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CONCENTRATING-COLLECTOR MASS-PRODUCTION FEASIBILITY

VOLUME I

FINAL REPORT

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MASTER

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NOTICE

FOREWORD

This report is intended to guide manufacturers in achieving efficient and economical production of concentrating collectors. The time is ripe for large-scale production and use of solar devices. The following study was conducted by the Central Solar Energy Research Corporation (CSERC) to help both potential manufacturers of solar devices and the nation take advantage of the opportunity offered for profitable expansion. Since solar energy has the potential to contribute up to 20 percent of the nation's energy requirements by the year 2000, the opportunity is enormous.

An effort is made throughout this report to give manufacturers practical answers to practical questions. The goal is to stimulate development of concentrating collector production and to show manufacturers how this can be done on a mass production scale. Mass production is needed to deliver the number of solar collectors required by the national market and to achieve essential production savings.

The extensive study conducted by CSERC staff and consultants in the industrial and university sectors covered manufacturing processes, tooling and equipment requirements, plant layouts, material and labor cost estimates. The result is nothing less than a how-to-do-it instruction manual on large volume assembly of the concentrating collector design chosen for in depth analysis.

Various subdesigns were assessed in the study process, and their competitive advantages and disadvantages are discussed in the report. Also covered is the critical choice of the system design analyzed by CSERC, with cost versus performance issues specifically addressed.

Principles derived from the high volume production experience gained in the automotive and other industries were applied in performing this study. The purpose was to learn ways of reducing material, process, and assembly costs for solar device production. In the course of this work, mass manufacturing feasibility was analyzed and design modifications recommended to facilitate production.

The report seeks to give manufacturers design and cost data that will help them start efficient and profitable operations. The use made of SAMICS methodology to cost solar devices accurately is explained. The Process Estimate Sequence followed is outlined with explanation of the Process Estimate Sheets used for each component and subsystem. These data enabled analysts to develop cost information that is indispensable for manufacturing decision-making.

Technical, design, and cost data assembled are intended to support early development of successful production, thus benefiting from the chance for industrial and financial progress now offered in conjunction with the national need for solar energy utilization. Manufacturers who want to participate in the nation's shift to alternate energy by producing concentrating collectors suitable for domestic and industrial uses may find this report an appropriate place to start.

Delivering a report to users as straightforward and easy-to-follow as possible was a leading concern among staff members involved in its compilation. Section 1.0, the Introduction, and Section 2.0, Study Methodology, carefully explain the report. They serve as a basic "road map" for the report as a whole, making it beneficial to read these sections carefully before proceeding.

The findings of CSERC engineers in this study show that mass production technology has the potential for successful application in solar device manufacturing, with clear-cut benefits available that serve business needs and the national interest at the same time.

Cumulatively the CSERC staff preparing the report possessed nearly two and a half centuries of professional experience in the technical fields that had to be merged in carrying out the assignment. The report that follows is their effort to make this experience work advantageously for solar device manufacturers in the United States.

Perhaps one of these manufacturers could be your organization. The concentrating collector report and its appendices should answer the questions of your technical personnel and instruct them methodically in how to proceed.

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SUMMARY

CONCENTRATING COLLECTOR MASS PRODUCTION FEASIBILITY

Introduction

The Central Solar Energy Research Corporation (CSERC) studied the mass production of concentrating collectors to give potential manufacturers of solar devices broad-based information from costs to processes that is sufficiently practical and specific to stimulate action in this dynamic field of energy development opportunity.

This report in two volumes covers CSERC's analysis of the Performance Prototype Trough (PPT) Concentrating Collector developed at Sandia National Laboratories and consisting of four 80-foot modules in a 320-foot row. Four different reflector concepts were considered including the sandwich reflector structure, sheet metal reflector structure, SMC molded reflector structure, and the glass laminate structure. This study mainly covers the sheet metal reflector and glass laminate structures with their related structure concepts.

Volume I of the report discusses the over-all CSERC study, cost estimates, and manufacturing processes to produce concentrating collectors in volumes from 100 to 100,000 modules per year. Volume II, the Appendices, contains backup materials for manufacturers who want to evaluate the promising solar device opportunity further, weigh their options, and start planning for active production. The report offers industry a preliminary manufacturing plan that includes:

- Documentation of the manufacturing process with production flow diagrams to guide manufacturing engineers.
- Labor and material costs at various production levels.
- Machinery and equipment requirements including preliminary design specifications.
- Capital investment costs for a new plant to carry out the manufacturing plan.

The specifics of concentrating collector production are given for annual production volumes of 100-500, 1,000, 5,000, 25,000, and 100,000 units. Five Sandia designs were carefully reviewed by CSERC to choose those best suited for mass production without delay. The designs, identified by their critically important reflector materials, are:

(Design A) Chemically strengthened glass and steel laminate on steel frame panel
(Design B) Chemically strengthened glass on steel frame panel
(Design C) Thin annealed glass and steel laminate on steel frame panel
(Design D) Thermally sagged glass and thin glass laminate
(Design E) Thermally sagged glass (slab)

Designs C and E appear to have better prospects, and these are the designs considered at length in this report. Why these designs were chosen is explained in discussions of the evaluations conducted by CSERC in the course of the study.

Cost Estimates Using SAMICS Methodology

Deriving accurate cost estimates was a key operation throughout this analytical study of the PPT concentrating collector. CSERC analysts adapted SAMICS methodology for this purpose.

The Solar Array Manufacturing Industry Costing Standard (SAMICS) was developed by the Jet Propulsion Laboratory for the Solar Array Industry. Previous CSERC experience with SAMICS confirmed its effectiveness for the current application. Over a period of years, SAMICS has proven applicable to any process industry and is especially helpful to new industries seeking reliable answers to questions that directly affect decision-making.

With the SAMICS computer program, analysts saved time and eliminated the kind of guesswork traditionally associated with comparable planning activities. SAMICS supplies a proven means of estimating indirect costs, developing a normative selling price that will yield a given rate of return on capital, and introducing precision to the solar device costing process.

An extension of SAMICS, the IPEG program (Improved Price Estimation Guidelines), also now permits complete sensitivity analyses at lower cost. CSERC applied this tool to analyze the response of total cost and selling price to changes in major material prices and financial parameters such as rate of return on investment, interest, inflation rates, and taxes.

Computer-derived costs and selling prices were derived for the five alternate collector designs. These computer results confirmed earlier manual estimates and supported the process and design decisions reached by CSERC engineers in the course of their feasibility study. The preliminary costing analysis that design C (thin annealed glass) and design E (slab glass) are economically preferable choices was supported by computer results. Computer results indicate that the slab glass design is lower in cost than the thin annealed glass design at both low and high volumes. However, thermally sagged (slab) glass is currently available only from foreign vendors, and thin annealed, low-iron glass is easily available from domestic sources. Thus the thin annealed glass design receives chief emphasis in the CSERC study, although cost and process data are supplied for the slab glass design as well.

Process Estimate Sheets

CSERC manufacturing engineers prepared process estimate sheets for the fabrication of each part and assembly in the concentrating collector studied. The contents and use of the process sheets are explained in Volume I of the report. The sheets are reproduced in Volume II to assist manufacturers. Each process sheet identifies labor needs, equipment and tooling requirements, the base purchase price, freight costs, installation costs of facilities and durable tools, and acquisition costs of expendable tools.

The process sheets gave a standard, logical place to store the growing mass of information accumulated during the assignment. The process sheets now collectively are virtually an authoritative data bank on the PPT concentrating collector. Once the process sheets existed, they served as a crucial reference source for direct cost information and the planning of streamlined manufacturing sequences. CSERC's involved work to complete the process sheets in effect carried out the methodical assessment required of each collector part, component, and subsystem.

The work sequence followed to accomplish the detailed process analysis includes the following steps:

- Preliminary Processing
  - Review concentrating collector designs
  - Select and detail the manufacturing process
  - Describe required machinery, equipment, tools
  - Calculate the number of machines and pieces of equipment required
- Process Extension
  - Estimate direct labor minutes
  - Estimate facility and tooling costs
  - Estimate special tooling costs
- Establish Process Flow
- Summarize Minute and Facility Costs from Process Sheets

Based on information from the process sheets, Volume I of the report contains a 100-page "Process and Equipment Description" section. The section offers manufacturers complete process analyses for production of design C (thin annealed glass and steel laminate on steel frame panel) in quantities of 100,000 modules per year or in quantities of 100 to 500 modules per year. The section also covers production of design E (thermally sagged glass [slab]) at a level of 100,000 modules per year.

The process analyses contain step-by-step process flow diagrams, detailed illustrations to clarify complex assemblies, and highly detailed descriptions of the various assembly processes. Potential manufacturers of concentrating collectors can use this information, together with complementary data in Volume II, as the basis for preliminary planning leading to plant construction (or plant retrofitting) to accommodate PPT concentrating collector manufacturing.

Market Opportunities

As an aid to potential manufacturers gauging the business logic of entering the field, this report includes market data acquired while determining the mass production feasibility of the concentrating collector. A market penetration model developed for CSERC shows the need for greatly increased production of concentrating collectors to meet solar energy utilization goals by the year 2000. Since 1978, the output of collector manufacturers has grown at annual rates exceeding 30 percent. This growth rate is inadequate to meet the recognized need or to launch solar manufacturing operations adequate to serve the potential market.

This report recognizes the serious difficulties ahead in persuading American industries and others that concentrating collectors of solar energy are practical economic alternatives to expensive conventional fuels. The efficiency of the PPT concentrating collector and the projected energy use and cost patterns of the 1980s and beyond emphasize that a strong case can be made both for making and buying this equipment. Initially vigorous marketing efforts will be essential. Time and energy facts of life will support those marketing efforts more and more as conventional fuels (oil, gas) offer the twin specters of declining supplies and rising prices.

Make/Buy Decisions

Another useful feature of the CSERC assessment is the well-researched advice about what components and subsystems can be produced in-plant cost-effectively and those that should be purchased from qualified vendors. Distinguishing between "make" and "buy" components is critical to the success of a manufacturing operation.

This report notes that make/buy decisions often are matters of judgment applying the experience and knowledge of manufacturing engineers expert on material and labor costs. At low volumes, the majority of parts may be purchased, while large volume production makes in-plant manufacturing more economical. The report helps clarify information and supports decision-making in this area of concern.

CSERC staff engineers and consultants brought many years of production experience and successful employment of value engineering principles in the automotive industry and others to the CSERC analysis. Make/buy analysis recommendations for design C are supplied for annual production volumes from 100-500 modules to 100,000. The multiple parts of the reflector substrate, mirror panel, pylon weldment, flexural assembly, double pylon weldment, drive pylon assembly, torque tube, receiver tube support, the receiver, and the receiver tube support bearing are individually identified in terms of manufacturing or purchasing at the different production levels.

Manufacturers will find the guidance on make/buy decisions a pertinent, time-saving benefit of the report as they move ahead in the planning and production of concentrating collectors.

The PPT Concentrating Collector

Few manufactured products have been subjected to more detailed scrutiny than that directed by CSERC researchers at this collector. The PPT concentrating collector consists of four 20-feet long, 6½-feet wide reflectors in 80-feet modules, possessing chemically treated, second-surface silvered glass mirrors.

The PPT concentrating collector contains five fundamental subsystems: Pylons, Reflector and Reflector Support, Receiver and Receiver Support, Driving Mechanism, and Flex Hose. Each subsystem underwent probing analyses from both manufacturing and design viewpoints. Could the subsystem be economically mass-produced? Were the materials and the design optimally effective in competition with alternate materials and designs?

Cost analyses showed that material costs account for 81 percent of the concentrating collector selling price at the 100,000 annual production volume. Thus, the conclusion was readily evident that significant cost reductions in the manufacture of the collector had to be achieved by reducing the cost of materials or substituting less expensive materials. The practical possibilities in this connection had to be considered in detail to identify economically as well as technically preferable choices.

Material consideration and selection were paramount concerns in the evaluation. Findings in this connection appear in Volume I with explanations why one material may have been chosen over others. In the reflector system (which can account for as much as 50 percent of the manufacturing cost of a concentrating collector), for example, three types of reflector materials were assessed: a) a thin silver or aluminum film deposited on glass, b) metallized plastic film, c) a polished bulk metal such as aluminum.

Environmentally protected second-surface silvered glass mirrors became the choice because of optical quality, durability, long-term performance, and cost. Silvered glass mirrors in CSERC tests proved optically superior to polished aluminum or aluminized plastic films. The problems of breakage and environmental degradation of silvered mirrors were found easier to manage and less costly to overcome than problems with alternate reflector materials.

The use of silvered glass mirrors led to the complex field of glass technology, including manufacturing, chemical strengthening, silvering, and forming. An appropriate glass thickness had to be determined that would lend itself to shaping and handling without breakage, but that would be thick enough to withstand wind impact and related environmental attacks.

