective Panels Bill of Materials
(per concentrator @ 10^5 units/yr, 11 m aperture, 1980$)

CBS Element	Amount/conc	Scrap	Waste	Total Amount	$/unit	$/conc	$/m^2
1000 Reflective panels 1100 cellular glass 7.5 Blks x 40 outer 7.5 Blks x 24 inner	480 blocks	2%	0%	490 blocks	3.72[a]	1821	19.17
1120 Reflective surface 16 ft^2 x 40 outer 14.7 ft^2 x 24 inner	993 ft^2	3.5%	0%[c]	1028 ft^2	0.90[b]	925	9.74
1130 Spar Cap 6.8 ft^2 x 40 gores 5.8 ft^2 x 24 gores	411 ft^2	2.5%	0%[c]	421 ft^2	0.40[b]	169	1.77
1140 Attachment hardware	64 pieces	1%	0%	65 pieces	6.54	425	4.47
1150 Adhesive	82 lbs	2%	30%	109 lbs	1.20	130	1.37
1160 Coating	17.4 gal	2%	10%	20.5 gal	7.00	144	1.52
1170 Protective cover	993 ft^2	2%	0%	1013 ft^3	0.05	51	0.54
Total material cost						$3665	$38.58

[a] Cost estimate source -- Pittsburgh Corning
[b] Cost estimate source -- Corning Glass Works
[c] Delivered cut to shape.

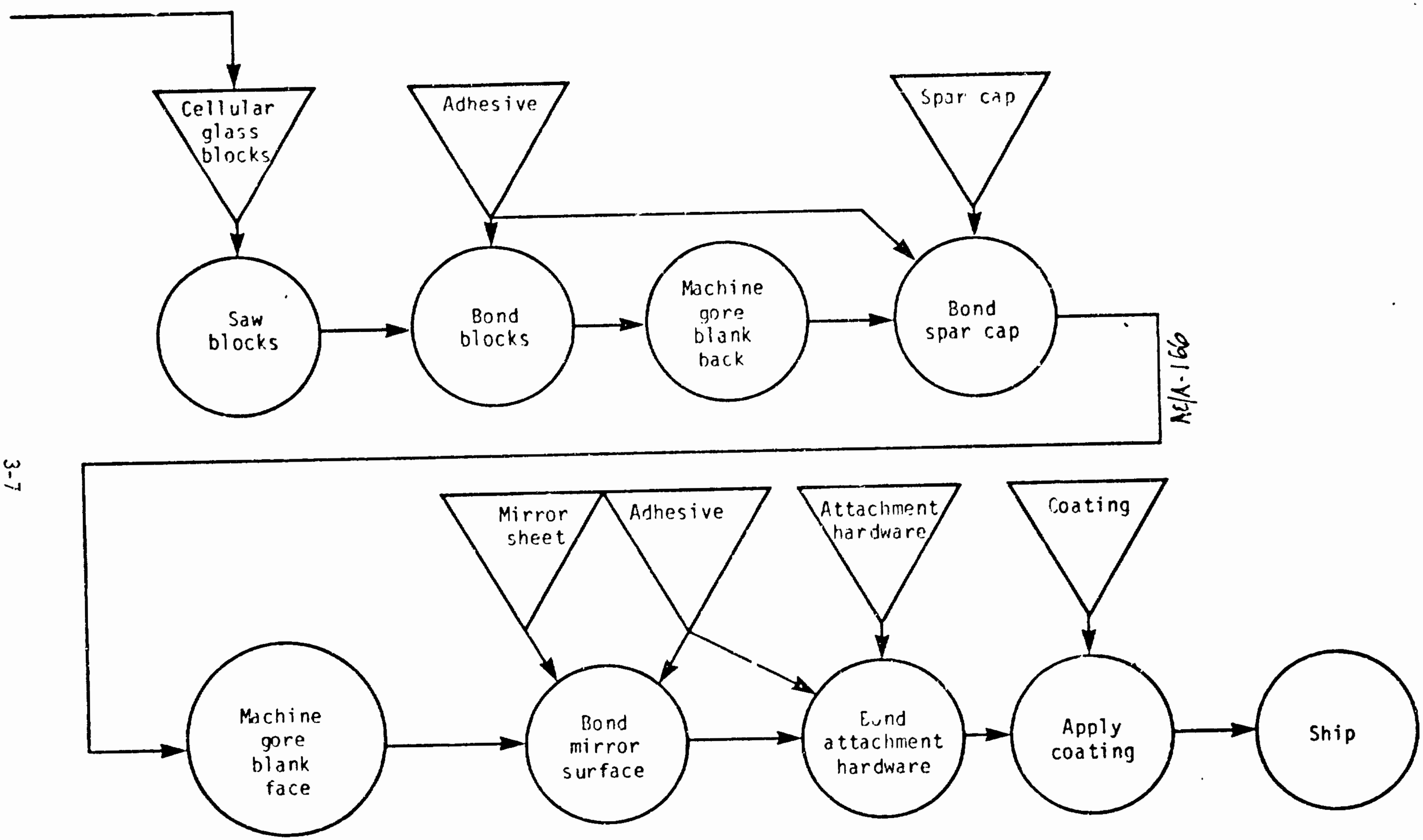

Figure 3-1. Panel Production Process Flow

1. Saw blocks -- The cellular glass blocks are automatically fed to saws and sawed into the various shapes which are to be bonded together to make up the gore blank.
2. Bond blocks -- The sawed pieces have adhesive applied, are loaded into bonding fixtures by robots, and are cured in a microwave oven to form adhesively bonded gore blanks.
3. Machine Gore Blank Back -- The back of the gore blank is machined to shape by numerically controlled cutters.
4. Bond Spar Cap -- The spar cap (back glass sheet) is bonded to the back of the machined gore blank back. The spar cap will now provide a hardpoint for mounting the gore in fixtures for later steps in the process.
5. Machine Gore Blank Face -- The gore blank is loaded into a fixture, using a vacuum chuck on the spar cap surface for the face machining operation. Large numerically controlled cutters machine the face of the gore to the required paraboloidal shape.
6. Bond Mirror Surface -- The gore blank is loaded into a fixture for the bonding operation and adhesive is applied. The mirror sheet (shipped cut to shape) is put in place and forced down on the gore face via a ram and a rubber faced plug. The bond is cured in an oven.
7. Bond Attachment Hardware -- The gore attachment hardware is adhesively bonded to the spar cap and to the cellular glass substrate.
8. Apply Coating -- An edge seal is applied to the mirror sheet and a protective cover is applied to protect it during

shipment. The exposed cellular glass areas of the gore are sprayed with the conformal coating and cured in an oven.

9. Ship -- The finished gores are loaded into reusable shipping cradles for shipment to regional assembly plants via rail or truck.

Labor, Equipment, and Overhead Requirements and Costs

Based on the process flow developed for the gores production, factory labor and equipment needs were estimated and costed.

Table 3-3 shows the requirements for labor application, equipment costs, facility space, and indirect material expenses which were estimated for each of the production process steps. Supervisory labor and warehousing costs are included. These requirements were then used to estimate total labor, equipment and overhead cost for reflective panel production. A summary of these costs are shown in Table 3-4.

Summary

The summary of production costs for the gores is shown in Table 3-5. This summary shows that the dominant cost for production of the panels is for materials. Only 6 percent of the costs are due to nonmaterial items.

Of the material costs, the dominant cost is for the cellular glass blocks used to make the gore blanks. Since approximately 50 percent of the glass is ground away in the process of shaping the gore blank, there is a potential cost reduction by additionally investigating schemes to reduce the cellular glass required to create the gore blank.

3.3 PURCHASED PARTS

The components for the drives (CBS 2000) and the electrical and control (CBS 3000) subsystems will be purchased from appropriate vendors and shipped to regional final assembly facilities.

Table 3-3. Gores Production Labor, Equipment, Space, and Indirect Materials Breakdown
(@ 10^5 units/yr, 11 m aperture, 1980$)

Operation	Men[a] Required per Shift	Total Men	Capital[a] Equipment ($K)	Space (kft^2)	Indirect Materials ($K/yr)
Saw	15	45	1,080	4.0	80
Bond blocks	13	39	2,622	5.8	78
Machine back	15	45	1,040	2.1	260
Bond hardback	6	18	315	1.9	55
Machine face	21	63	2,520	20.7	1,080
Bond face	48	144	4,801	10.3	161
Bond hard paint	7	21	1,276	2.4	28
Package	51	153	1,540	5.8	100
Aisles and offices	25	45	1,200	20.0	175
Warehouse	15	40	1,100	1,200	100
Total		613	17,494	1,273	2,117

[a]Maintenance and other downtime included in labor and equipment efficiency factors.

Table 3-4. Gores Production Nonmaterial Cost Summary
(@ 10^5 units/yr, 11 m aperture, 1980$)

	$K/yr	$/conc
Labor (Direct)		
613 people @ $12 K/yr average[a]	$ 7,356	$ 74
Tooling and equipment		
$17,494 K @ .20 CRF[b]	$ 3,499	$ 35
Overhead		
Gross rent - space, taxes, utilities, etc.		
73 kft^2 @ $5.40/yr	$ 394	
1200 kft^2 @ $2.50/yr	$ 3,000	
Indirect materials	$ 2,117	
Inventory		
15 days @ $3665/conc @ 23%/yr	$ 5,058	
Fringe benefits		
(0.21 x 613 people x 12 K/yr)	$ 1,545	
Miscellaneous	$ 1,000	
OH cost	$13,114	$ 131

[a]Average of workers over three-shift operation
[b]Capital recovery factor.