Four types of glass compositions were evaluated: Sodalime, aluminosilicate, borosilicate, and lead glass, with low-iron sodalime glass and aluminosilicate glass found suitable for use in concentrating collectors.

Equivalent studies were carried out by CSERC on materials and processes to pinpoint those ideally meeting twin design criteria:

- Producing a concentrating collector of high quality equipped for years of dependable performance.
- Allowing the collector to be mass-produced in a cost-effective manner.

One important result of the CSERC research concerning materials and processes was a series of recommended design changes. The changes sought to achieve concentrating collector improvements and/or reduced costs through the substitution of alternate materials for those specified in the original design. Some changes were also called for in order to facilitate the manufacturing process. The recommended changes would require further development.

Reducing Costs and Improving Reliability

CSERC was concerned from the start of the concentrating collector assignment to identify cost saving opportunities related to production, materials, and design. The basic techniques of lowering manufacturing costs were successfully applied. These techniques include: Simplifying designs. Minimizing the number of components. Reducing material costs. Eliminating various process activities.

By applying value engineering principles during each phase of the mass production assessment, practical steps and options were identified that have served to expedite production and reduce costs. The whole thrust of this study was to confirm the cost benefits of mass production and to achieve optimum efficiency through the selective use of transfer lines, automation, and robotics when the production volume justifies them.

The cost and quality improvements introduced during the CSERC project are described in Volume I of the final report. Some of the adopted changes reduced cost without harming quality or performance. Other changes enhanced quality while simultaneously lowering costs. Various recommendations were made by CSERC and adopted to upgrade the producibility of different components and to assist in refining the manufacturing process.

The goal of all concerned was to produce a collector design that would live up to performance expectations and to establish a production plan that would deliver the collector profitably in large quantities or even quite small quantities. Of course, a plan suitable for 100,000 collectors per year would not serve for a production volume under 500 collectors. That is why different process analyses were done, thus giving manufacturers specific processes appropriate for their individual needs. Although the primary intent of the project was to assist large-scale production of solar collectors, recognition was given the fact that initial production volumes may be only a few hundred modules per year as manufacturers limit their investments and work to build a market.

CSERC Research Proposals

A special issue addressed as the study occurred was determining areas in which further research could be beneficial. The CSERC staff was in a particularly good position to see the whole picture--design as well as manufacturing needs and problems. Some proposals made by CSERC as work progressed were self-evident in the light of current manufacturing practice. These proposals when cost-effective were immediately adopted by modifying the baseline design. Other proposals raised more complex considerations and are described in Volume I as future research options. The proposals involve collector assembly, components, and materials. Research proposals in various ways stress the following:

- Maximum use of low cost materials.
- Simplified assembly.
- Minimum use of secondary operations (through high-precision use of casting, molding, cold and hot forming, and available modern technology.)

These objectives were emphasized both in original process studies and in research proposals. CSERC recommendations were also shaped by the experience and insights gained from working closely with design and manufacturing engineers. This established awareness concerning the needs and obligations of each group in solar device manufacturing.

In addition to immediate improvements in existing equipment, solar research should include exploring new technology and seeking better ways to use the energy of the sun. In effect, solar research has only modestly advanced, and the opportunities for major breakthroughs are plentiful.

Since CSERC was involved in a highly specific project, the proposals that resulted, logically focus on particular opportunities for improvement in connection with the concentrating collector.

Future research programs listed for implementation as a follow-up to the mass production feasibility study explored in this report include the following.

- Precision Factory-Focused Reflector: CSERC proposes a way to facilitate focusing the parabolic trough upon the line receiver/absorber. Success would minimize field costs and provide the means of verifying a critical relationship.
- Production of no-iron glass by the float process.
- Pedestal Mounted Reflector: Mass production efficiencies and simpler components might result by modularizing the collector so two identical modules perform the task of one 80-foot collector.
- Frame panel stamping from thinner material.

- Receiver Hardware Improvements: To simplify the receiver system, reduce costs, and improve performance, CSERC outlined three research activities for follow-up: a) low cost high temperature fluid fittings, b) I.D. grinding of the absorber tube, c) hexagonal lateral receiver bearing. The envisioned research in these areas primarily involves completing engineering appraisals started during the study.
- Pylon Design: Nodular iron castings, reinforced plastic composites, and stamped assembly are among alternates to be considered in a research program to redesign the pylon for greater standardization, fewer components, and lower costs through modularity and use of more cost-effective materials.
- Drive Alternates: To conserve energy and reduce costs, drive alternates to the electric motor and speed-reducing gear box need research attention. Using thermal energy directly in the tracking system in combination with hydraulic cylinders or rotary actuators is one avenue to explore. Another is an air flotation system in conjunction with an air jet motor adapted as a drive alternate for a concentrating collector.
- Wood for Structural Members: Reconstituted wood research and resin technology have the potential to provide low-cost, low-weight wood structural members for solar devices. Solar research should include this option on the list of things-to-do.
- Composites for Structural Members: Fiber-reinforced composites also give researchers a versatile possibility to consider for solar applications.

Further practical and useful research openings are still plentifully available in this dynamic field. The CSERC project makes clear that production efforts need not delay for research to occur and findings to be applied. Aircraft manufacturers and users did not wait for modern jet technology before they acted to get their ideas off the ground--or they would probably still be on the ground. Industrial research traditionally strives to improve what may already be excellent, but which conceivably can be better. It is certainly too early with the swiftly expanding technology of solar energy to conclude that any design, product, approach, practice, or concept is already perfected with nothing better likely to be developed and improvements impossible.

This report concludes that designs analyzed and processes planned on the basis of that evaluation give manufacturers a strong start toward profitable large-scale production of concentrating collectors that will attract many users in the U.S. market and give effective service for years. Research, meanwhile, will work for something better.

The report outlines processes that are backed by proven methodology and tested by experience. The processes are ready for early production of the sophisticated and highly functional PPT concentrating collector.

Well Beyond the Starting Point

The manufacturing processes in this report eliminate large amounts of costly work and time-consuming analyses for interested manufacturers. If such work had to be independently performed, the research and development burden would probably be too discouraging for many potential contributors to the nation's solar energy resources.

Concentrating collectors can successfully and economically meet the energy needs of many American energy consumers who are not yet aware that this is true. Volumes I and II of the report give manufacturers a unique chance to enter this important area of industrial development while it is still in the formative stages.

Theirs will be the satisfaction, the excitement, and the profit of pioneering and opening up a new field in order to serve a new market.

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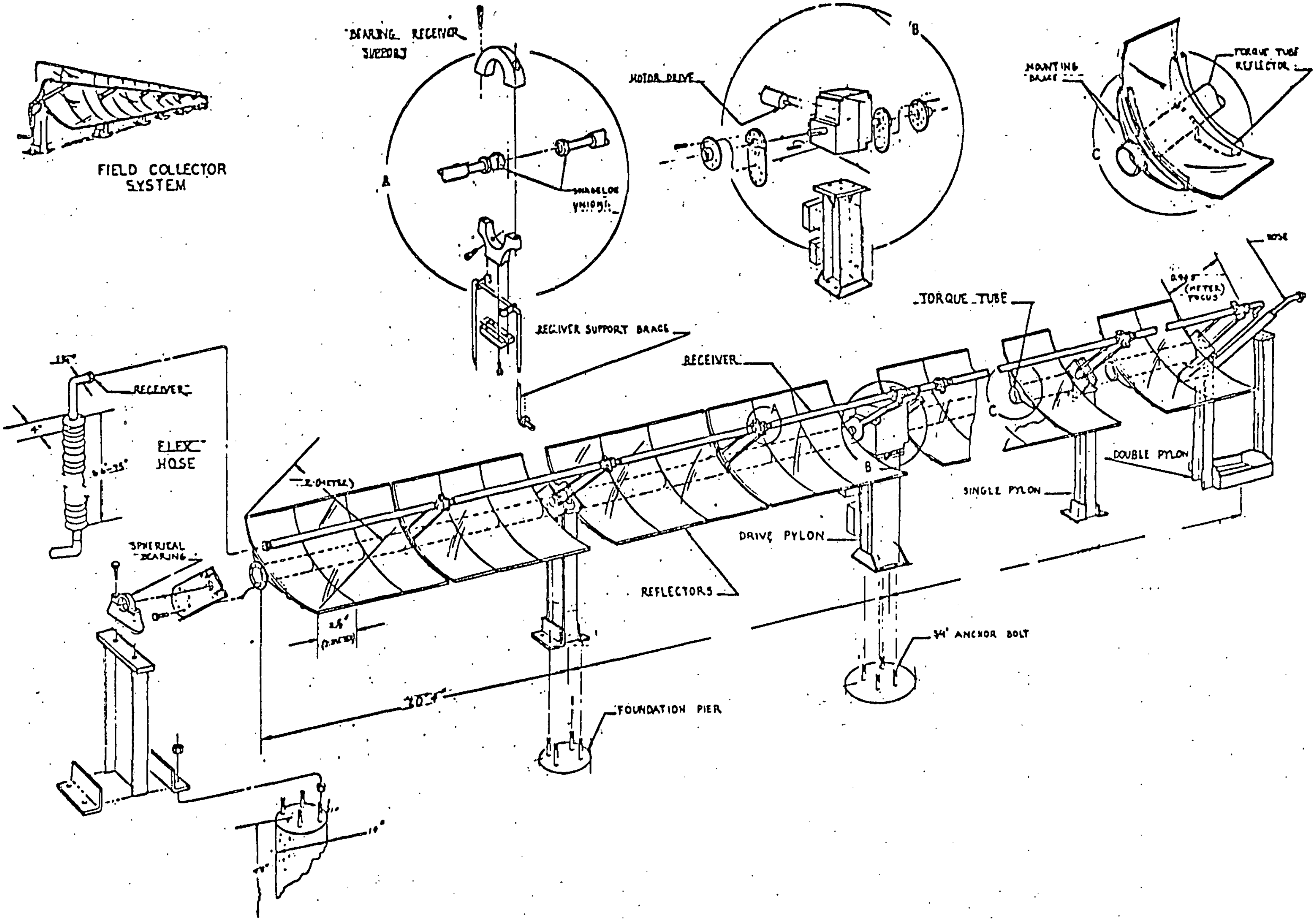


PPT CONCENTRATING COLLECTOR

CENTRAL SOLAR ENERGY RESEARCH CORP.

1.0 INTRODUCTION

1.1 BACKGROUND

The Central Solar Energy Research Corporation (CSERC) was formed to introduce mass production technology into solar energy manufacturing. This report covers an intensive study on the high volume producibility of the Performance Prototype Trough (PPT) Concentrating Collector. The collector is intended to exemplify a line focus system and to demonstrate what a high performance system can do. The system consists of components that came out of continuing research and development work at Sandia National Laboratories. Since the collector is still in development, certain features studied and used by CSERC may differ from current features.

The objective of this study is to give potential manufacturers the technical and cost information they require to undertake production. Volume I of the report analyzes CSERC findings concerning production feasibility. The volume provides cost estimates and recommendations for cost reduction as well as design improvements. Volume II, the Appendices, contains Process Estimate Sheets for components and subsystems. The SAMICS computer output for alternative annual production volumes is also included for reference.

The work performed by CSERC and the following report emphasize practical manufacturing methods and design features that will deliver a solar device that is cost-effective, marketable, and highly functional. The challenge to researchers and to manufacturers is producing a concentrating collector which provides maximum useful energy for minimum total cost.

Achieving the lowest cost can be managed through correct application of mass production techniques, designs that lend themselves to such techniques, using the smallest number of components, and reducing the cost of materials. This report gives industry a preliminary manufacturing plan for the concentrating collector at different production levels. The plan includes:

- Detailed documentation of the manufacturing process.
- Labor and material costs at several production levels.
- Machinery and equipment requirements including preliminary design specifications.
- Capital investment costs for a new production facility.

The data are sufficient to support informed decision-making. Users of the report will find appropriate manufacturing processes recommended with specific information adaptable to existing facilities and to production volumes ranging from small to large. The report identifies design modifications that will enhance producibility and provide the basis for research leading to further design improvements. Promising avenues for additional cost reductions through future research and development are indicated.

The following subsection explains the scope and objectives of the work performed by CSERC.

1.2 SCOPE AND OBJECTIVES

The CSERC approach in this study is to determine the large-scale producibility of the PPT Concentrating Collector through application of mass production experience gained in the automotive and various consumer products industries.

The study is structured to assure that all facets of mass production planning are covered. The starting point is a detailed examination of the product design, followed by selection of materials, machinery, equipment, tools, and skilled personnel required by the manufacturing process used. Planning necessarily includes identifying and estimating each cost element.

Other concentrating collector designs were assessed by CSERC to assign generic criteria for analysis of the concentrating collector given detailed producibility analysis. The PPT concentrating collector string developed through Sandia National Laboratories was selected in consultation with the Department of Energy as an advanced design embodying recent engineering test data and applying suggestions made from the manufacturing industry.

The PPT prototype has been the focus of cooperation and interaction among design and manufacturing engineers, including CSERC personnel. The result has been frequent design changes. To allow sufficient lead-time for the costing and sensitivity analysis included in this report, the design and manufacturing process analysis was frozen at an appropriate point. Further design improvements are identified in the report and are anticipated as a result of the report.

1.3 THE PPT CONCENTRATING COLLECTOR

The PPT concentrating collector modules designated by the Department of Energy for this producibility analysis consist of four 20-feet long, 6½-feet wide reflectors in 80-feet modules possessing chemically strengthened, second surface, silvered glass mirrors. The apparatus features a parabolic design, line-focus, and a single axis tracking mechanism. The PPT concentrating collector offers high efficiency (60% and above) and is designed to produce working fluid (Therminol 66) temperatures of 600° Fahrenheit in either an East/West or North/South orientation. The collector is suitable for generation of industrial process heat. Complete descriptive details are given in Section 4.0.

1.4 ANNUAL PRODUCTION VOLUMES

The Department of Energy set annual production volumes to be used in developing mass production processes as follows:

1,000 units	25,000 units
5,000 units	100,000 units

In addition to these provisions of the original contract, the

Department of Energy also requested that a volume of 100 to 500 modules per year be considered. After technical and economic factors were evaluated, a base process design volume of 100,000 was selected.

1.5 SITE LOCATION REQUIREMENTS

Before equipment, material, labor, transportation, and plant construction costs can be realistically estimated, a specific geographic location for the proposed manufacturing facility must be selected. Effective plant location is a function of relative production costs and market access at each alternative site.

The size of the labor market is another significant factor in plant location. A large mass production facility needs a sizable pool of skilled manpower. In this analysis, the assumption was made that a labor market should have a minimum of 50,000 to be considered as a viable site.

1.6 FACTORS AFFECTING CONCENTRATING COLLECTOR PLANT SITING

CSERC examined various site locations around the United States for potential mass production of concentrating collectors and found that different areas have benefits to offer in terms of production facilities and access to the market. Southeastern Michigan was evaluated as a potential site and was found to be one of the locations possessing characteristics appropriate for concentrating collector mass production. The cost estimates in this report are based on the location of the plant in Southeastern Michigan using site specific costs for that region as of 1981. Other areas also offer suitable locations for production of the concentrating collector, and the costs determined for Southeastern Michigan can be adjusted for the conditions existing in these areas.

Later sections of the report establish that labor costs are a small portion of total production costs with materials emerging as the major cost item. Thus high wage areas may be able to compete with low wage areas of the country in this production field since mass production expertise, manufacturing facilities, skilled labor, raw material and market access exceed wages as priority concerns.

Factors such as a large pool of skilled labor, manufacturing and mass production experience, and convenient availability of basic raw materials can help make a region a suitable location for concentrating collector manufacturing. To meet anticipated national requirements, a number of production centers may develop as market expansion dictates future growth.

In addition to skilled labor and a long history of mass production, Southeastern Michigan is well-located with respect to the availability of reflective surface glass and structural steel components required in large quantities to produce the collector. Southeastern Michigan is also close to major glass production centers in Michigan, Ohio, and Pennsylvania.

It is a major primary metals production area and centrally located in the nation's manufacturing belt. Proximity to major suppliers of basic materials will minimize freight charges and significantly reduce inventory-carrying charges by limiting raw material inventory time to days instead of weeks.

Experts believe the primary market for concentrating collectors will be medium-temperature agricultural and industrial process heat applications. Regions where these potential applications are extensively found will have an advantage as production sites for the concentrating collectors. In this respect, Southeastern Michigan benefits from being centered in the nation's manufacturing belt as well as its most productive agricultural region.

The data in this report, based on Michigan conditions and factors, can be applied to many other production sites located in additional prime regions for solar energy development. Concentrating collector manufacturing might develop successfully at numerous sites within the United States offering a positive combination of the factors that will support sustained mass production operations.

Strong commitments and vigorous efforts will be needed to achieve the production levels future growth in solar energy utilization could eventually require.

1.7 DESCRIPTION OF THE CSERC STUDY

The CSERC manufacturing feasibility analysis included the following specific areas:

a. Characterization of the system, subsystems, and components. Specifying functions, design specifications, physical characteristics, materials, mating components, assembly, and inspection requirements.

b. Selection of materials and economical sizes. Determining material costs at different volumes. Choice of manufacturing processes to achieve economical operations and quality products. Choice of appropriate equipment, jigs and fixtures (conventional or specially designed), and inspection tools.

c. Designating labor classifications and labor requirements for each manufacturing process. Performing time and motion studies to assess the time required to perform each process. Studying the efficiency of the various processes in connection with tool changeovers on machines, preventive and breakdown maintenance, and operator considerations.

d. Selection of annual production volumes and determination of the costs involved in plant construction and production at the different annual levels analyzed.

This report, including Volume II (Appendices), provides explanations and data for each of the above areas. Plant layouts were prepared including direct and indirect plant equipment and facilities. The SAMICS program developed by the Jet Propulsion Laboratory was modified to generate indirect requirements. Labor rates (direct and indirect) were calculated by allocating indirect expenses on work stations. Marginal and full costs for systems, subsystems, and components were calculated. Make/buy decisions were reached based on manually and SAMICS-generated costs. Bills of material were prepared. High cost components were then analyzed for cost reduction. Cost reductions were achieved by modifying parts, substituting materials, changing processes, and evaluating concepts. Cost effective designs and processes were evolved through cooperation with designers, especially to achieve optical accuracy and tolerancing.

Note:

A module, as defined in this study, includes Pylons, four 20-feet Reflector and Reflector Supports, Receiver, Flex Hose, and Driving Mechanism. Detail study covers a module and its installation.

Manufacturing feasibility study does not include the Foundation, Controls, Manifolds, Heat Exchanger, etc. (designated as Auxiliary Equipment in Section 10.1 - Energy Cost Analysis).

Normative Selling Price of a module does not include marketing expenses.

The following sections give details on and the results of these interconnected activities.

2.0 STUDY METHODOLOGY

2.1 DEVELOPMENT OF MASS PRODUCTION PROCESSES

This section discusses the methodology used for the study. The aim of this information is to help assure effective employment of the report by prospective manufacturers.

To analyze the feasibility of mass production, CSERC manufacturing engineers began the evaluation process by preparing process estimate sheets for the fabrication of each part and assembly. The process estimate sheets are based on the part design prints supplied by Sandia. During this step, a make/buy decision was reached for each part; and relative cost factors as well as line balance and other manufacturing considerations were taken into account.

Each process estimate sheet specifies labor needs, equipment and tooling requirements, the base purchase price, including freight, installation costs of facilities and durable tools, and acquisition costs of expendable tools.

2.2 COST ESTIMATES USING SAMICS METHODOLOGY

The costs are estimated using the Solar Array Manufacturing Industry Costing Standard (SAMICS) originally developed by the Jet Propulsion Laboratory for the Solar Array Industry. This methodology is readily adaptable for costing the mass production of any solar energy system including the PPT concentrating collector.

SAMICS provides an efficient, standard method of estimating all indirect costs, developing a normative selling price that will yield a given rate of return on capital for investors, performing make/buy and sensitivity analyses. Section 7.0 discusses SAMICS in detail.

Estimated manufacturing costs are established by a summation of:

- Direct labor and material costs
- Indirect labor and material costs
- Amortization of capital expenses

SAMICS can also be used to estimate the costs of alternative processes or alternative annual volumes. Assumptions concerning plant construction costs, labor wage rates, return on capital, inflation and interest rates can be standardized for cost comparisons.

The SAMICS methodology is useful for realistic make/buy decisions. A recent extension, the Improved Price Estimation Guidelines (IPEG) lets the user perform sensitivity analyses at minimal cost, for the response of total cost and selling price to changes in major material prices and financial parameters such as the rate of return on investment, interest, inflation rates, and taxes.

Direct cost information derives from the bill of materials and the process estimate sheets described below. Direct material and direct labor are totaled from the process sheets and overhead is applied to determine the total manufacturing cost. Overhead includes estimated costs such as labor fringe benefits, hourly and salaried indirect labor, depreciating equipment, expense of tools, maintenance material, and utilities which vary with production volume. Overhead also includes estimated costs of building maintenance and depreciation, which do not vary directly with production volume. These estimates include taxes, insurance, utilities, and return on equity.

Each process estimate sheet specifies the component material, equipment, tooling, and direct labor requirements, including the basic purchase price, freight, and the installation cost of all required facilities and tools.

2.3 DESIGN REVIEW

The first step in developing the manufactured cost of each device was to obtain all available engineering design and production data. These included details of the product design, volume assumptions, location of the study plant, and the basis for costing methods.

For this study, the product design was not arbitrarily modified during manufacturing analyses; however, many design changes occurred when a component or assembly proved nonfeasible, with product engineers and manufacturing engineers agreeing that a change was required to meet the design intent. In addition, during the study, engineers compiled a list of product changes that may facilitate future cost reduction and product improvement.

In connection with production volume assumptions, processing was specific for each volume considered. Thus sufficient equipment and facilities could be determined for each given volume while avoiding over-capacity which could place an unnecessary burden upon the proposed plant.

A plant location assumption was necessary to develop labor costs and to calculate transportation costs for raw materials and finished goods. As noted in section 1.6, cost estimates in this report are based on the location of the plant in Southeastern Michigan using site specific costs for that region as of 1981. Along with the assessment that determines the suitability of a location for the plant, the availability of sufficient skilled labor must be determined as well.

2.4 PROCESS ESTIMATE SEQUENCE

Following the establishment of basic assumptions concerning design, volume, location, and costing methods, the cost analysis flows from a series of sequential steps that include:

Preliminary Processing

- Review design
- Select and detail the process
- Describe the machinery, equipment, and/or tools required
- Calculate number of machines and pieces of equipment required

Process Extension

- Estimate direct labor minutes
- Estimate facility and tooling costs
- Estimate special tooling costs

Establish Process Flow

Summarize Minute and Facility Costs from Process Sheets

2.5 PRELIMINARY PROCESSING

Preliminary processing, as outlined above, starts with a thorough review of the product design. To assure that each element of the design is sufficiently considered, a full characterization of the design is made. This characterization begins with a statement of the engineering function of the total assembly and then expands, in sequence, to the function of each subassembly and finally of each component. Information derived from product design documents includes design features, design tolerances, and inspection requirements.

In the present study, cost analyses could be performed when component and subsystem characterizations were completed in the preliminary processing stage. The process estimate sheet, reproduced in Figure 2.1, is an important tool in the analytical process. A process estimate sheet for each manufactured part will be found in Volume II, the Appendices, of this report.

2.6 COMPLETING PROCESS ESTIMATE SHEETS

Refer to Figure 2.1 for items on the process estimate sheet coded using numbers corresponding to the numbers with the following descriptions.

(1) Heading: The heading of each process estimate sheet was completed with all available information concerning the component or assembly covered by the sheet.

(2) Material description: A complete material description is particularly important, since it includes information that will support a purchase specification. When possible, an industry or generic standard is incorporated into this description. Rough as well as finished weights of the component as designed were made parts of the material specification. At this point, an Engineering Parts List was generated preparatory to tabulating cost elements for each part.

PROCESS ESTIMATE SHEET

(1) PROGRAM: COMPLETE HEADING; USE AS MANY SHEETS AS NECESSARY TO COMPLETE EACH PROCESS SEQUENCE RETAINING NUMBERING SEQUENCE FOR EACH COMPONENT OR ASSEMBLY.	PART NAME		ISSUE DATE	PART NUMBER
	MATERIAL (2) PROVIDE PURCHASABLE DESCRIPTION- USE INDUSTRY STANDARDS AS AVAILABLE	WT(LB) RGH. FIN.		SHEET OF

OPER. NO.	OPERATION DESCRIPTION	TOOL-MACHINE-EQUIPMENT DESCRIPTION	NUMBER MACHINES REQ'D	NET HOURLY CAP.	EST. MINUTES	FACILITY AND DURABLE TOOL COST				SPECIAL TOOL COST		
						BASIC	FREIGHT	INSTAL-LATION	TOTAL	DESIGN	BUILD	TOTAL
(3)	(4)	(5)	(6)	(7)	(8)			(9)			(10)	
TOTALS												

(3) ASSIGN SEQUENCE NUMBER TO EACH OPERATION

(4) IDENTIFY THE ENTIRE PROCESS SEQUENCE NECESSARY TO:
FABRICATE THE PURCHASED MATERIAL TO THE FINISHED PART BLUEPRINT,
AND
ASSEMBLE COMPONENTS INTO SUB AND FINAL ASSEMBLIES

DESCRIBE EACH STEP OF THE ENTIRE PROCESS IN TERMS OF OPERATION FUNCTION, PHYSICAL CHARACTERISTICS, ETC.