Table 3-5. Reflective Panels Cost Summary
(per concentrator @ 10^5 units/yr, 11 m aperture, 1980$)

	Mat'l	Labor	Burden[a]	Total
1000 Reflective panels	$3665	$74	$166	$3905

[a]Equipment and overhead costs.

To develop these estimates, Pioneer (the structure and drives subcontractor) and Acurex surveyed various firms to obtain cost estimates for the components. Vendors were requested to supply the estimates at a 100,000 concentrators per year production rate.

3.3.1 Drives

The cost estimates and sources for the drive components are listed in Table 3-6.

3.3.2 Electrical and Control

The cost estimates and sources for the electrical and control components are listed in Table 3-7.

3.4 STRUCTURAL STEEL PRODUCTION PLAN

The production plan for the structural steel components of the Advanced Solar Concentrator was developed by Pioneer. To provide an accurate costing, based on detailed work, and still keep the scope manageable, Pioneer used a cost driver technique. This technique involves the detailed analysis of a portion of the elements to be costed which is judged to be representative of the total. The costs are then scaled

Table 3-6. Cost Estimates for Drive Components
(per concentrator @ 10^5 units/yr, 11 m aperture, 1980$)

CBS Element	$/conc	$/m^2	Source
2000 Drives			
2100 Azimuth			
2110 Motor	187	1.97	Boston Gear list price/scaled by Acurex
2120 Gear reduction	172	1.81	Boston Gear est @ 10^5/yr (Pioneer)
2130 Sprockets (2)	32	0.34	" " " " " "
2140 Wheels (2)	54	0.57	Pioneer est. @ 10^5/yr
2150 Chain assembly	167	1.76	Boston Gear list price/scaled by Acurex
Azimuth Total	612	6.44	
2200 Elevation			
2210 Motor	70	0.74	Boston Gear list price/scaled by Acurex
2220 Gear reduction	71	0.75	Est. by Acurex from CBS 2120 by $/lb.
2230 Ball screw actuator	600	6.32	Ball Screw and Actuator Corp. estimated @ 10^3/yr/scaled by Acurex
Elevation total	741	7.80	
Total drives cost	1353	14.24	

Table 3-7. Cost Estimates for Electrical and Control Components (per concentrator @ 10^5 units/yr, 11 m aperture, 1980$)

CBS Element	$/conc	$/m²	Source
3000 Electrical & Control			
3100 Tracker (Control)			
3110 Microcomputer	20	0.21	Intel price @ 10^5/yr
3120 Photodetector assembly	100	1.05	Estimated by Acurex
3130 Shaft encoders (2)	200	2.11	BEI Corp. list price/scaled by Acurex
3140 Cabling	60	0.63	Estimated by Acurex
3150 Enclosure/hardware	78	0.82	Hoffman list (box)/scaled by Acurex; others estimated by Acurex
Control total	458	4.82	
3200 Electrical			
3210 Receiver/generator fused disconnects (2)	19	0.20	Square "D" list price/scaled by Acurex
3220 Drive motor controls (2)	187	1.97	Square "D" design/cost estimated by Acurex
3230 Distribution panel	18	0.19	Electrical Material Inc., cat. price/ scaled by Acurex
3240 Cabinet	106	1.12	Hoffman list price/scaled by Acurex
3250 Cabling	91	0.96	Est. by Acurex
3260 Lightning protection	38	0.40	Manfufacturer's list prices/ scaled by Acurex
Electrical total	459	4.83	
Total E&C costs	917	9.65	

upwards by an appropriate means to estimate the costs for the overall assembly.

For the concentrator, the cost driver element selected was the gore support ring, and the means used to scale the costs upward to represent the total was to scale by dollars per pound of steel.

The steps taken by Pioneer to perform the detailed analysis of the gore support ring were:

- Conduct manufacturing process analysis (production plan)
- Estimate material costs
- Estimate labor time required for each process
- Calculate labor cost
- Apply variable burden rates

In the production plan developed by Pioneer, the structure fabrication plant is a highly automated facility using robotics, automatic fixtures and automatic welders to perform the many repetitive tasks. Corten steel was selected as the material to be used for the structure elements. Corten is a weathering steel which forms its own protective oxide coating upon exposure to the elements. This eliminates the need for painting at the factory, touchup painting after installation, and periodic repainting in the field. The slight extra cost of Corten (about 2 cents per pound) is offset by the savings in factory painting alone.

The work flow developed by Pioneer for the gore support ring is shown in Figure 3-2. In this work flow, the Corten is received as sheet stock and rolled to tube in-house. The gore ring is assembled in 45^{0} segments and then assembled into the complete gore support ring.

Pioneer developed a detailed work element breakdown based on this work flow. This breakdown was used to develop detailed estimates of the

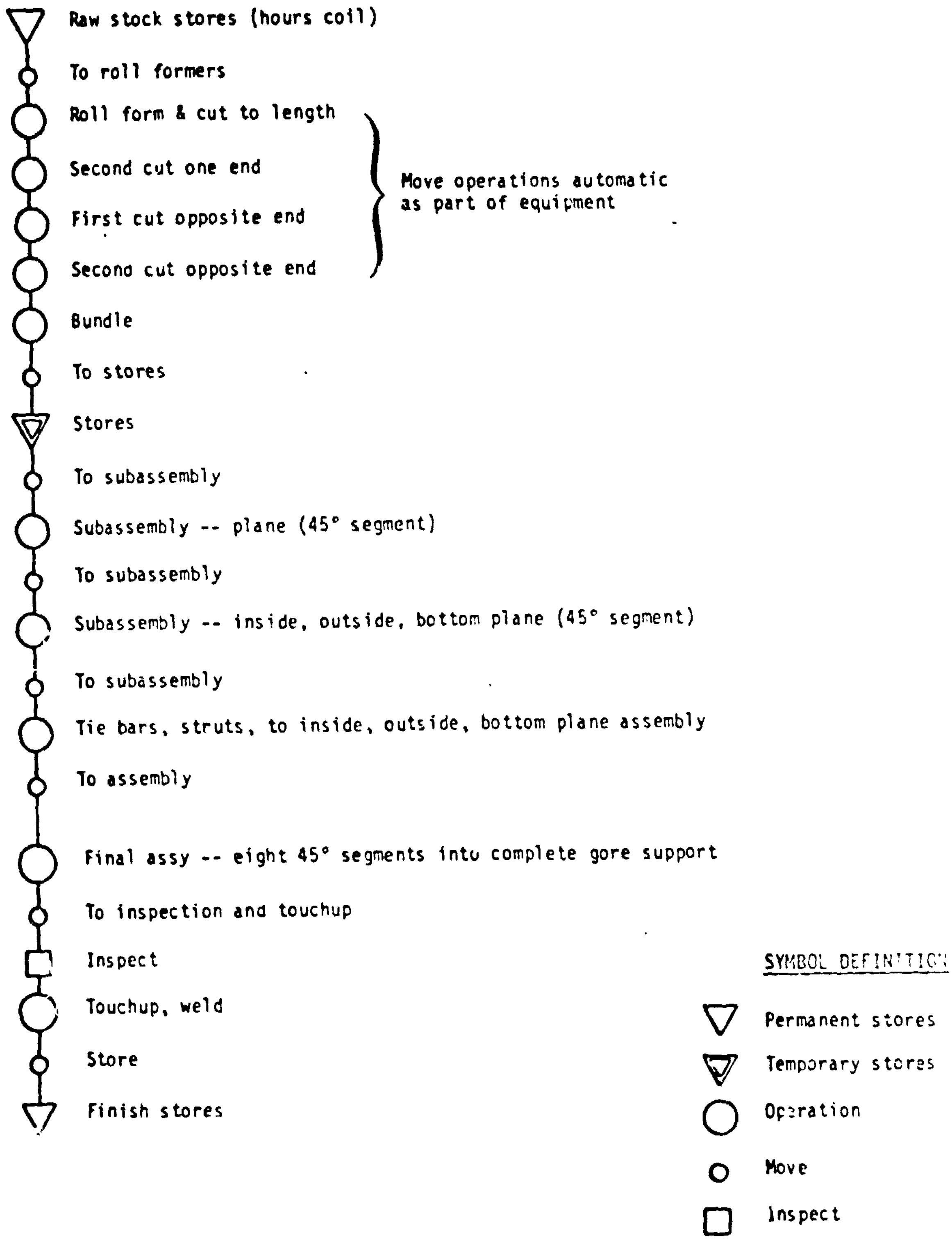

Figure 3-2. Work Flow -- Gore Support Ring

manufacturing direct labor requirements and costs. Pioneer then applied variable and fixed burden costs to the work elements based on their experience in manufacturing engineering and costing. Table 3-8 lists the elements included in variable and fixed burden.

Table 3-9 presents a summary of the cost estimates for the structure. Included is the cost for the counterweights although they are not manufactured in the structure plant. The counterweights are precast concrete and are delivered directly to the field site. They are included in the structure costs as they are an integral part of the structure design.

3.5 FACTORY ASSEMBLY

The concentrator is shipped to the site as an assembled unit under the overall production approach. Specifically, this means that the concentrator is shipped as a completed track ring, a completed pedestal, and a completed concentrator assembly comprising the remaining elements including the structure, drives, and gores, mounted and aligned. The factory assembly task (CBS 5000) addresses the mounting and aligning of the gores on the gore ring and the final fabrication of the concentrator assembly.

The final assembly facility is a highly automated plant located next to the structure plant. The drives, electrical, and control components and gores are shipped to the facility for integration with the structure.

The gores are mounted to and aligned with the gore support ring at a large automated mounting station. The structure (including the gore ring with gores mounted), drives, electrical, and control elements are assembled on wheeled carts. The wheeled carts provide a temporary

Table 3-8. Variable and Fixed Burden Elements

Variable burden includes: Offal losses Setup charges Manufacturing scrap Perishable protection tools Inbound freight Operating utilities Operating supplies Line inspection Material handling Production inventory cost Fixed burden includes: Indirect labor (all support) Indirect material Taxes Insurance Depreciation (building, equipment)

Table 3-9. Structure Cost Summary
(per concentrator @ 10^5 units/yr, 11 m aperture, 1980$)

		Material	Labor	Burden	Total
4000 Structure					
4100	Gore support ring	$ 407	$ 61	$152	$ 620
4200 thru 4600	Balance of structure and track	1715[a]	152	381	2248
		$2122	$213	$533	$2868

[a]Includes precast concrete counterweights delivered directly to field site @ $535.

pedestal on which the concentrato. ·· assembled and a means of moving the concentrator to the staging area where it is picked up for air shipment to the site. The carts are moved about by tractor units. The final assembly station has automated material handling equipment to speed assembly of the large structure elements.

In the stow position, the elevation actuator shaft extends well beyond the structure. It will therefore be mounted in the field, and a short, temporary tiedown shaft used for factory assembly and shipping.

A summary of the direct labor and burden costs for the factory assembly tasks is listed in Table 3-10.

Table 3-10. Factory Assembly Cost Summary
(per concentrator @ 10^5 units/yr, 11 m aperture, 1980$)

	Material	Labor	Burden	Total
5000 Assembly				
5100 Gores mounting/aligning	0	$23	$100	$123
5200 Final assembly	0	22	83	105
	0	$45	$183	$228

SECTION 4

SHIPPING PLAN

An integral part of this mass production plan for the concentrator is the use of airships (nonrigid types, also known as blimps) to ship the concentrator. This section reviews the reasons for selecting this innovative shipping technique and the estimate of its cost.

4.1 SHIPPING TRADE-OFF

For large structures to be installed in the field there exists a trade-off between factory assembly, shipping and site assembly costs. To minimize site assembly cost, one should automate factory assembly and ship the largest assemblies possible. To minimize shipping costs, one should break the structure down as much as possible to ship as little "air" as possible. To minimize total installed costs, one must choose the approach which results in the lowest total of factory assembly, shipping, and site assembly costs.

The standard commercial shipping method to deliver the Advanced Solar Concentrator to the site would be either rail or truck. However, both have approximately the same shipping size limits and both would require considerable structure breakdown and field assembly labor. It is size, not weight, that is the constraint in shipping the concentrator in a manner which minimizes field labor.

Airshipping via helicopter or airship is essentially a no-size limit shipping method. Such an airshipping operation would involve the aircraft picking up a virtually complete concentrator at a regional assembly plant and airlifting it to the field site.

To investigate which shipping method results in the lowest total installed cost, a trade-off was performed. Costs for factory assembly and site assembly were estimated based on Acurex experience. Costs for truck shipping were estimated based on a truck fleet owned by the concentrator production company. Costs for shipping by helicopter and airship were estimated using information in a report on potential civil markets for airships prepared for NASA by Booz-Allen (Reference 3) and information obtained through communications with Goodyear Aerospace.

This preliminary trade-off developed the following conclusions:

- Helicopter shipping of assembled concentrators results in higher total installed cost than truck shipping when present helicopter charter costs are used. Helicopter shipping can be competitive using a dedicated fleet owned by the concentrator production company.
- Airships offer cost reductions beyond helicopters due to lower fuel and powerplant maintenance costs.
- Airshipment of assembled concentrators results in lower total installed cost than truck shipment.

4.2 TECHNICAL FEASIBILITY OF AIRSHIPPING

In one sense, airships can be considered a 1930 technology as most current work relies heavily on development which took place at that time. Airships were used by the Navy up to the early 1960's for patrol and reconnaissance missions. Presently, the only operating U.S. airships are a fleet of three Goodyear promotional blimps. However, there is currently a serious revival of interest in the use of airships.

Heavy-lift helicopters are currently used commercially in the U.S. for logging, construction, transmission tower erection, and servicing off shore oil platforms. Boeing-Vertol and Sikorsky are both currently marketing civilian versions of military heavy-lift helicopters to meet the expanding civil demand.

The current interest in airships stems from their advantages over helicopters in fuel costs and powerplant maintenance. Since the lifting capacity comes in total or in part from the airship's buoyant force and not from engines, the fuel use is significantly reduced, powerplant maintenance costs are lower as the engines are not as heavily loaded, and engines can be smaller. Airships can be built with present technologies in lifting capacities up to 500 tons, compared to the helicopter's capacity of approximately 10 to 20 tons. This opens up many new markets for airshipment, including transport and rigging of heavy oversized equipment such as powerplant components.

Airship development is currently active at the study level. NASA has funded and is funding several studies on airship design for cargo and passenger airship markets. The contractors conducting these studies include Boeing, Goodyear Aerospace, and Booz-Allen. The Province of Alberta Ministry of Transportation has commissioned a study by Goodyear on the feasibility of using airships to meet current and projected transportation needs (Reference 4). The U.S. Navy and Coast Guard have shown interest in the use of modern airships for submarine patrol and 200 mile fishing limit regulation.

There is currently a prototype airship development project under way. The Piasecki Aircraft Corp. is under contract to the U.S. Department of the Interior to construct a heavy-lift logging airship using a surplus Navy airship envelope and four Navy Sikorsky S-61 helicopters as propulsion and control units.

4.3 AIRSHIPPING COST ASSESSMENT

This section discusses the cost estimates for operation of a candidate airship for delivering assembled solar concentrators from regional final assembly facilities to the field sites. The assembled concentrator elements would be carried in a shipping cradle to distribute the load over the structure. With the precision hover capabilities offered by modern propulsion and control technologies, the airship would be able to pick up and drop off the concentrators without landing and with a minimum of ground assistance. Air speed would be kept below 80 km/hr when loaded to keep below the wind specification for the concentrator. An alternative allowing higher transport velocities would be the use of an aerodynamic shroud which would protect the concentrator while reducing drag. The airship concept selected as the candidate for shipping the assembled concentrator units is a type similar to that shown in Figure 4-1. Its propulsion and control will be provided by combination rotor/propeller engine units to provide horizontal and vertical thrust or by vectorable engine modules which can be oriented to provide thrust in the desired direction.

The costs for purchase and operation of this airship were estimated using costing formulas developed by Booz-Allen in a market study of civil markets for heavy-lift airships (Reference 3). Table 4-1 lists the cost

Figure 4-1. Airship Concept

Table 4-1. Cost Elements in Airship Costing Formulas

- Development cost (including certification)
- Flyaway cost versus quantity produced (including all production associated costs)
- Spare costs
- Vehicle depreciation
- Insurance costs
- Helium replenishment
- Flight crew cost
- Maintenance labor costs
- Maintenance material costs
- Burden on direct labor
- Fuel and oil costs
- Operations support cost
  - Buildings, equipment, vehicles, storage facilities
  - Ground support equipment
  - Ground handling and mooring facilities and equipment
  - Operations support maintenance and maintenance burden
  - Real estate taxes
  - Operations support operating costs
  - Operations support staff costs

elements included in these formulas. The inputs to the formulas used for this costing were:

- 25 ton useful capacity (5 concentrators @ 9650 pounds per concentrator)
- 140 mile round trip to deliver concentrator (average round trip to deliver within 100 mile radius)
- 2000 hours of operation per year
- 80 kilometers per hour speed to site, 150 kilometers per hour speed returning
- 5 minutes of hover time at each end
- 2.3 hour round trip time
- 23 airships required to service a 100,000 per year concentrator production rate
- Costing performed assuming airship production run of 25

Based on these inputs, the costs for airship operation were estimated and are listed in Table 4-2. The total estimated shipping cost per concentrator is $962 (1980$). This total cost of airshipping could be justified by a savings of only 42 hours in field labor (at $23 per hour, loaded) or a 6 man crew working for one day. As the installation section will discuss, the savings in field labor is more than sufficient to justify this approach.