LIST DESCRIPTIONS ON SEPARATE LINES

(5) PROVIDE A GENERIC DESCRIPTION OF MACHINE, EQUIPMENT AND RELATED TOOLS REQUIRED TO PERFORM OPERATION UNDER (4)

(6) (7) BASED ON MACHINE NET HOURLY CAPACITY AND DAILY PLANNING VOLUME (A GIVEN) CALCULATE THE NUMBER OF UNITS (MACHINES), EQUIPMENT, TOOLS, MATERIAL HANDLING EQUIPMENT) REQUIRED

(8) ESTIMATE DIRECT LABOR MINUTES BASED ON MACHINERY, EQUIPMENT AND MANPOWER OUTPUT

(9) DETAIL ESTIMATES OF FACILITY (MACHINES AND EQUIPMENT) AND DURABLE TOOL COSTS DESCRIBED UNDER (10) - BASED ON SOURCE QUOTES

(10) ESTIMATE DETAILED COST OF SPECIAL TOOLS REQUIRED UNDER (5)

(12) CALCULATE TOTAL MINUTES, TOTAL FACILITY AND DURABLE COSTS AND TOTAL SPECIAL TOOL COSTS FOR EACH COMPONENT AND ASSEMBLY

REMARKS:	PROCESS ENGINEER	DAILY PLANNING VOLUME	NEXT ASSEMBLY
		GIVEN	(11) IDENTIFY NEXT ASSEMBLY

FIGURE 2.1: PROCESS ESTIMATE SHEET

After completing detailed material specifications, the process engineer in greater detail identified the material in terms of its precise form, shape, or tolerance. The engineer calculated the amount of stock to remove, the number of welds required, the number of fasteners, and other relevant factors, depending on the materials processing method.

At this point tentative judgments were made concerning which parts should be manufactured and which purchased. Many considerations influenced the decisions. With an existing plant involved, current facilities and their utilization are factors. When a new plant or a plant addition is considered, factors such as availability of special skills and expertise may require attention. There may be proprietary concerns affecting the decision to manufacture or purchase. Generally, the principal issue is cost, with in-sourcing preferred wherever it is possible and profitable.

In this study, the experienced processor made an initial financial judgment based on his knowledge when the choice was clear-cut. For borderline cases, more formal engineering approaches were employed.

(3) and (4) Engineering Analysis: Actual processing began with an examination of the part print in conjunction with component characterizations. The sequence of operations to meet the design intent was established step-by-step starting with locator points until the finished component was "produced." This engineering analysis was documented on the process estimate sheet, as shown under 3 and 4. Individual process steps were identified. Sequence numbers were assigned to each discrete part with intervals between operations. These intervals can accommodate unforeseen operations that may be added without renumbering the entire manufacturing design sequence. Thus, numbers such as 10, 15, 20, 30, 40, 45, 50 may be encountered to preserve the part numbering flow.

With the rough numbers established, the process engineer identified the entire process sequence within the framework of his assigned numbering system. This sequence identified each process or operation step necessary to fabricate the purchased material into the finished part or to assemble individual components into sub- and final-assemblies.

The process engineer described each step in terms of the operation function and physical characteristics. This work established a "road map" showing the way to the next operation or process. To achieve clarity, the process engineer listed only a single process description or station on each line.

(7) Net Hourly Capacity: Upon completing each required step for a component or assembly, the engineer developed a complete generic description of each machine, piece of equipment, and related tools or inspection equipment to satisfy processing requirements. Identification of machinery and equipment allowed the engineer to estimate the gross and net hourly capacity for each piece of equipment and to tabulate the data in column 7.

(6) Number of Machines Required: Using the net hourly capacity and the daily planning volume, the engineer calculated the number of machines needed to produce components and assemblies in accordance with the schedule. At this point, the working pattern for the plant needs to have been established. Emulating the mass production industry, the process engineer would prefer two to three shift operations, if assumed production volumes are sufficiently high. The number of machines required was entered in column 6.

Often in the analysis, the notation "same as" will be noticed. This represents a condition of cross loading where individual machines or material handling devices are used to process more than a single piece. Identification of the cost of individual equipment items was made on only one process sheet.

(8) Estimated Minutes: In column 8, the process engineer records the direct labor minutes required for each step in the operation, to assist in analyzing labor costs. The applicable hourly wage rate is applied to the direct labor minutes to determine the direct labor cost.

(9) Facility and Durable Tool Costs: These costs were tablulated in column 9 where provision was made for each cost element.

(5) Tool-Machine-Equipment Description: The generic description of machinery and equipment in this column supplied the basis for cost estimates. Actual costs were obtained from qualified vendors, catalogs, or derived from experience with identical or similar equipment. Freight and installation costs depend on local conditions, distance from vendors, the difficulty of installation, and local trade relationships.

(10) Special Tool Cost: Similarly, the costs of special tools were identified and tabulated in column 10. Assistance was obtained from the machine supplier when necessary to achieve accurate estimates for special machines. Machine vendors customarily will process estimates for such special machinery through a conference discussion of machine function in support of the proposed processing. In other cases, rough sketches of the part or assembly contour, together with the concept process sheet, provide sufficient engineering background to project the cost of special machines with sufficient accuracy for decison-making.

(11) Identify Next Assembly: Tabulations on the process sheet were completed by identifying the next assembly under 11 to document the flow toward final assembly.

(12) Totaling the Cost Elements: To complete identification of total facility costs, the various cost elements were totaled under 12. Total facility costs along with certain other indirect costs were identified by incorporating data from the process sheets into a block plant layout. Provisions for space to accommodate each production operation were supplemented with provisions for material receipt, storage, and movement as direct adjuncts to processing. Other provisions on the block plant layout include facilities for Quality Control, Maintenance, Tool Cribs, Amenities, and Shipping.

Using data from the process estimate sheets, the cost analyst summarized material costs, direct labor costs, and overhead to determine a manufacturing cost. Total facility costs were summarized to establish total capital costs for the proposed design and process at the specific volume in question. Facility costs were also built into the total overhead and burden costs to assess the financial impact of the system.

2.7 DEVELOPMENT OF ALTERNATE DESIGNS

In the course of this study, many design change recommendations were made by CSERC. Thus processing and costs in this report reflect these changes. As a reference point, the Appendices (Volume II) include processing data and costs for the baseline design.

The development of alternate designs, though shown as a separate task, starts before preliminary processing is complete. The manufacturing engineer begins his search for improved processes, including design changes required by the processes, while he is identifying the process that will produce the baseline design.

The manufacturing engineer actively seeks to achieve both lower costs in production and high performance in the finished product. His recommendations typically will aim at reducing cost while preserving functional effectiveness. In this study, the design changes suggested by CSERC engineers and accepted by Sandia characteristically followed this pattern.

2.8 FOLLOW-UP MANUFACTURING RESEARCH

While analyzing PPT concentrating collector producibility and searching for designs that would lower production costs, CSERC investigators identified various unproven processes with good potential for eventually supplying effective solar devices economically. To demonstrate feasibility, these processes need applied research efforts that could not be undertaken in the present study. Areas with significant promise worthy of special research effort are considered in section 9.0.

Evidence mounted as the study proceeded that further objective study and follow-up manufacturing research will bring cost-saving benefits. This is a natural evolution in the development of new designs and manufacturing facilities to accommodate their production. CSERC findings and recommendations in this connection are based on the study conducted and the experience gained. Building on this foundation inevitably will achieve still more progress in refining the mass production feasibility of concentrating collectors for the large, waiting U.S. market.

2.9 DEVELOPMENT OF GENERIC DESIGNS

In addition to assessing and improving the producibility of the PPT concentrating collector, CSERC also was requested to develop a generic design for line-focusing concentrating collectors.

Such a design was developed, although further research needed to reach final conclusions is beyond the scope of the current study. CSERC personnel applied information and data gained from design and manufacturing analyses of the PPT concentrating collector to this complementary research. Lessons learned and knowledge derived from the PPT concentrating collector review, supplementing the knowledge and experience of the CSERC staff, helped validate new findings and support the development of recommendations for a generic design.

The analysis involved assessing Sandia designs possessing the following reflector materials:

- Chemically strengthened glass and steel laminate on steel frame panel (Design A)
- Chemically strengthened glass on steel frame panel (Design B)
- Thin annealed glass and steel laminate on steel frame panel (Design C)
- Thermally sagged glass and thin glass laminate (Design D)
- Thermally sagged glass (slab) (Design E)

Following the initial review of these five types, two were selected for the present study: thin annealed glass (Design C) and slab glass (Design E). Subsequent sections cover these in detail.

3.0 MARKET CONSIDERATIONS

3.1 MARKET POTENTIAL

Although comments on the market potential for concentrating collectors are not required by the study assignment covered in this report, CSERC personnel acquired information as their work continued that is relevant to include for the guidance of potential manufacturers in the field.

Line concentrating collectors are a subclass among solar collectors including flat plate, evacuated tube, and others such as point-focusing and non-imaging systems. The Sandia Laboratories PPT concentrating collector, designed to produce temperatures up to 600° Fahrenheit, is considered one of the leading solar energy systems with an opportunity to capture a significant share of the agricultural and industrial process heat market.

According to the 1979 Domestic Policy Review of Solar Energy (DPR), the potential energy displacement by solar energy systems of 1.0 quads for agricultural and industrial applications by the year 2000 is greater than the projected 0.9 quad displacement for residential and commercial heating, hot water and cooling. (See Domestic Policy Review of Solar Energy, TID-22834, February 1979.)

The March 1981 Energy Data Report (Solar Collector Manufacturing Activity, July-December 1980) from the Department of Energy indicates the current status of the solar collector manufacturing industry. Table 3.1 and Figure 3.1 summarize the situation. Production of medium temperature collectors declined from 1977 to 1978 primarily because of the long delay in Congress to pass tax incentive legislation. Since 1978, the output of collector manufacturers has been growing at an annual rate exceeding 30 percent. (Table 3.2)

A market penetration model, developed by John A. Clark, shows that the medium temperature collector manufacturing output rate would have to reach approximately 60 percent for the industry to produce medium temperature collectors in sufficient volume to meet the DPR goal. This goal has these collectors supplying 5.81 percent of the nation's annual energy requirements at medium temperatures by the year 2000. (Figure 3.2) According to Clark, the current growth rate of 36 percent per year for medium temperature collectors, projected to follow a typical industry growth path, would yield only one percent of the nation's energy requirements at this temperature level by the year 2000. (See John A. Clark, "The Solar Industry in the United States: Its Status and Prospects, 1981," to be published by the Florida Solar Energy Center in a Solar Assessment volume, David L. Block, editor.)

These figures make clear the dimensions of the immediate and future opportunity as well as challenge for concentrating collector production. The nation's energy goals with respect to solar energy cannot be achieved unless substantial manufacturing growth occurs. The purpose of this report is to stimulate this growth and to show potential manufacturers how they can profit from the opportune and highly favorable current situation.

TABLE 3.1: SUMMARY OF SOLAR COLLECTOR MANUFACTURING ACTIVITY[a]

Year	Number of Manufacturers[b]	Area (Thousand Square Feet)		
		Low Temperature	Medium Temperature Special, & Other	Total
1974	45	1,137	137	1,274
1975	131	3,026	717	3,743
1976	186	3,876	1,925	5,801
1977				
First Half	196	2,514	2,506	5,020
Second Half	294	2,229	3,063	5,292
Total	321	4,743	5,569	10,312
1978				
First Half	297	3,595	2,681	6,276
Second Half	247	2,277	2,307	4,584
Total	340	5,872	4,988	10,860
1979				
First Half	250	4,356	2,545	6,901
Second Half	248	4,039	3,312	7,350
Total	349	8,395	5,857	14,251
1980				
First Half				
Reported	(R)215	(R)5,650	(R)2,729	(R)8,379
Estimated	(R) 13	(R) 416	(R) 118	(R) 534
Total, First Half	(R)228	(R)6,066	(R)2,847	(R)8,913
Second Half				
Reported	195	5,188	3,069	8,257
Estimated	55	674	1,611	2,285
Total, Second Half	250	5,862	4,680	10,542
Total	364	11,928	7,527	19,455

[a] Sum of components may not equal total figures due to independent rounding.