Table 4-2. Airship Cost Estimates (1980$)

•	Capital cost	$10.1 million (including all support equipment and facilities)
•	Fixed annual cost	$1070/flight hour (depreciation, interest, insurance)
•	Variable cost	$ 985/flight hour (fuel & oil, maintenance)
•	Total cost	$2055/flight hour
•	Shipping cost per concentrator	$962/concentrator

SECTION 5

INSTALLATION PLAN

This section discusses the installation plan and cost estimates prepared by Newbery Constructors. Newbery has wide experience in construction in the U.S. southwest and in transmission tower erection, a type of construction similar to that of a point focus solar concentrator. The results will be presented here at the summary level.

The assumptions used in developing the plan were:

- 100 concentrators per field
- 10 rows of 10 concentrators on 30 foot centers
- Fields located in U.S. southwest
- Site is flat, without ravines or hills

Based on the types of construction tasks involved and an expressed interest by the International Brotherhood of Electrical Workers-Outside Line Constructors in obtaining jurisdiction over such work, they were selected as the basis for productivity and labor rates for the installation cost estimates.

Equipment rental rates used in the preparation of this estimate were derived from the "Rental Rate Blue Book for Construction Equipment" (Reference 5). The rental rates are used although the equipment will be owned by the concentrator company. Rental rates reflect the contractor's costs of owning and maintaining the various pieces of equipment. Blue

Book monthly estimates for equipment rental are based on a regular shift of 8 hours per day, 40 hours per week, 176 hours per month, for a total of 22 working days per 30 day period. Hourly rental rates used in this cost estimate were arrived at by using the Blue Book monthly rental, divided by 176 hours, plus operating and maintenance costs.

The cost summary breakdown for the installation tasks is shown in Table 5-1. The total cost shown for installation is $5,730 per concentrator (1980$). The following sections will discuss the plans in greater detail.

5.1 SITE PREPARATION

The site preparation task addresses surveying, clearing of brush, and preparation of the topsoil for foundation installation. The total cost for site preparation is $1762 per concentrator (1980$). The site preparation costs and the scope of work proposed by Newbery were compared to actual site preparation costs for construction jobs in which Acurex is actively involved. The estimated costs are consistent with those jobs. This estimate was also compared to a JPL study on site preparation costs for solar thermal power plants (Reference 6). The cost estimated for the Advanced Concentrator ($9170/acre, 1980$) falls within the lower part of the range of the study's estimated costs, which varied from $8,000 to $62,175 per acre (1979$).

The detailed cost estimates supplied by Newbery for labor, equipment, and materials for site preparation, along with the details on the assumptions used in preparing them, are presented in Appendix A.

5.2 FOUNDATION INSTALLATION

The foundation installation task covers the installation of the cast-in-place reinforced concrete piers for the track and pedestal. The

Table 5-1. Installation Cost Summary

(per concentrator @ 10^5 units/yr, 11 m aperture, 1980$)

	Material	Labor	Equipment	Total
7000 Installation				
7100 Site preparation	$ 24	$ 754	$ 984	$1762
7200 Foundation installation	1074	1280	516	2870
7300 Site assembly	26	840	232	1098
	$1124	$2874	$1732	$5730

activities covered are drilling of the holes, placing of the rebar cages, and pouring of the concrete. The total cost for the foundations is estimated to be \$2870 per concentrator or \$590 per cubic yard (cyd) of concrete (1980\$). This compares to actual costs for Acurex solar installations with reinforced cast-in-place concrete piers of \$400/cyd and \$605/cyd (Coolidge, Arizona irrigation system and Sherman, Texas industrial process heat system, respectively, in 1980\$). The Advanced Concentrator costs occur in the higher part of the range due to the arrangement of the piers, i.e., the 12 piers for the track arranged in a circle with the 3 piers for the pedestal in the center. The circular arrangement adds to the cost by requiring more time for accurate locating of the piers and difficulty of access for repositioning of installation equipment. Large automatic equipment was considered but for installations of 100 units per field, the equipment would have to be moved often and the setup and teardown expenses outweigh the cost benefits.

The detailed cost estimates for the foundation installation are provided in Appendix B.

5.3 SITE ASSEMBLY

The site assembly task covers the mounting of the airshipped structural elements to the foundations, using helicopters for movement of components at the site, and the final hookup of drives and control components. Receiver/power conversion installation is not part of the concentrator installation.

Newbery, which has experience in transmission tower erection using helicopters, developed the detailed cost estimates for these tasks, which are shown in Appendix C. The total cost is \$1098 per concentrator (1980\$). This includes 36 hours of field labor over a period of time of 6.5 hours.

The field assembly procedure for the concentrator is as follows:

- The three elements of the concentrator, track assembly, pedestal, and concentrator assembly would be airshipped to the site and placed in a laydown area
- The track with chain assembly mounted is carried to the foundation by a small helicopter, landed on the foundation bolts, and tightened down
- The pedestal, with the azimuth bearing and control boxes mounted, is carried by the same small helicopter and mounted in the same manner
- The concentrator assembly, comprising the remainder of the concentrator, is mounted in the same manner, to the azimuth bearing, by a larger capacity helicopter (8500 pounds)
- The drives are already mounted to the concentrator assembly. However, the elevation actuator shaft, which is not mounted in the factory due to clearance problems when shipping in the stowed position, must be attached in the field and the azimuth drive chain placed on the drive sprockets and tightened.
- The counterweights are lifted into place and attached
- The controls are connected from the pedestal to the concentrator assembly and to the field wiring to complete the site assembly
- The concentrator is functionally checked

SECTION 6

OPERATIONS AND MAINTENANCE

This section discusses the requirements and costs for operating and maintaining the concentrator. The analysis is based on costs unique to the concentrator; that is, costs for maintenance of roads, site, and other field related items are not included.

The estimated annual costs for operation and maintenance of a single concentrator are summarized below:

		Cost per year (1980$)
• Operation		$ 8
• Scheduled maintenance		159
• Unscheduled maintenance		32
	Total	$199 per concentrator per year

The corresponding costs per 100 unit field and per unit aperture area are:

- Cost (1980$) per 100 unit field -- $199,000 per field per year
- Cost (1980$) per m^2 aperture area -- $2.09 per m^2 per year

6.1 OPERATIONS

Operating costs are limited to parasitic electric power requirements. Table 6-1 describes the parasitic power, annual hours of operation and total annual energy use.

Table 6-1. Parasitic Energy Requirements

Parasitic Power Use	Power (kW)	Operation (hrs/yr)	Annual Energy Use (kW-hr/yr)
• Azimuth drive motor (1/5 hp)	0.15	216	32.4
• Elevation drive motor (1 hp)	0.75	94	70.5
• Instrumentation and control	0.01	8760	87.6
		Total	191

The annual hours of operation for the azimuth and elevation drives were developed as follows:

- All motors stepper-type (start and run currents equal)

Azimuth

- 180^{o} average travel tracking per day
- 180^{o} travel returning to morning position per day
- 300 days operation per year
- 20 percent other use factor (for cleaning, maintenance)
- 10^{o} per min slew rate

Elevation

- 15^{o} dish rotation at wake-up
- 90^{o} average rotation tracking
- 15^{o} to retire each day
- 300 days of operation per day
- 60 stow cycles per year (due to clouds, high winds)

- 180° total travel per stow cycle
- 20 percent other use factor (for cleaning, maintenance)
- 10° per min slew rate

Based on the above assumptions, the azimuth drive operates for 216 hours per year and the elevation drive operates for 94 hours per year.

The annual cost of parasitic power is $7.64 per year based on a present delivered electric energy cost of $0.04 per kW-hr and a yearly consumption of 191 kW-hr.

6.2 SCHEDULED MAINTENANCE

Scheduled maintenance is performed to maintain performance and prevent failure of the concentrator. The elements of the scheduled maintenance plan are presented in Table 6-2. The estimates of labor, material, and frequency of scheduled maintenance operations are based on component duty cycles, vendor information, and Acurex experience. A loaded labor rate of $16 per hour was assumed.

The annual and 5-year scheduled maintenance costs were estimated at $153 per year and $32 per every 5 years for an average annual scheduled maintenance cost of $159 per year (1980$). The reflective panel cleaning cost is the major scheduled maintenance cost element. The development of the reflective panel cleaning cost estimate is presented below.

Reflective Panel Cleaning Costs

Two types of cleaning activities are required for the concentrator. Regularly scheduled operations are required to remove normal dust accumulation. Unscheduled cleaning is required in the event of muddy rains (light rain on a dusty surface) which cause an immediate and significant loss in surface reflectance. For the purpose of this cost assessment, unscheduled cleaning is reported in the scheduled maintenance

Table 6-2. Scheduled Maintenance
(per concentrator @ 10^5 units/yr, 11 m aperture, 1980$)

Task Description	Unit Labor*		Material Cost ($)	Frequency (act/yr)	Annual Cost ($)			5-Year Cost ($)		
	Hours	Cost ($)			Labor	Material	Total	Labor	Material	Total
7110 Scheduled maintenance										
7110 Reflective panels										
7111 Cleaning	0.27	4.27	3.63**	12	51	43	94	0	0	0
7112 Inspection	0.25	4	0	2	8	0	8	0	0	0
7113 Aligment	2	32	0	1/5	0	0	0	32	0	32
7120 Structures inspection	0.25	4	0	1	4	0	4	0	0	0
7130 Drive systems										
7131 Azimuth drive inspection & lubrication	1	16	10	1	16	10	26	0	0	0
7132 Elevation drive inspection & lubrication	0.25	4	1	1	4	1	5	0	0	0
7140 Foundations -- no maintenance	0	0	0	0	0	0	0	0	0	0
7150 Instrumentation and controls										
7151 Inspection	0.25	4	0	2	8	0	8	0	0	0
7160 Electrical subsystems										
7161 Inspection	0.25	4	0	0	8	0	8	0	0	0
Totals					99	48	153	32	0	32

*Based on loaded labor rate of $16/hour

**Includes amortized equipment cost

cost breakdown element, because the two types of cleaning are interactive (for example, both use the same cleaning equipment and an unscheduled cleaning replaces a scheduled cleaning).

The annual cost of unscheduled and scheduled cleaning of the reflective panels is dependent on the frequency of cleaning and the number of fields served by a single set of cleaning equipment. The optimum cleaning frequency and sets of cleaning equipment per field were determined by an economic trade-off between the four applicable cost elements, namely:

- Cost of cleaning labor and material
- Amortized cost of equipment
- Cost of energy loss due to ordinary dust buildup reflectance degradation
- Cost of energy loss due to muddy rain reflectance degradation

The development of each of these cost items and the results of the economic trade-off are developed in the following paragraphs.

The cost for labor and materials to clean the concentrator was estimated based on the results of Sandia studies (Reference 7). The Sandia results were extrapolated based on the concentrator reflective surface area (approximately 1200 ft^2).

The recommended cleaning procedure is:

- Fog on a deionized (DI) water/detergent 40:1 mix (3 gal DI water and 0.075 gal detergent per concentrator)
- Allow detergent mix to thoroughly wet surface
- Rinse with high pressure power spray DI water (15 gal DI water per concentrator)

The material and labor costs per concentrator cleaning are summarized in Table 6-3. Automated cleaning equipment will be used allowing the cleaning operation to be performed by one man.

At a cleaning rate of 16 minutes per concentrator, a 100 unit field can be serviced in approximately 27 working hours. With the consideration of field-to-field transmit, one set of cleaning equipment can service one 100 unit field in approximately 1 elapsed time week.

The cost of labor and materials per cleaning per concentrator is $5.20 (1980$).

The cleaning equipment will be self-powered and mobile, have storage tanks for DI water and detergent mix, and a movable extension arm with spray heads attached. The estimated initial cost of the cleaning system equipment is $60,000 with a 10 year life. Operations and maintenance costs for the equipment will be $4,000 per year. The annual equipment cost based on capital recovery factor of 0.149 is:

•	Capital investment recovery ($60,000 x 0.149)	= $ 8,940
•	Operations and maintenance	= 4,000
•	Yearly amortized equipment cost	= $12,940
•	Yearly amortized equipment cost per concentrator for a 100 unit field serviced by a dedicated set of cleaning equipment	= $129.40

Studies at Sandia (Reference 8) have developed a correlation between average reflectance loss and cleaning frequency. This data is presented in Figure 6-1 as average loss of reflectance versus cleaning cycle.

Sandia reports that a muddy rain (light rain on dust accumulation) will cause an immediate 40 percent degradation of reflectivity and will

Table 6-3. Cost per Cleaning per Concentrator
(@ 10^5 units/yr, 11 m aperture, 1980$)

a. Material	
• Deionized water 18 gal @ $0.01/gal	$0.18
• Detergent 0.075 gal @ $10/gal	$0.75
Total material cost	$0.93/cleaning/ concentrator
b. Labor	Time
• Spray detergent mix	2 min
• Detergent mix dwell time	½ min
• Rinse	6 min
• Equipment transit and set-up	1½ min
Time subtotal	10 min
• 20% factor-tank filling, interfield transit	2 min
• 75% field labor efficiency	4 min
Time total	16 min
Total Labor Cost = (16/60 hour)($16/hour) = $4.27/cleaning/concentrator	
Total Labor + Material Cost = $5.20/cleaning/concentrator	

1 man operation
loaded labor rate $16/hour

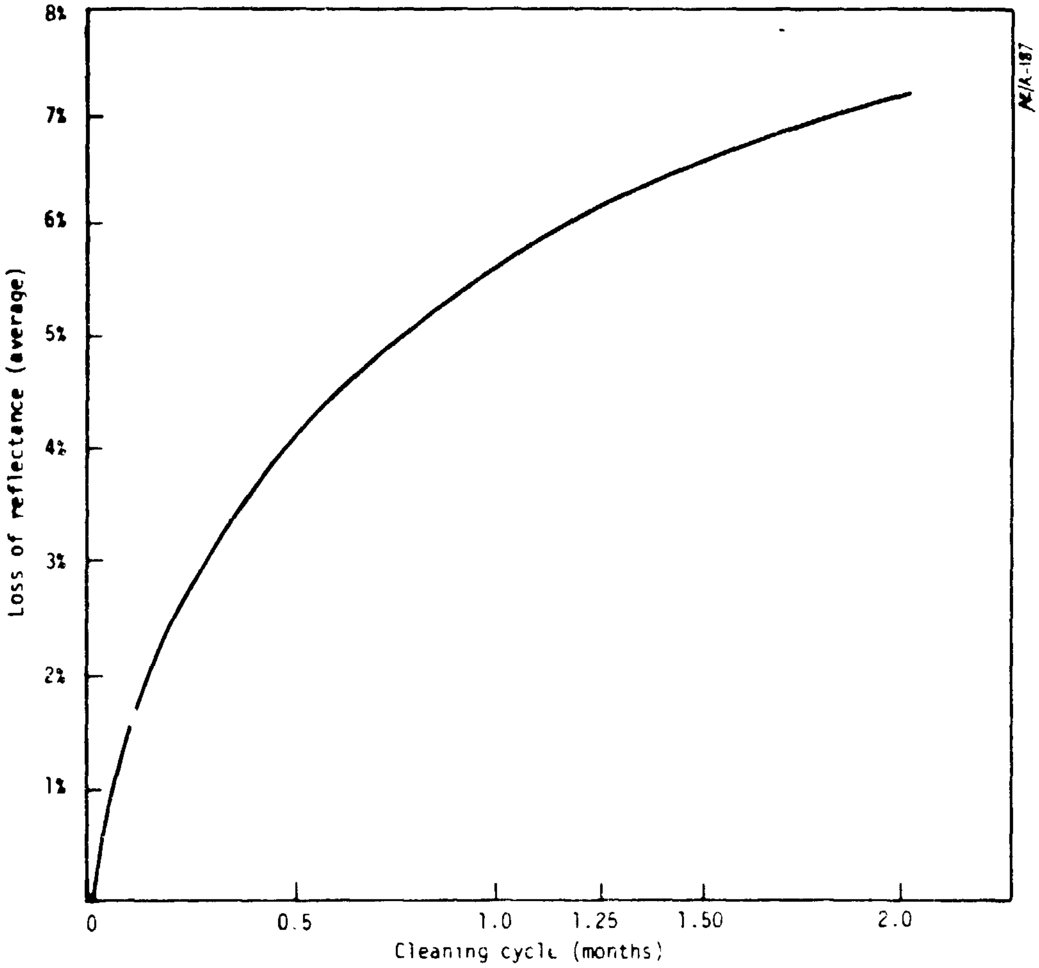

Figure 6-1. Loss of Average Reflectance versus Time

occur about three times a year. It was assumed that concentrators would be cleaned on a 24 hour per day basis in response to a muddy rain.

Preliminary performance and economic analyses using nominal values place a cost of energy from the receiver/generator at approximately $4400 per concentrator per year. The cost of losing one percent in reflectance on an average annual basis is therefore $44 per concentrator per year.

The economic trade-off for finding the optimum cleaning frequency and number of fields served by a single set of cleaning equipment to minimize the yearly cost of cleaning reflective panels is presented in Table 6-4.

Cleaning periods of one half month to two months (concentrator cleaning frequencies of 6 to 24 times per year) were investigated. For any choice of cleaning period, there exists a maximum limit on the number of fields which can be regularly serviced by a single set of cleaning equipment. For a cleaning period of once per month a maximum of four 100 unit fields can be serviced by a single set of cleaning equipment. Cases where less than the maximum number of fields are serviced by one set of cleaning equipment were also investigated. The cost of cleaning for each case in the matrix were developed.

The yearly cost of cleaning labor and material is $5.20 times the total number of cleanings per year. Since one unscheduled cleaning will replace one scheduled cleaning, the total number of cleanings per year is 12 divided by the cleaning period in months.

The amortized yearly cost of equipment is simply $129.40 divided by the number of 100 unit fields serviced by a single set of cleaning equipment.