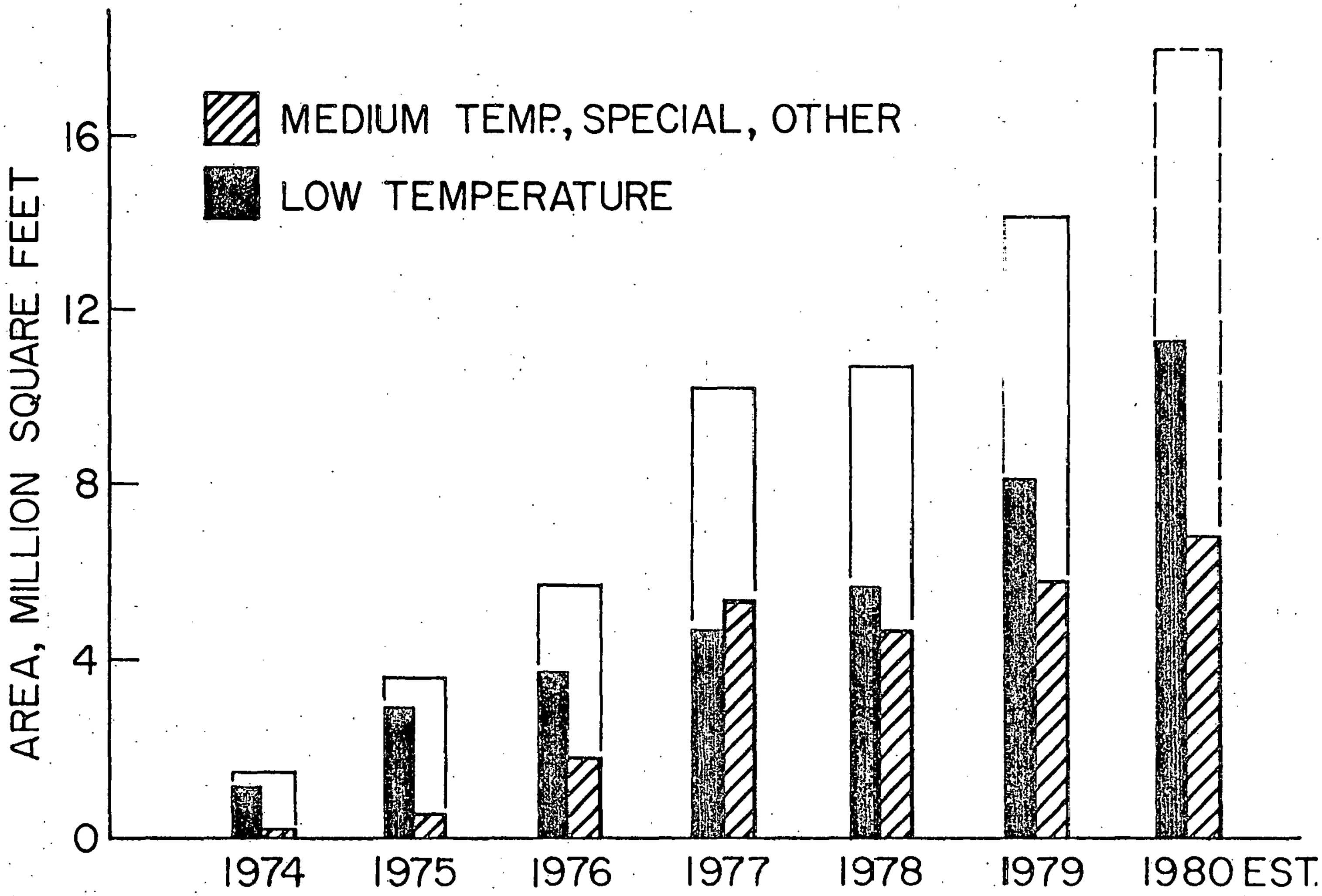
[b] Total number of manufacturers for 1974 through 1980 represents the number of companies reporting activities for one or both halves of the calendar year.

R = Revised

Sources: Energy Data Report, Solar Collector Manufacturing Activity, July through December 1980, U.S. Department of Energy, March 1981.

FIGURE 3.1:

U.S. SOLAR COLLECTOR MANUFACTURING ACTIVITY (6)



SOURCE: DOE COLLECTOR REPORT (EIA, 1980)

TABLE 3.2: ANNUAL APPLICATIONS ACCORDING TO MARKET SECTOR[a] (Thousand Square Feet)

Year and Collector Type	Market Sector						
	Residential	Commercial	Industrial	Agricultural	Other	Total	Government[b]
1980							
Low-Temperature, Nonmetallic..	8,168	1,034	112	35	0	9,367	0
Low-Temperature, Metallic.....	2,030	457	33	16	24	2,561	23
Medium-Temperature, Air.......	555	43	1	15	7	621	44
Medium-Temperature, Liquid....	5,216	710	274	19	203	6,423	350
Special, Concentrator.........	108	71	89	1	46	315	112
Special, Evacuated Tube.......	16	109	13	(c)	8	145	11
Other.........................	8	7	0	0	9	24	8
Total[d]......................	16,119	2,431	512	86	297	19,456	548
1979							
Low-Temperature, Nonmetallic..	6,064	756	115	11	0	6,946	0
Low-Temperature, Metallic.....	1,057	170	22	5	193	1,447	2
Medium-Temperature, Air.......	735	80	3	21	7	846	9
Medium-Temperature, Liquid....	3,377	764	93	31	195	4,460	170
Special, Concentrator.........	135	79	38	0	14	265	6
Special, Evacuated Tube.......	17	1,163	41	0	7	229	120
Other.........................	2	2	1	52	11	57	4
Total[d]......................	11,387	2,015	314	120	427	14,251	313
1978							
Low-Temperature, Nonmetallic..	4,198	577	23	60	(c)	4,859	NA
Low-Temperature, Metallic.....	740	124	2	1	24	891	NA
Medium-Temperature, Air.......	538	91	10	35	50	673	NA
Medium-Temperature, Liquid....	2,545	858	167	17	59	3,647	NA
Special, Concentrator.........	71	89	29	26	10	114	NA
Special, Evacuated Tube.......	2	108	18	0	0	141	NA
Other.........................	NA	NA	NA	NA	NA	NA	NA
Total[d]......................	8,095	1,848	163	140	145	10,492[e]	NA

a Includes adjusted data for nonrespondents.
b Government sector overlaps other sectors.
c Less than 500 square feet.
d Sum of components may not equal total due to independent rounding.
e No application was reported for 368,369 square feet.
Note: NA = Not Available
Source: EIA-63, "Solar Collector Manufacturers and Importers Survey"

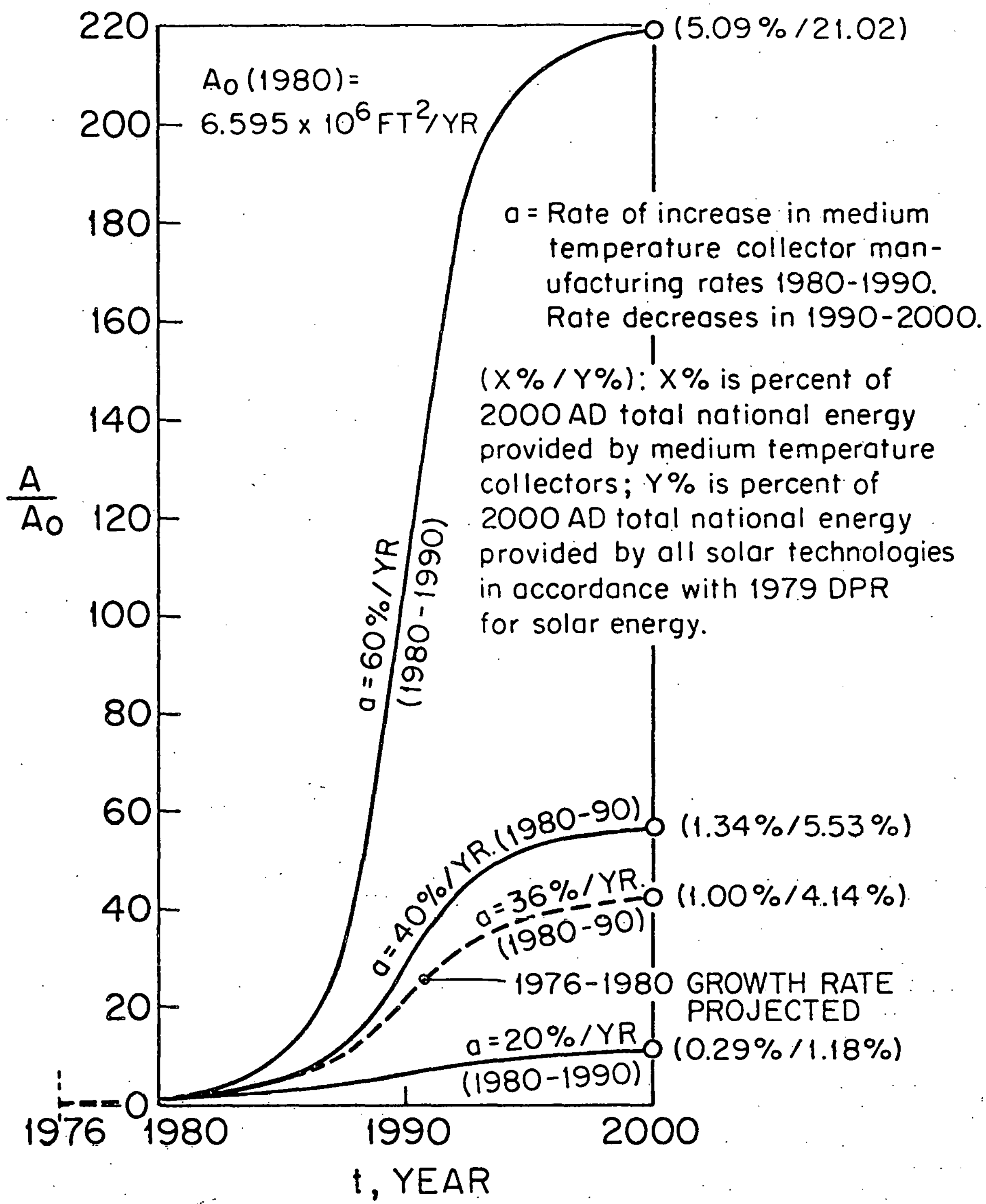


FIGURE 3.2: MEDIUM TEMPERATURE COLLECTOR MANUFACTURING RATES (1980 - 2000)

3.2 LEADING PROSPECTIVE MARKETS

Agricultural and industrial process heat applications are considered the primary markets for concentrating collectors. Solar energy use in agriculture and industry is currently small, but they are markets ready for development on a national scale.

Agricultural and industrial solar applications have the potential for significant growth in many parts of the United States. They are viewed as the markets with the greatest prospect for solar energy use in quantities that can have a meaningful impact on the country's over-all-energy consumption pattern.

Historically there is a tendency for manufacturers to wait for the existence of a market before they make capital investments and start production. There is a parallel tendency for potential users to wait until mass production efforts successfully lower costs. The CSERC mass production feasibility study of the PPT Concentrating Collector is an effort to solve this paradox and to expedite the process of bringing manufacturers and potential users together. The sections that follow in this report show manufacturers how to take the lead in responding now to a waiting market.

4.0 PPT CONCENTRATING COLLECTOR SYSTEM DESCRIPTION

4.1 TECHNICAL FEATURES

The PPT concentrating collector, evaluated by CSERC staff, consists of four 20-feet long, 6½-feet wide reflector modules possessing chemically strengthened, second surface, silvered glass mirrors.

The design characteristics of the system are given in Table 4.1

TABLE 4.1: SYSTEM DESCRIPTION

General:	Parabolic, line focus, single axis tracking 225°, modular ~2m aperture, 24 m length, 0.489 m focal length.	
Peak Noontime Efficiency:	60% at 600° Fahrenheit fluid temperature	
Working Fluid:	Therminol 66	
Reflector:	Second surface, silvered glass	
Receiver:	Sealed/unevacuated, black chrome selective surface.	
Orientation:	E/W or N/S	
Operation Environment:	Temperature	-30° C (-22°F) to 49°C (120°F)
	Dust	Blowing dust as described by method 510.1 of MIL-STD 810°
	Rain	Annual average of 750 mm (20.5 in.) Maximum 24 hour fall of 75 mm (3 in.)
	Ice	Freezing rain and ice deposits up to 25 mm (1 in. thick)
	Hail	20 mm (3/4 in.) diameter, with specific gravity of 0.9, falling at 55 ft/sec.
Tracking Capability:	Track in 25 mph wind speed, resist wind 80 mph (referred at 30 ft height), computer/aperture based (hot wire/microprocessor) tracking, combine functions of tracking with fluid control, system safeties, operational control and status display for entire field of collectors, emergency stow capability.	
Life:	10 to 20 years	
Cost - Goal:	$10 to $20/square foot of aperture (1978 dollars)	

4.2 MAJOR SUBSYSTEMS

The PPT concentrating collector consists of five major subsystems identified as follows:

- Pedestals
- Reflector and Reflector Support
- Receiver and Receiver Support
- Driving Mechanism
- Flex Hose

Each subsystem is considered at length in section 4.6 and in section 6.0, "Process and Equipment Descriptions."