Table 6-4. Reflective Panel Cleaning Economic Trade-off

Cleaning Period (months)	Maximum No. of Fields Served by One Set of Cleaning Equipment	Possible No. of Fields Served by One Set of Cleaning Equipment	Cost of Cleaning Labor and Material ($/conc/yr)	Amortized Cost of Equipment ($/conc/yr)	Cost of Ordinary Dust Build Up Reflectance Loss ($/conc/yr)	Cost of Muddy Rain Reflectance Loss ($/conc/yr)	Total Cost ($/conc/yr)
0.5	2	2	124.8	64.7	180	16.2	385.7
		1	124.8	129.4	180	8.1	442.3
1	4	4	62.4	32.3	242	32.3	369.0
		3	62.4	43.1	242	24.2	371.7
		2	62.4	64.7	242	16.2	385.3
1.25	5	5	49.9	25.9	264	40.4	380.2
		4	49.9	32.3	264	32.3	378.5
		3	49.9	43.1	264	24.2	381.2
1.50	6	6	41.6	21.6	286	48.5	397.7
		5	41.6	25.9	286	40.4	393.9
		4	41.6	32.3	286	32.3	392.2
2	8	8	31.2	16.2	317	64.6	429.0
		6	31.2	21.6	317	48.5	418.3
		4	31.2	32.3	317	32.3	412.8

The yearly cost of the energy loss from ordinary dust buildup is the average reflectance over the cleaning period (see Figure 6-1) times the cost of energy ($44 percent reflectance loss per concentrator per year).

The yearly cost (c) of the energy lost from muddy rain is the average response time (t), which is a function of the number of 100 unit fields serviced by a single set of cleaning equipment (n), times the yearly cost (K) of the 40 percent reflectance loss per concentrator. The applicable relationships are as follows:

$$t = \frac{100(\text{conc/field}) \times 16(\text{min/conc}) \times n(\text{fields})}{2} = 800 \times n(\text{min})$$

$$= 0.56 \times n(\text{day})$$

$$K = \frac{40(\%) \times 44(\$/\%/\text{conc/yr})}{365(\text{days/yr})} = 4.81\ (\$/\text{conc/day})$$

$$C = 0.56\ n(\text{days}) \times 4.81(\$/\text{conc/day}) \times 3(\text{occurrences/yr}) = 8.08 \times n(\$/\text{conc/yr})$$

The results of this economic trade-off show that a cleaning period of one month and 4 fields serviced per set of cleaning equipment produce the minimum total cost of reflective panel cleaning including the cost of energy loss due to reflectance degradation. Other important results from this trade-off are as follows:

- The cleaning cost is not strongly dependent on the cleaning period within the range of 0.5 to 1.5 months
- At any cleaning period above 1 month, the minimum cleaning cost is obtained with four 100 unit fields being serviced by a single set of cleaning equipment
- Within the cleaning period range of 0.5 to 1.5 months, the cleaning cost is not strongly dependent on the number of fields serviced by a single set of cleaning equipment

The cleaning approach for the reflective panels is therefore:

- Immediate response to muddy rains
- Scheduled cleaning once per month
- Each unscheduled cleaning will replace one scheduled cleaning
- One set of cleaning equipment services for every four fields of 100 concentrators each
- A total of 12 cleanings a year.

The annual cleaning cost breakdown for a single concentrator is:

Component	Cost/cleaning	Cost/year
Labor	$4.27	$51.24
Materials	$0.93	$11.16
Equipment	$2.70	$32.35
Total	$7.90	$94.75

6.3 UNSCHEDULED MAINTENANCE

The unscheduled maintenance plan selected for the concentrator is the repair-upon-failure approach. No periodic replacement of components is performed and they are only replaced upon failure or imminent failure as detected through periodic inspection

A preliminary economic analysis indicated that there was a cost advantage to the repair-upon-failure approach due to two main factors. The use of high reliability, long life components in a low duty cycle manner means their failure rate will be very low over the nominal 30 year life of the concentrator. Also, because of field modularity, the cost implications relative to field performance or damage due to any single oncentrator failure are small.

Average failure rates of the components over the life of the concentrator are needed to estimate the costs for repair and replacement. Based on component duty cycles, vendor information, and related Acurex experience, the average replacement rates have been estimated for a 30 year concentrator life.

The estimated component replacement frequencies, labor, material, and equipment costs, and annual unscheduled maintenance costs are presented in Table 6-5. The total annualized unscheduled maintenance cost is $32 per concentrator per year.

Note that the total annual cost of unscheduled maintenance under the repair upon failure approach is low. A doubling in expected failure rates would result in a cost increase of only $32 per concentrator per year.

Table 6-5. Unscheduled Maintenance
(per concentrator @ 10^5 units/yr, 11 m aperture, 1980$)

Task Description	Unit Labor[a] Hours	Unit Labor[a] Cost ($)	Material[b] Cost ($)	Frequency (act/yr)	Annual Cost ($) Labor	Annual Cost ($) Material	Annual Cost ($) Total
7200 Unscheduled maintenance							
7210 Reflective panels							
7211 Panel replacement	3	48	90	0.06	2.88	5.40	8.28
7220 Structures							
7221 Azimuth pivot bearing replacement	8	128	75	0.001	0.13	0.08	0.21
7222 Elevation pivot bearing replacement	8	128	50	0.002	0.26	0.10	0.36
7223 Elevation drive pivot replacement	8	128	30	0.001	0.13	0.03	0.16
7230 Drive systems							
7231 Azimuth drive							
o Motor replacement (using rebuilt unit)	2	32	120	0.02	0.64	2.40	3.04
o Gearbox replacement (using rebuilt unit)	2	32	120	0.01	0.32	1.20	1.52
o Sprocket replacement	1	16	16	0.002	0.03	0.03	0.06
o Chain repair	8	128	40	0.01	1.28	0.40	1.68
o Wheel replacement	2	32	41	0.002	0.06	0.08	0.14
7232 Elevation drive							
o Motor replacement	2	32	100	0.02	0.64	2.00	2.64
o Ball screw jack replacement (rebuilt unit)	8	128	200	0.01	1.28	2.00	3.28
7240 Foundations -- no maintenance	0	0	0	0	0	0	0
7250 Instrumentation and controls							
7251 Microprocessor battery replacement	0.50	8	5	0.1	0.80	0.50	1.30
7252 Microprocessor replacement	1	16	40	0.01	0.16	0.40	1.04
7253 Active sensor replacement	4	64	150	0.01	0.64	1.50	2.14
7254 Shaft encoder replacement	8	128	150	0.02	2.56	3.00	5.56
7260 Electrical subsystems							
7261 Disconnect switch replacement	1.5	24	30	0.01	0.24	0.30	0.54
7262 Motor starter replacement	1.5	24	140	0.01	0.24	1.40	1.64
Totals					12.29	19.72	32.01

[a]Based on loaded labor rate of $16/hour

[b]Material costs for components include spare parts overhead costs

SECTION 7

COST SCALING

Relationships as a function of aperture diameter, production rate and receiver/power conversion package weight were developed to scale the detailed cost estimates (at 11 meter diameter, 10^5 units per year rate and 1350 kg receiver per power conversion weight). Specifically, the cost for the concentrator was to be estimated at:

- Aperture diameters of 5, 10, 11, 15 meters
- Production rates of 10^2, 10^3, 10^4, 10^5, and 10^6 units per year
- Receiver/power conversion package weights as listed in Table 7-1 for the various aperture diameters

7.1 OVERALL SCALING RESULTS

The combined effects of aperture diameter and production rate variations are shown in Figure 7-1. These results show that the 11 meter diameter is the optimum aperture size for this particular design concept. Other design concepts, i.e., different foundation or counterweight approaches may be most cost effective at other aperture diameters. This figure quantifies the economies of scale realized at high production rates.

The effect of receiver/power conversion weight variations is to change the amount of steel and concrete required for the concentrator. A

Table 7-1. Receiver/Power Conversion Package Physical Properties for Various Concentrator Aperture Diameters

Concentrator Aperture Diameter D (m)	Package Mass (kg)	Center of Mass from Focal Point (cm)	Package Dem. Dia. x Length (cm)
5	135 350 675	30 40 50	50 x 60 60 x 80 80 x 100
10	675 1350 2700	50 60 75	80 x 100 100 x 120 130 x 150
11	675 1350 2700	50 60 75	80 x 100 100 x 120 130 x 150
15	1350 2700 4050	60 75 85	100 x 120 130 x 150 150 x 170