4.3 GENERIC DESIGN CONSIDERATIONS

The CSERC manufacturing and design analysis was limited to concentrating collectors of the line-focusing parabolic trough type. Other kinds of line-focusing collectors (Fresnel lens, fixed-mirror tracking-receiver, fixed-receiver tracking mirror, and compound parabolic concentrator) are excluded.

The parabolic trough collector is the most developed of these five line-focusing concentrator design approaches in terms of current application and production. It appears to offer the greatest potential for high performance, durability, and cost reduction through manufacturing development and materials selection.

The various design options available in connection with the line-focusing parabolic trough concept share several common features. The system must consist of a receiver, a parabolic reflector (mirror), reflector support, tracking and drive mechanisms, and module support.

A typical unit would be about 6 meters long, the parabolic trough being pivoted about its center of gravity, and having an aperture width of about 2 meters and rim angle between 90° and 130°. Such units can be connected in strings to form a module.

The design and materials used for each component of the collector may vary widely from one system to another. Design and manufacturing parameters significantly influence the thermal and economic performance of a concentrating collector, and these parameters were fundamental concerns throughout the CSERC study.

The optical efficiency of the collector is a design parameter of paramount importance. This can be analyzed in terms of mirror reflectivity, mirror/receiver tube intercept factor, absorptivity of receiver tube and transmissivity of cover modified for incident radiation angle, end loss factor, and errors in tracking and receiver misalignment.

The mirror reflectivity and mirror/receiver intercept factor (which incorporates surface slope errors in the mirror) are major factors in the choice of materials for the reflector subsystem. Specific design alternatives for glass mirror reflectors were considered and recommendations made in terms of cost-effective manufacturing. Details on this and on other design/material factors will be found in this section and in other sections throughout the report. For a comprehensive design study to be successfully conducted and an effective manufacturing system identified, thorough understanding is needed concerning design parameters and their influence on thermal and economic performance.

The point to note here is that a number of factors affect the performance characteristics of a concentrating collector, and potential manufacturers will want to consider them. The thermal loss from the receiver tube has to be kept small; and this concern is an example of a design/manufacturing consideration requiring both knowledge and vigilance. Another obligation is taking into account the lifetime performance of the various materials used in a collector. Durability of the reflector surface, for instance, is a major factor, which discourages the use of reflecting surfaces such as metallized plastic film whose performance degrades substantially with time in an open environment.

4.4 THE REFLECTOR SYSTEM

As much as 50 percent of the manufacturing cost of a parabolic concentrating collector may be accounted for by the reflector subsystem. In general, the reflector may consist of polished metal, metallized plastic film, or a glass mirror, supported if necessary by a skin or sheet backing of glass, metal or plastic and in turn by a rib or frame structure connected to the drive system.

The reflector must conform to a precise geometrical contour, have high reflectance, low specularity and "figure," and must be durable. Reflectance losses caused by ultraviolet degradation, abrasion by wind-blown particles, rain erosion, hail damage, atmospheric corrosion, periodic cleaning, etc., must be held to acceptably small limits. Since no single material can satisfy all these requirements, the best choice must be sought that balances such criteria as materials cost, manufacturing cost, optical quality, initial performance, and long-term performance.

Size is another factor in reflector design, processing, fabrication, and assembly. There are limits on the sheet widths available for some reflector materials. There are maximum sheet sizes which can be fabricated or handled conveniently during manufacturing, assembly, or shipping.

Weight may prove to be an important cost item in reflector design. Weight directly affects material and manufacturing costs for the drive mechanism and support structure. A dominant issue is the requirement of structural rigidity which depends on wind and hail survival specifications.

The materials from which a reflector is made can be divided into three groups:

1. The reflecting material (e.g., a thin silver or aluminum film deposited on glass, a metallized plastic film, or a polished bulk metal such as aluminum).

2. Mirror support materials.

3. Protective films or coatings.

Silvered glass mirrors, more than about 3 mm thick, are structurally rigid over the anticipated reflector dimensions and need not be supported across their entire area to prevent breakage. Thin reflecting films, such as metallized plastics, thin polished metal sheets, or glass mirrors less than about 1 mm thick, must be bonded to a structurally rigid support over their entire area. The minimum glass thickness depends on such factors as chemical strengthening when this is possible, consistent with glass chemistry.

If a supporting sheet is needed, it too must conform to the precise geometrical contour required. In the case of plastic films, the supporting surface must be sufficiently smooth to avoid print-through of surface irregularities to the reflecting surface.

The materials commonly employed for the reflector--polished metals, metallized plastic films, and silvered glass--offer different advantages and disadvantages with respect to cost, reflectance, specularity, formability, durability. The relative merits and deficiencies of these materials were assessed by CSERC in the course of its producibility study.

4.4.1 Polished Metal

Roll-polished and anodized aluminum reflector sheet, made primarily for the lighting industry, is available in a variety of thicknesses at moderate cost ($10-$20/m^2). Kingston Industries (King-Lux Type C-4) and Alcoa (Alzak and Coilzak) are two major suppliers. Since prolonged outdoor exposure leads to pronounced soiling or discoloration of anodized aluminum, especially in urban environments, surface protection is required.

This material has the advantage of being readily bent and fastened to a curved support and is reasonably rigid in thicker gauges (.040 in.). Their major drawback is poor specularity, due largely to the presence of fine rolling marks on the surface. Some improvement in specularity may be possible, but it is doubtful the rolling marks can be completely eliminated during manufacture.

A conclusion of the CSERC evaluation is that polished metal is uneconomical to use as the reflecting surface in concentrating collectors for high temperature service.

4.4.2 Metallized Plastic Films

Such materials are available under many trade names and covering a wide price range. Among the materials utilized are aluminized or silvered acrylics, Teflon, Mylar--one of the most commonly used reflecting materials is FEK-244 marketed by the 3M Company. FEK-244 and similar materials such as aluminized Teflon are customarily used in a back-surface configuration with the aluminized side adhesively bonded to a contoured reflector support. Metallized films may also be laminated to secondary plastic films for additional strength, toughness, or backside protection for the metallized surface. The laminated sheet is then attached to a curved support.

Metallized plastic films are light-weight, easily available, and relatively inexpensive. Properly applied to a smooth support, the optical properties of the reflecting surface are fairly good. However, the films are difficult to apply evenly to a support surface; and losses in figure because of problems such as entrapment of dust between the film and the substrate or variations in thickness of the adhesive, may reduce the specular reflectance to 0.8 or lower. Thus the optical properties are sensitive to the bonding procedures used. Metallized plastic films also suffer degradation in their mechanical and optical properties as a result of outdoor exposure. This degradation may be their chief drawback.

Acrylics have the highest resistance to ultraviolet degradation, but their surfaces are easily damaged or scratched by wind-blown particles. Reflectance losses (up to 20 percent in a month) can occur due to dust accumulation on their surfaces. Once attached, these dust particles are often difficult to dislodge. Scratching and permanent damage to the reflector surface may occur if surfaces are cleaned improperly.

Stresses in plastic film due to temperature and humidity may cause lifting or splitting of the film.

These are potentially serious problems with metallized plastic films that can adversely affect long-term optical performance. The films have been used in prototype or first-generation designs mainly because they are inexpensive and available. However, unless abrasion-resistant surface coatings can be developed or polymer surfaces protected in other ways, metallized plastic films should not be seriously considered in concentrating collector designs.

4.4.3 Silvered Glass

Suitably-protected second-surface silvered glass mirrors currently offer the best choice in terms of optical quality, durability, long-term performance, and eventually, cost. The only serious disadvantage is the inherent brittleness of glass and its tendency to fracture under impact or static loads. This could reduce manufacturing yield, increase costs, or make replacement prohibitively expensive. However, high-quality silvered glass mirrors are optically superior to polished aluminum or aluminized plastic films. With suitable back and edge protection, they prove durable. The problem of breakage can be overcome by appropriate design and manufacturing procedures and materials selection.

The solar average hemispherical reflectance of good-quality second-surface silvered mirrors made from ordinary 0.125 in. thick float glass (ordinary window glass) is only about 0.85, primarily due to a broad absorption band in the infrared portion of the solar spectrum caused by the presence of iron (Fe^{2+}) in the glass. Because of their thickness, uniformity, and surface smoothness, such mirrors have good specularity. The reflectance can be increased to about 0.91 by using low-iron glass such as Jeanette's "Solarkleer." Reflectance may reach as high as 0.95 if silvered mirrors are made from so-called water-white or solar grade glass (e.g., Schott B270 "Solarwite" glass). At present, however, such "specialty glasses" are made by fusion or drawing processes and are available only in limited quantities. The reflectances of low-iron and water-white glass are found to be comparable for thinner sheets. High-quality silvered glass mirrors in flat sheet form cost approximately $\$10/m^2$ when float glass is used. The cost of low-iron or no-iron glass is approximately double this figure. There is no inherent reason why solar grade glass could not be made using the float process if the required volume were sufficiently high. The silvering of flat glass sheet is automated and adaptable to a wide range of production volumes.

The optical degradation of silvered glass mirrors resulting from outdoor exposure may be a problem in concentrating collectors. Side-view mirrors exposed up to twenty years on automobiles show little sign of corrosion except at the edges. The findings, however, suggest that development of improved corrosion and edge protection techniques will be needed to meet lifetime performance goals.

Curved glass mirrors with the necessary contour and optical quality for concentrating collector use can be manufactured by two methods:

1. Precision sagging or hot forming (pressing) of a relatively thick glass (5 mm or more) sheet followed by silvering is one method. This yields free-standing, structurally rigid, curved mirrors which do not require elaborate supports but need only be positioned in the proper orientation relative to the receiver. A variation of the method is to use the sagged thick glass to support a previously silvered sheet of thin annealed glass which could be sagged either prior to joining the two glass sheets or simultaneously with the thicker sheet.

2. Thin glass (approximately 1 mm) is silvered while flat, elastically bent to fit the precise contour of a structurally rigid support, and then bonded in place. A variation is to use chemically-strengthened thin glass which can be bent elastically to a precise contour without a structural support over its entire area.

The baseline design chosen for the CSERC study used glass silvered on the second (back) surface in the critically important reflector sub-assembly. Depending on the particular design, a second-surface silvered glass may be supported over its entire area by a thicker glass slab, by a plastic slab, or by a metal sheet. It may also be free-standing and supported only by a metal frame or rib structure.

This study is limited to collectors incorporating a second-surface glass mirror reflector supported by steel or glass sheet, or by a metal frame or rib-stiffened structure. The specific designs evaluated by CSERC are listed in section 2.9 and discussed at length in section 6.0.

4.5 PROCESSING OVERVIEW

The processes involved in manufacturing concentrating collectors cover a broad range of technologies. The major processes are:

Reflector Surface	Reflector Support	Receiver
. Basic glass manufacturing	. Metal stamping	. Induction brazing
. Glass forming	. Roll forming	. Black chrome plating
. Silvering	. Welding	. Grinding
. Bonding	. Machining	. Straightening
	Milling	
	Drilling	
	Tapping	
	Chamfering	
	Deburring	
	Boring	

Many of these processes require skilled labor. This was a factor considered in locational planning for concentrating collector manufacturing sites. Southeastern Michigan became a recommended site in part because the area is particularly well-endowed with skilled labor resources.

4.6 SUBSYSTEM DESCRIPTIONS

In addition to the five major subsystems discussed below, a typical installed solar energy system supplying steam also includes items such as manifolds, controls, pumps, valves, and heat exchanger. These collectively account for approximately 15-20 percent of an installed system cost. Such items are not individually discussed in this study. The following subsystems, however, require comment.

4.6.1 Pedestals

These are fabricated from commercially available structural steel. Conventional material forming processes such as cutting, stamping, milling, and CO_2 welding are required. Weathering steels such as Corten or Mayari-R are recommended rather than shotblasting and galvanizing or painting to withstand environmental conditions. (Corten and Mayari-R are not commercially available in small quantities, and thus are primarily considered for high volume production. These steels are currently produced for buildings and bridges. Their availability for low volume concentrating collector production [1,000 modules/year] depends on the development and scope of the solar market.)

The following points are noteworthy:

- Galvanizing or painting at overlapping surfaces does not seem feasible.
- Galvanizing thin wall sections (.075 in.) would introduce distortions at galvanizing temperatures of 850° Fahrenheit.
- Durable paints such as polyurethane-based materials are expensive, and there is no evidence the required 15-20 year protection could be achieved.
- Cost of the pedestal subsystem is $0.61/sq. ft. of aperture area.
- Further cost reduction is feasible by redesigning sectional areas to take advantage of the higher tensile strength (70,000 psi) of weathering steels compared to ordinary mild steel.

Required tolerances can be achieved by welding components in fixtures and following the right sequence. These tolerances are not critical since the design allows for adjustment in all three axes while aligning them in the field. Stress-relieving after welding by vibration, shotblasting, or ultrasonic methods is recommended to ensure dimensional stability of the assembly throughout its life cycle. Wooden spherical bearings (costing about 10% of metallic bearings) could reduce cost. The use of laminated wood as the pedestal material should also be evaluated. It is probable that pedestals could be molded to the required shape using wood at a cost between 30-50 percent of the cost for steel pedestals.

4.6.2 Reflector and Reflector Support

The four major components of the reflector and reflector support subassembly are the mirror, mirror support, torque tube, and adhesive.

Mirror: Front surface mirroring offers an advantage in reflectivity, but more development work is needed to achieve the necessary environmental protection. Second-surface mirrors are the current preference. Since solar-averaged reflectance for silver is 6% greater than for aluminum with little cost penalty, silver is the choice for the reflective surface. Overall mirror cost is derived from glass manufacturing, surface strengthening (if required), silvering, and glass forming (if required). Because of their critical importance in the production of concentrating collectors, these key processes are extensively discussed in the next subsection 4.7.

Mirror Support: A strong mirror support is necessary to retain the mirror shape if formed elastically and to protect the mirror from overloads during operation. Three of the five design concepts evaluated by CSERC (designs A, B, and C, described in section 6.0) use a sheet steel frame, formed by stamping.

Frame materials considered include aluminized steel, galvanized steel (electro or dip), galvalume, zincrometal, or plain carbon steel. The material, with corrosion-resistant coating if necessary, should be suitable for drawing operations without cracking on the surface. It should withstand environmental exposure 15-20 years.

Aluminized steel suffers from poor formability. Plain carbon steel and zincrometal require painting which is not cost effective or weather resistant for long life use.

Galvanized and galvalume steel (aluminum killed) are cost effective and technically appropriate. Steel 0.030 in. thick has been used successfully to form the mirror support. Steel 0.025 or 0.020 in. thick should be used to reduce costs. The steel can be formed using a typical automobile hood or fender forming process, with double action press followed by piercing, blanking, and restriking operations to achieve the required tolerance of ± .025 in.

The estimated cost is $1.00-$1.10 per square foot of aperture area (including adhesive). To form a composite structure as suggested in designs A and C, an intermediate steel skin (.030 in. thick, galvalume) is chosen, costing about $.50-$.55 per square foot of aperture area (including adhesive).

For design D, sodalime glass 0.20 in. thick is recommended for the reflector support. Window glass (containing 0.1% iron) may be more cost-effective; however, simultaneous forming (sagging) of dissimilar glasses requires further development work. In design E, the mirror is thick enough to support itself and does not need another support. Sodalime glass is selected for this design.

Torque Tube: Functional requirements for the torque tube can be met using electrically welded Corten steel tube or an equivalent weathering steel. Ribs are formed by stamping from galvalume material. The torque tube should be fabricated using CO_2 MIG welding. Puddle welds instead of fillet welds are recommended.

Location, size, and co-centricity of holes on flanges are important for optical reasons. To achieve the desired tolerances, a sequence of operations is recommended which assures location of the holes within a .004 in. circle on the pitch circle and hole diameter accuracy of $\left(^{+.001}_{-.000}\right)$ in. accuracy.

The recommended sequence of operations is weld, vibration stress relieve, facing on flanges, drill and ream 2 manufacturing holes, drill remaining holes with reference to the 2 manufacturing holes. Both flanges on the torque tube should be machined simultaneously with the tube supported on ribs. The use of adjusting elements (component or shims) eliminates the need to straighten commercially available torque tube.

Adhesive: Various adhesives were evaluated for void-free bonding, required peel strength and shear strength, and ability to endure environmental conditions 15-20 years. Among the materials considered were: 3M Scotch-A10 (Acrylic), Goodyear 2-component 6000 series (polyurethane), Norwood's Urethane Tape, Quinn's moisture-cured urethane, Shell Epon 828, and Versamid (resin).

Selection criteria included handling,tacking time, full curing time, cost of material, equipment cost, desired film thickness (e.g., .010 in., .025 in., and .070 in.) to compensate for component tolerances.

Goodyear 2-component 6000 series became the recommended adhesive, at a cost of about $0.25/sq. ft. with a film thickness of .025 in.

4.6.3 Receiver and Receiver Support

The Sandia receiver tube specification of 1¼ in. O.D. is the basis for the design assumption that a 1¼ in. O.D., 0.065 in. wall, electric welded low carbon steel tube is used for the receiver. Tubes cut to lengths of 10 feet and end-finished are available from commercial sources. Commercial tolerances are: O.D. ± 0.005 in., wall $\left(^{+0.004}_{-0.007}\right)$ in., and straightness .030 in./3 ft. length.

An additional straightening operation is required to meet design tolerances. Straightness can be brought to the required tolerance using a six-roll rotary straightener. "O" ring supports can be manufactured by a stamping operation, in either a progressive die set up or a transfer press. The progressive die is economical for low volumes, and the transfer press for high volumes.

Required tolerances can be achieved by welding components in fixtures and following the right sequence. The receiver tube should be cleaned with trichloroethylene and glass bead blasted before final cleaning and nickel/black chrome plating. Suitable plating processes have been developed by Sandia National Laboratories.

Selective coating should be done on an automated line under controlled conditions so that process consistency is maintained. Strict quality control is essential. A Gier Dunkle meter should be used to check absorptance and emittance. Ends of tubes should be blocked to restrict chemical action on the internal surface of the tube. The need to rotate or relocate the tube during plating to ensure uniform plating thickness should receive further cost-benefit analysis.

A straight glass tube can be used for the cover. Glass tubing is supplied with I.D. tolerances of $\left(^{+.020}_{-.040}\right)$ in. To seal the tube properly from dust and environmental attack, the desired tolerance is $\left(^{+.002}_{-.000}\right)$ in. on the tube ends (1 in. length). This can be achieved by a grinding operation.

For high volume production, induction brazing of the "O" ring support is the choice. For low volume production either flame brazing or argon gas arc welding can be used.

Receiver Support: The stainless steel parts are largely made by stamping. Receiver bearing parts can be made by investment casting to hold tolerances, although further boring/broaching treatment is advised. It is possible to include holes in the casting process, followed by a tapping operation.

To eliminate the effect of tolerance errors in various components, an adjustable joint should be part of the receiver support. The receiver support should be assembled by means of a special fixture. The receiver bearing should be located on the theoretical focal point and the flexural member located on the torque tube flange dowelling holes. This will ensure positioning of the receiver tube on the theoretical focal line.

4.6.4 Driving Mechanism

Driving mechanism (gearbox and motor) can be obtained from manufacturers at $1.12/sq. ft. and $1.00/sq. ft. of aperture, at low and high volumes respectively. An alternate approach is to use a hydraulic drive, which might be more economical. A cost-benefit analysis is required to identify the preferable system.

4.6.5 Flex Hose

This is a standard product of some vendors now using mass production equipment. Purchasing flex hose from these sources will be economical.

4.7 GLASS MANUFACTURING, CHEMICAL STRENGTHENING, SILVERING, AND FORMING

Equipping the reflector with an effective mirror arrangement is a vital concern in the production of concentrating collectors. The task is accomplished through efficient management and application of glass technology.

4.7.1 Glass Manufacturing

The glass thicknesses considered by CSERC imposed limitations at one extreme because of difficulties in handling thin glass without breakage. At the other extreme, wind loading requirements imposed restrictions on the "thick glass" concept.

The thinnest glass that can be handled in the sheet sizes required without prohibitive breakage losses is approximately 0.025 in. thick. For designs A through D, CSERC evaluated "thin glass," using a nominal glass thickness of 0.040 in., since this glass is readily available. Wind loading is likely to cause breakage for glass thicknesses less than about 5 mm (0.20 in.), although this limitation may be eliminated in the future. For designs D and E, glass 0.20 in. or 0.25 in. thick was evaluated.

Glass sheet may be manufactured by the float process for high volume production. Drawing or fusion processes are customary at lower volumes (so-called "specialty glass"). The float process is two to three times faster than the fusion process and much faster than the drawing process.

Four types of glass compositions generally available are: Sodalime, aluminosilicate, borosilicate, and lead glass. Borosilicate glass has good thermal and chemical stability but is too expensive for the present application. The refractive index of lead glass is too high. Sodalime glass and aluminosilicate glass are the two types suitable for solar applications including concentrating collectors.

Sodalime Glass: Sodalime glass, with a softening temperature of 700^{o} Centigrade, is softer than aluminosilicate (softening temperature 915-950^{o} Centigrade). The iron content (and iron valency state) of the glass is critical for solar applications since the absorption coefficient of the glass is very sensitive to the presence of iron. Both sodalime and aluminosilicate glasses can be produced with acceptable iron content. CSERC evaluated sodalime glass with essentially no iron ("water-white" glass) and low-iron sodalime glass (0.05-0.06 ·/· iron).

Water-white sodalime glass sheets in 0.040 in., 0.20 in., and 0.25 in. thicknesses are commercially available, manufactured by the drawing process. Transmittance of this material is 91.6 percent for the 0.040 in. glass and 91.0 percent for the 0.25 in. glass. Sodalime no-iron glass can probably be produced by the float process at high volume; however, this process needs further development. Sodalime glass (no-iron/low-iron) is not yet produced by the float process, because the demand for solar applications has been limited. Given sufficient demand, the float process might be adapted to supply sodalime glass. One batch of low-iron (.06%) sodalime glass was manufactured by the Ford Glass Company employing the float process. The glass was intended for use in heliostats.

Low-iron sodalime glass sheets (0.057% iron) are currently being produced using the drawing process in thicknesses of 0.040 in. and 0.187 in. Production of 0.028 in. has been demonstrated. Transmittances are 91.3 percent for 0.040 in. glass and 88.5% for 0.187 in. glass.

Aluminosilicate Glass: CSERC evaluated low-iron aluminosilicate glass (iron in a +3 valence state). This "specialty glass" can be produced by the fusion process. The transmittance of aluminosilicate glass is 91.6 percent for glass 0.040 in. thick and 91.0 percent for glass 0.25 in. thick. The float process is unlikely to be adaptable to the manufacture of specialty glass.

Table 4.2 summarizes costs for sodalime and aluminosilicate glasses.

TABLE 4.2: GLASS SHEET MANUFACTURING COSTS
(Data from Ford Studies and CSERC Research)

Composition	Process	Thickness (in.)	Transmissivity (Percent)	Cost, \$/sq.ft (Depends on Volume)
Sodalime (Standard)	Float	0.040 0.25	90.5 (est.) 80.0	0.43-0.72
Sodalime (Low Iron)	Drawn	0.040 0.19	91.3 88.5	0.60-0.95
Sodalime (No Iron)	Drawn	0.040 0.25	91.6 91.0	0.60-0.95
Aluminosilicate	Fusion	0.040 0.25	91.6 91.0	0.90-1.40

4.7.2 Chemical Strengthening

Chemical strengthening is an ion exchange process carried out at elevated temperature in which glass sheets are immersed in molten salt. The process introduces compressive stresses in the glass surface. The penetration depth depends on glass and salt composition, immersion time, and temperature. Adequate penetration depth for the thin glass mirror of a concentrating collector is approximately 6 to 8 mils, which produces an associated modulus of rupture of about 40,000 psi.

Only aluminosilicate glass is routinely strengthened chemically to these specifications. Manufacturers of low-iron and no-iron sodalime glass report that such glasses can also be strengthened chemically to meet these specifications. Because of this assurance, sodalime glass is recommended in the present application.

The process of chemical strengthening is performed at a temperature of approximately 500^{o} Centigrade, and the rate of penetration is about 1 mil/hour. Increasing the rate of penetration in the chemical strengthening process is an objective of current development efforts.

The cost of a chemical strengthening facility with a capacity of 15 million square feet per year is estimated at \$3 million. The cost of chemical strengthening is between \$.80 and \$1.50 per square foot.

Table 4.3 shows the recommended glass type and manufacturing process for each of the five designs evaluated by CSERC. In design D, low-iron glass is recommended for both the mirror sheet and mirror support slab in order to match thermal expansion characteristics during manufacturing (sagging). Recommended thicknesses are controlled by the present availability of glass in the appropriate size (for example, 0.03 in. glass could be used for designs A through D; 0.20 in. glass could be used for design E).