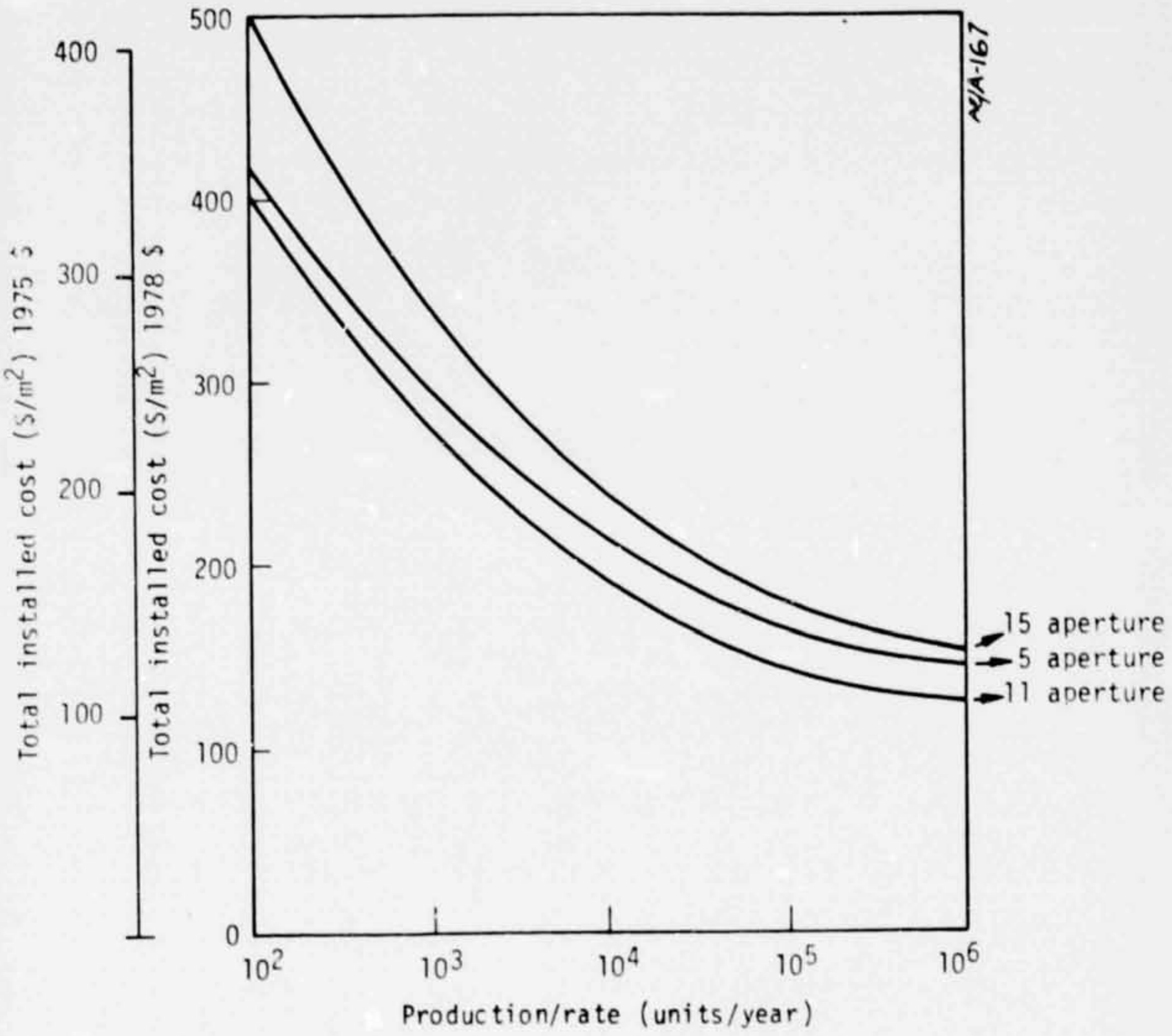

Figure 7-1. Cost Scaling Results

50 percent decrease in receiver/power conversion weights results in a 4 percent decrease in concentrator cost at an 11 meter aperture diameter and 10^5 units/year production rate. A 100 percent increase in weight results in a 7.5 percent increase in costs.

7.2 APERTURE DIAMETER SCALING

The design of the concentrator was evaluated at each of the aperture diameters of interest to determine weights, sizes, or other figures of merit for the cost elements of the concentrator. Components and subsystems were resized as required, but no design changes were allowed. To account for the cascading effect of changes in component weights, the design at each aperture diameter was evaluated serially, that is it was evaluated in the same order in which loads cascade through the concentrator. The order of evaluation was

1. Reflective panels
2. Structure
3. Drives
4. Electrical and control
5. Foundations

The detailed costing was used to develop cost factors to be applied to the figures of merit from the design evaluation. For example, the cost per pound of structure was applied to the structure weights at each of the aperture diameters to estimate the structure costs. This approach was used for the production, shipping, and installation costs.

7.3 PRODUCTION RATE SCALING

Variations in costs with changes in production rate were addressed via application of a typical exponential cost equation which describes the variation in cost as a function of production rate and a factor which reflects the type of cost being scaled. The cost equation is as follows

$$\text{Cost at X per year} = (\text{Cost at Y per year})\left(\frac{Y}{X}\right)^{\frac{-\log n}{\log 2}}$$

where n is the factor for the particular type of cost.($0 < n < 1$).

For material costs for production and installation a 95 percent factor was used. This factor was validated by actual cost vs. production rate data gathered for some concentrator components during the detailed costing.

Production labor, equipment, and overhead expenses were scaled using an 85 percent cost factor. This produces a greater variation in costs than the 95 percent factor and reflects the greater impact which production rate changes have on labor, equipment, and facility efficiency. The use of this factor for these costs is comparable to the variation shown for these same types of costs in the General Motors heliostat cost analysis conducted for SERI (Reference 9).

Shipping and installation costs were modified using a 95 percent factor as production rate changes have a lesser effect on their application efficiency.

7.4 RECEIVER/POWER CONVERSION WEIGHT SCALING

The variation in receiver/power conversion package weight was assessed by evaluating the changes in the 11 meter aperture diameter design and costs at the 10^5 units er year production rate as the weight was varied from 1350 kg to both 675 kg and 2700 kg with the physical parameters listed in Table 7-1. The results of this assessment are as follows:

Receiver Weight (kg)	Total Installed Costs (1980 $)	Percent Change
675	15,356	-4.0%
1350	15,963	0
2700	17,157	+7.5%

The effect of receiver/power conversion weight changes would be diminished as the production rate decreases from the 10^5 unit per year rate, since the concentrator costs becomes less material intensive at lower production rates.

As aperture diameter changes, structure costs change at a faster rate than total costs; however, concrete costs change at a slower rate than total cost. The net effect due to receiver/power conversion weight variations at different aperture diameters is therefore expected to be small.

SECTION 8

RECOMMENDATIONS

Since the preliminary design is but one iteration in the evolution of the Advanced Solar Concentrator system, the cost analysis presented in this report should be viewed as an indication of where effort should be expended to achieve cost reductions rather than as providing absolute and nonchanging values. Over the course of the design and cost analysis efforts, several potential cost reduction areas have been identified. These areas are categorized and are discussed as follows:

- Specification Requirements -- wind load specifications
- Redesign -- wide base carousel mount/foundation and counterweight assembly
- Materials Technology -- full size monolithic cellular glass substrate and large, high strength temperable sheet glass
- Foundation Installation Technology -- automated techniques for boring holes, placement of the rebar and concrete pouring

Specification Requirements

Since operating and survival wind loads are major drivers in the design of virtually all components of the concentrator, their specified values must be critically evaluated to determine the appropriateness of the requirement. The preliminary design of the Advanced Concentrator is based on meeting the operational performance specification of 5[illegible] kW thermal through a 22 cm diameter receiver aperture with an 845 W/m^2 direct normal insolation under a 50 km per hour wind at the worst angle of attack. Survival specification requirements are a wind speed of 80 km per hour at the worst angle of attack (while slewing to stow) and a 120 km per hour wind speed in the stowed position.

A brief review of national wind speed statistics indicates that speeds of 50 km per hour are typically met or exceeded less than 0.5 percent of the hours in a year. Accounting for the finite probability that the wind vector will be near the worst case angle of attack and the fact that less than 30 percent of the annual hours typically have insolation levels sufficient for collector system operation, yields an extremely low probability of encountering the specified operational design conditions.

For the Advanced Concentrator preliminary design, the operating wind specification impacted little more than the final dish diameter. This is due to the fact that the slew-to-stow survival wind speed with the concentrator in the worst angle of attack position governed the structure and drive design. Again, the probability of experiencing such a condition is low. The probability is further reduced by the fact that a stow command is given at a wind speed of 50 km per hour.

Should the 80 km per hour specification be relaxed, the 120 km per hour stowed survival wind speed may become the dominant load for much of the concentrator. The incorporation of wind screen fences in the layout of collector systems may reasonably allow this requirement to also be reduced.

Any reduction in component weight due to decreased desigr wind loads has the additional cascading benefit of reducing dead loads on other concentrator components.

Concept Redesign

Two areas of the Advanced Solar Concentrator preliminary design which could potentially be significantly improved through redesign were identified. The first area is the two-axis tracking mount and foundation design, and the second is the drive system counterbalance scheme.

While a wide base perimeter drive approach allows the use of low-cost chain and sprocket azimuth drive components and provides a light-weight mount structure, it requires a significant amount of on site labor and equipment to install the foundations and assemble the concentrator. A more material intensive design using a single large diameter support pedestal with a turret azimuth drive provides the potentia; for a lower installed system cost. The benefits of reduced site preparation requirements and reduced field equipment and labor costs more than offset the additional production costs for th heavier pedestal and drive components.

The use of counterweights to reduce elevation drive component loads is believed to have a negative cost impact. While parasitic operating power can be reduced through the use of the counterweights, good design practice requires that the drive components be sized to withstand design load condition with no counterweights in place. This will prevent the catastrophic failure mode of cascading structural failures due to the loss of a counterweight through a separate component failure. Only static restraint capability is required, but the aggregate effect of reducing drive motor requirements and parasitic operating power costs is more than outweighed by the additional costs of the counterweights and their on-site installation.

A reevaluation of the preliminary design to incorporate these design changes could potentially offer a significant reduction in the installed cost of the concentrator.

Materials Technology

The key element of the Advanced Concentrator is clearly the cellular glass/mirror glass reflective gores. The use of these largely self supporting panels has allowed a significant reduction in the weight and hence cost of the supporting structure. The mass production cost of the reflective panels account for 42 percent of the total factory concentrator cost. Two areas of material technology development have the potential for reducing this cost element. These are structural cellular glass development and high strength, large sheet, thin mirror glass development.

Due to current manufacturing limitations, the cellular glass material is limited to 24 inches x 18 inches x 4 inches monolithic blocks. In order to obtain the full size core blank required for a reflective panel, 7.5 blocks must first be adhesively bonded. The development of a full size monolithic core blank could eliminate this fabrication step thereby reducing labor and tooling. The development of fabrication techniques allowing hot sagging, press forming or foaming to shape could eliminate the currently planned contour grinding operation. Higher strength cellular glass or the development of controllable densified face skins could significantly improve the structural efficiency of the gore design thereby allowing reduced weight with its beneficial cascading effect on the balance of the concentrator.

The sheet glass development area holds promise for reducing costs through the fabrication of large high strength temperable glass sheets. The current gore design is constrained to a maximum width of approximately 33 inches. This limitation is due to the combination of membrane and bending stresses due to the compound panel curvature. Higher strength glass would allow the use of wider panels thereby reducing the number of attachment points and the resulting supporting structure, number of individual alignment operations and number of components to be inventoried. The development of thinner mirror glass sheets would also allow slightly increased gore widths due to reduced bending stresses, but the increased handling difficulty may not warrant the same degree of emphasis as the high strength glass should receive.

Foundation Installation Technology

Foundation installation labor cost, which is a significant portion of the total installed concentrator cost, can be dramatically reduced through the use of automated reinforced concrete foundation installation equipment. The increased cost of equipment, assuming effective utilization and transportation between solar system fields, can be low on a per unit basis at very high production rates. Effective equipment utilization requires installations greatly exceeding the 100 units per field assumed for purposes of this study.

The automated equipment would consist of easily moved motorized platforms which drill the holes, place preconstructed rebar cages in the holes and pour the concrete. For effective utilization, the equipment would have to install many foundations per day.

It is recommended that JPL consider each of these factors in their continuing development of advanced point focusing solar concentrators.

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APPENDIX A

DETAILED SITE PREPARATION COST ESTIMATES

Site Preparation Assumptions

- Assumed terrain to be flat, without ravines or hills, with light brush cover
- Assumed dust and noise abatement ordinance is in effect
- Assumed soil conditions to be "sandy loam," a damp mixture consisting of fine sand and silt with clay particles not exceeding 25 percent
- Estimate is based on the concentrator field area of 880 feet x 880 feet and a plant laydown, assembly and storage area of 250 feet x 250 feet
- Topsoil stripping, stockpiling, replacing and compaction is based on a cutting depth or fill from original ground and finished grade elevation of 1.0 foot for the concentrator field and 0.25 foot for the plant area
- Measurement of volume for earth work is based on bank measure quantities except for loading and hauling to disposal of non-usable and excess materials which have a 35 percent swell factor
- Cut, fill and compaction length of haul is based on maximum average of 1000 feet and return of stockpiled materials at 50 percent for blade and compaction. All materials are assumed to be available within the site and aggregates will not have to be hauled in.
- No allowance has been made for snow removal, dewatering or inclement weather delays, nor has dumping fees or permits been included

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- It is assumed that the grading contractor will complete the field in quarter increments to allow for installation of foundations
- Production is based on the 50 minute hour formula for labor and equipment

Site Preparation Installation Labor

(100 concentrators/field, 11 m aperture, 1980$)

Activity	Time required (hrs/field)	Men required	Manhours/ conc	$ per manhour	$ per conc
Project manager	400.00	1	4.00	23.61	94.44
Layout engineer	80.00	1	0.80	22.85	18.28
Rod & chainman	80.00	1	0.80	19.94	15.95
Grade checker	320.00	1	3.20	19.94	63.80
Scraper operators	840.00	3	8.40	21.86	183.62
Grader operator	320.00	1	3.20	21.86	69.95
Dozer operator	264.00	1	2.64	21.86	57.71
Roller/compactor operator	264.00	1	2.64	19.94	52.64
Wheel loader operator	80.00	1	0.80	22.85	18.28
Mechanic/service	144.00	1	1.44	20.73	29.85
Water truck driver	280.00	1	2.80	20.73	58.04
Dump truck Driver	80.00	2	0.80	20.73	16.58
Laborers	240.00	3	2.40	15.94	38.25
Subtotal job expense @ 0.051%	3392.00	18	33.92	21.15	717.39 36.59
Totals	3392.00	18	33.92	22.23	753.98

Site Preparation Installation Material

(100 concentrators/field, 11 m aperture, 1980$)

Activity	Quantity	$ per unit	$ per field	$ per conc
Grade stakes-flags-streamers & miscellaneous	100 ea	16.50	165.00	1.65
UTILITIES				
Contractors plant	2.5 mos	165.00/mos	412.50	4.13
Mobilization/ demobilization move in-out contracted costs	9 loads	205.00/ea	1845.00	18.45
Totals			2422.50	24.23

Site Preparation Installation Equipment

(100 concentrators/field, 11 m aperture, 1980$)

Activity	Quantity (units)	Time required unit	$ per unit	$ per conc
Office trailer	1	2.5 mos	233.20/mos	5.83
Pickup truck	1	10.0 wks	126.50/wk	12.65
Fuel & service truck	1	18.0 days	140.80/day	25.34
Surveyor's vehicle	1	40.0 hrs	8.80/hr	3.52
988B loader	1	80.0 hrs	103.40/hr	82.72
12G motor grader	1	320.0 hrs	37.40/hr	119.68
Elevating scrapers	3	840.0 hrs	44.00/hr	369.60
D-8 dozer	1	264.0 hrs	73.70/hr	194.57
Roller/compactor	1	264.0 hrs	15.40/hr	40.66
Water truck	1	280.0 hrs	20.90/hr	58.52
Dump trucks	2	80.0 hrs	28.60/hr	22.88
Subtotal Job expense @ 0.051%				935.97 47.73
Total				983.70

APPENDIX B

DETAILED FOUNDATION INSTALLATION COST ESTIMATES

Foundation Installation Labor Costs

(100 concentrators/field, 11 m aperture, 1980$)

Activity	Men required	Manhours per conc	$ per manhour	$ per conc
Foreman	1	14.00	26.33	368.62
Journeyman	1	10.83	23.68	256.45
Groundman	2	16.94	17.80	301.53
Crane operator	1	3.75	23.68	88.80
Equipment operator	1	3.00	20.12	60.36
J/L welder	1	6.00	23.68	142.08
Subtotal				1217.84
Job expense @ 0.051%				62.11
Total				1279.95
$ per cyd 262.28				

Foundation Installation Material Costs

(per concentrator @ 100 concentrators/field, 11 m aperture, 1980$)

Activity	Quantity	$ per unit	$ per conc
Aggregates for base	0.437/cyd	8.45/cyd	3.69
10 foot rebar cage	12 ea	51.00	612.00
13 foot rebar cage	3 ea	66.00	198.00
6SK 3000 psi concrete	4.88 cyd	46.32/cyd	226.04
Welding rod	60 lb	0.572/lb	34.32
Total			1074.05
$ per cyd			220.00

Foundation Installation Equipment Costs

(per concentrator @ 100 concentrators/field, 11 m aperture, 1980$)

Activity	Quantity (units)	Time required per unit (hrs)	$ per hr per unit	$ per conc
Aircompressor	1	6.70	23.10	154.77
Vibrator	4	6.70	4.00	26.80
Crane	1	3.75	73.70	276.38
Welder	1	6.00	5.50	33.00
Subtotal Job expense @ 0.051%				490.95 25.04
total				515.99
$ per cyd				105.74

APPENDIX C

DETAILED SITE ASSEMBLY COST ESTIMATES

SITE ASSEMBLY COST ESTIMATES

(per concentrator at 100 concentrators/field, 11 m aperture, 1980$)

Track	
Labor	
11 man-hours at $23 per hour	$ 253
Equipment	
Air compressor, torque wrenches	
2 hours at $7.51 per hour	15
	$ 268
Pedestal	
Labor	
6.5 man-hours	149
Equipment	
Air compressor, torque wrenches	
1 hour	8
	$ 157
Structure	
Labor	
6 man-hours	138
Equipment	
Air compressor, torque wrenches	
1 hour	8
	$ 146
Drives	
Labor	
4 man-hours	92
Equipment	
Air compressor, torque wrenches	
0.5 hour	4
	$ 96

Counterweights

Labor	
4 man-hours	92
Equipment	
Fork lift	
1 hour at $21 per hour	21
	$ 113

Electrical and Control

Labor	
3 man-hours	69
Equipment	
2 man hand auger	
2 hours at $0.85/hour	2
Materials	
(For ground rod enclosure)	
Clay pipe (8" x 4') with steel cover (2)	24
Aggregates/sand	2
	$ 97

Checkout

Labor	
2 man-hours	$ 46

Air Crane

Track (8 min ea.)	
(1500 lb capacity helicopter at $150 per hour)	$ 20
Pedestal (5 min each)	
(1500 lb capacity helicopter at $150 per hour)	13
Concentrator Assembly (10 min each)	
(8500 lb capacity helicopter at $850 per hour)	142
	$ 175

Total Site Assemby Cost	$1098