TABLE 4.3 GLASS RECOMMENDATIONS FOR THE FIVE EVALUATED DESIGNS

Design Concept	Glass Type	Manufacturing Process	Glass Thickness	Chemical Strengthening
A	Sodalime (low iron)	Drawn	0.040	Yes
B	Sodalime (low iron)	Drawn	0.040	Yes
C	Sodalime (low iron)	Drawn	0.040	No
D	Sodalime (low iron)	Drawn	0.040 0.20	No
E	Sodalime (water-white)	Drawn	0.25	No

4.7.3 Silvering of Flat or Curved Glass

Silvering of glass is accomplished by three processes: chemical, sputtering, or vacuum.

Although a potential corrosion problem exists with the process, chemical silvering costs only $0.40 to $0.75 per square foot depending on volume, compared with $1.25 to $2.25 per square foot for either sputtering or vacuum silvering.

Corroded areas on silvered glass mirrors contain silver agglomerates which may be caused by high operating temperatures, the presence of standing water, or outgassing of adhesives. The exact cause of corrosion is not known. How much it is attributable to standing water, present in chemical silvering but absent in sputtering or vacuum silvering, is undetermined. Although better data on these processes and their effects are needed, the chemical silvering process was selected in the CSERC study because of its favorable cost/benefit ratio.

A typical chemical silvering line for flat glass costs about $600,000. The line is continuous and runs at 10 feet per minute. Equipment for curved glass chemical silvering is estimated at $800,000 for the same process and production rate. The cross-section of the process line should match the curvature of the glass, which must be more precisely located on the conveyor system than flat glass.

A maximum of 25 percent increase in silver film thickness is needed to compensate for nonuniformities caused by surface curvature. Silvering costs will be 15-20% higher for curved glass than for flat glass; however, the necessary equipment is available.

4.7.4 Glass Forming

Glass can be formed elastically or plastically by thermal conditioning. Elastic forming is accomplished by increasing the modulus of rupture, or by shifting the neutral axis of a glass sheet to another material in the laminate so the glass remains in compression during and after forming. The cold forming process (elastic forming) is used in designs A, B, and C. Glass is formed thermally in designs D and E.

Depending on its composition, glass can be formed plastically at 700-950^{o} Centigrade. The four different processes of plastic forming are:

- Gravity sagging
- Vacuum sagging
- Press sagging
- Hot air gas hearth sagging

Each process needs further research to determine its full potential for solar applications. Prototype work has been performed to sag solar glass using gravity and press sagging. The slope error achieved is 3 to 4 milliradians (mrad), which is within reach of the budgeted error of 2.5 mrad. The conclusion is that a 2.5 mrad slope error can be maintained for these processes if a solid ceramic mold is used. Accurate components are being produced by applying a combination of gravity and press sagging.

Although vacuum sagging and gas hearth sagging have not been tried for solar applications, there is confidence that either would produce favorable results. The gas hearth process is cost-effective for high volumes (50 million square feet/year), with an estimated forming cost of about $0.47/square foot. Gravity sagging, vacuum sagging, and press sagging processes are cost-effective at lower annual production rates. Table 4.4 gives estimated glass forming costs as a function of annual production volume.

TABLE 4.4: ESTIMATED GLASS FORMING COSTS

Process	Annual Volume in Square Feet	$/Square Foot	Source
Vacuum, Gravity, or Press	600,000	2.30-5.10	CSERC Research
Vacuum, Gravity, or Press	3,000,000	1.10	Ford
Vacuum, Gravity, or Press	15,000,000	1.00	CSERC Research
Hot Air Gas Hearth	50,000,000	0.47	Ford

4.7.5 Make/Buy Decisions Concerning Glass

In the development of processes, informal make/buy decisions are reached on the basis of production volumes by process engineers. In-plant manufacture may be cost-effective at 100,000 modules per year while purchasing may be indicated at lower volumes. In this study, both sheet and tube glass are considered available for purchase at all volumes. In-plant forming is cost-effective at high volumes (i.e., 25,000 and 100,000 modules per year). In-plant silvering is cost-effective at high volumes, but purchasing is advisable at volumes of 1,000 and 5,000 modules per year.

4.8 MISCELLANEOUS PROCESSES

Stamping processes produce the following major components:

- Frame panel
- Reflective surface supports
- Flexurals
- Receiver tube "O" ring supports
- Torque tube flanges
- Receiver tube supports

Make/buy decisions once more are volume-sensitive. Torque tubes and receiver tubes are roll-formed and welded tubes available for purchase at all volumes. Assembly of the torque tube to the reflective surface supports and pylon weldments is accomplished with MIG welding. Assembly of the torque tube to the supports is accomplished in-plant at all volumes to maintain dimensional integrity. Welding is either manual or automatic depending on volume.

Machining operations are performed on conventional production machines and generally carried out in-plant. Cross-loading of various components makes machining operations cost-effective at most production volumes for in-plant execution.

Induction silver brazing of the "O" ring support to the receiver tube is performed in-plant at all volumes to avoid shipping problems.

Black chrome plating of the receiver tube to enhance its absorption is performed in-plant at production volumes of 25,000 and 100,000.

Further aspects of make/buy decision-making are covered in section 5.0.

5.0 APPLYING SAMICS TO DESIGN AND MAKE/BUY ISSUES

In addition to providing a complete manufacturing cost and selling price analysis for a given design of a solar energy system, SAMICS can be used economically to resolve other problems manufacturing and process engineers confront. Most components of any manufactured article lend themselves to alternative designs, and often they can be fabricated from several types of materials using different manufacturing processes. SAMICS helps determine the most economical alternative, subject to technical feasibility.

Decisions must also be reached whether to make or buy various components. At low volumes, most parts will be purchased, unless special features require facilities and tools not possessed by outside vendors. At greater volumes, the decision to make or buy may be less obvious. SAMICS can be effectively used to resolve so-called "marginal" or "border line" cases.

5.1 ALTERNATIVE DESIGN COST ANALYSIS

The following analysis of relative costs for alternative designs of the torque tube flange illustrates the use of the computer to select the most cost-effective design. Four alternative process designs were considered:

1. Flange stamped from 5/8 in. x 10 in. x 10 ft. strips of Corten material using 17.36 pounds of material per flange.

2. Flange stamped from 1/8 in. x 12 in. x 20 ft. strips of Corten material using 5 pounds of material per flange.

3. Flange cut from 9½ in. O.D. x 1¼ in. wall seamless tubing using 6.88 pounds of material per flange.

4. Flange formed from 1¼ in. x 1¼ in. x 1/8 in. x 20.5 ft. angle ASTM A-36 material using 1.88 pounds of material per flange.

The computer-estimated cost for each alternative appears in Table 5.1. The reported cost represents the total contribution of the flange to the SAMICS-estimated selling price.

TABLE 5.1: COST ANALYSIS OF FOUR ALTERNATIVE DESIGNS FOR THE TORQUE TUBE FLANGE

Flange Design	Cost per Collector	Cost per Flange*
#1 Stamped 5/8 in. x 10 in. x 10 ft. Corten	$73	$9.125
#2 Stamped 1/8 in. x 12 in. x 20 ft. Corten	20	2.50
#3 Cut 9½ in. O.D. x 1¼ in. Wall Seamless Tubing	49	6.125
#4 Formed 1¼ in. x 1¼ in. x 1/8 in. Angle	9	1.125

* Eight flanges per collector.

The eightfold increase from $1.125 (alternate #4) to $9.125 (alternate #1) amounts to $64 per collector, or $6.4 million for 100,000 collectors. Alternate #4 is the most cost-effective of the evaluated designs.

5.2 MAKE/BUY ANALYSIS ILLUSTRATION

The frame panel and the flexural plate were chosen to illustrate the application of SAMICS in make/buy analyses. Twenty-four frame panels, required per collector, could be purchased from a vendor at about $470 per collector plus a one-time $710,000 tooling cost. Flexural plates bought from a vendor would cost about $40 per collector plus a one-time $45,000 tooling cost. The make/buy analysis of these components shows that the wrong decision at the 100,000 level can mean a loss of millions. The wrong decision on the flexural plate could cost the manufacturer $1 million, and on the frame panel as much as $5 million.

Two SAMICS runs were made for each component at 1,000, 5,000, 25,000, and 100,000 annual volumes to produce the thin annealed glass reflector design. See Table 5.2 for final cost estimates, derived by including the most favorable decision for other components. For example, since it is cheaper to make the flexural plate at all volumes, this alternative was included in deriving cost-estimates for making and buying the frame panel.

The results of the make/buy analysis for the frame panel are clear-cut and expected. At low volumes, it is economical to buy the frame panel. Even at the 25,000 volume the conservative buy decision was based on the vendor's firm quote and the larger margins of error in the make price estimate. According to the SAMICS analysis, $5 million can be saved if the frame panel is made at the 100,000 volume.

The make/buy analysis of the flexural plate shows this component can be made in-plant more economically at all volumes than it can be bought. The analysis reveals no significant economies of scale because no quantity discounts were offered by the vendor in the quoted price for this item.

TABLE 5.2: MAKE/BUY ANALYSES - FRAME PANEL AND FLEXURAL PLATE

	Estimated Selling Price/Collector (1981 Dollars)		
Annual Volume	Buy	Make	Savings if Made
FRAME PANEL			
1,000	$9,118	$39,890	-$30,772
5,000	6,399	6,646	- 247
25,000	4,510	4,502	8
100,000	4,026	3,976	50
FLEXURAL PLATE			
1,000	$9,147	$9,118	$ 29
5,000	6,421	6,399	22
25,000	4,518	4,510	8
100,000	3,985	3,976	9

6.0 PROCESS AND EQUIPMENT DESCRIPTIONS

6.1 FIVE DESIGNS EVALUATED

In response to a request by Sandia Laboratories, CSERC extended the scope of the study to include three parabolic trough designs. Two others were added by CSERC because of their potential. The five designs (shown in Figures 6.1, 6.2, 6.3, 6.4, 6.5) evaluated by CSERC are:

- Design A (Figure 6.1) - Chemically strengthened glass and steel laminate on steel frame panel
- Design B (Figure 6.2) - Chemically strengthened glass on steel frame panel
- Design C (Figure 6.3) - Thin annealed glass and steel laminate on steel frame panel
- Design D (Figure 6.4) - Thermally sagged glass and thin glass laminate
- Design E (Figure 6.5) - Thermally sagged glass (slab)

In each alternate design, the 24 reflective surfaces consist of two pieces of glass, 45 in. x 39.37 in., although a single piece of glass, 91 in. by 39.37 in., would be preferable. Glass making technology cannot yet accommodate this preference.

CSERC staff members made careful assessments of these five designs with the key objective of selecting the particular design to be used in the manufacturing process and cost analyses of this study. Component, construction, and cost factors were considered in detail on each design.

Manufacturing cost comparisons of reflector assembly concepts for the five designs were made for volumes of 1,000 modules per year (Table 6.1) and 100,000 modules per year (Table 6.2).

6.1.1 Construction Features

Design A (Figure 6.1): This parabolic trough is manufactured by bonding a second-surface silvered sheet of chemically-strengthened glass (Chemcor or equivalent) to a flat sheet of .030-inch low carbon steel, which is vacuum-formed over a parabolic form fixture and then bonded to the frame panel. This subassembly is then assembled on a 7-inch diameter torque tube, to which reflector support assemblies are welded, with screws from the supports to the frame panel.

Design B (Figure 6.2): In this design, the chemically-strengthened glass on steel frame panel is manufactured using essentially the same process as in design A, except that the glass (Chemcor or equivalent) is bonded directly to the frame panel.

Design C (Figure 6.3): The thin annealed glass and steel laminate on steel frame panel design is produced by bonding a second-surface silvered, .040-inch thick annealed glass to a flat sheet of .030-inch thick low carbon steel, which is vacuum-formed over a parabolic form fixture and then bonded to the frame panel. This subassembly is then assembled on a 7-inch diameter torque tube to which parabolic trough surface supports are welded with screws from the supports to the frame panel. The process is identical to that used in design A. The advantage over design A is that the thin annealed glass is substantially cheaper than chemically-strengthened glass. The ability to cold form this glass results from shifting the neutral axis of the laminate from the glass to the steel, thus maintaining compressive stresses in the glass.

Design D (Figure 6.4): The thermally sagged glass and thin glass laminate design is manufactured by bonding a second-surface silvered, .040-inch thick glass sheet, thermally sagged into a parabolic shape, to a 1/4-inch thick simultaneously sagged glass sheet which serves as a substrate. The resulting laminate is then bonded to the reflective surface supports on a 10-inch diameter torque tube subassembly.

Design E (Figure 6.5): This design, thermally sagged glass (slab), is made by bonding a second-surface silvered, 1/4-inch thick sheet of glass, thermally sagged into a parabolic shape, directly to the reflective surface supports on a 10-inch torque tube subassembly. The advantage over design D is eliminating the need for thermal sagging and bonding of two glass sheets.

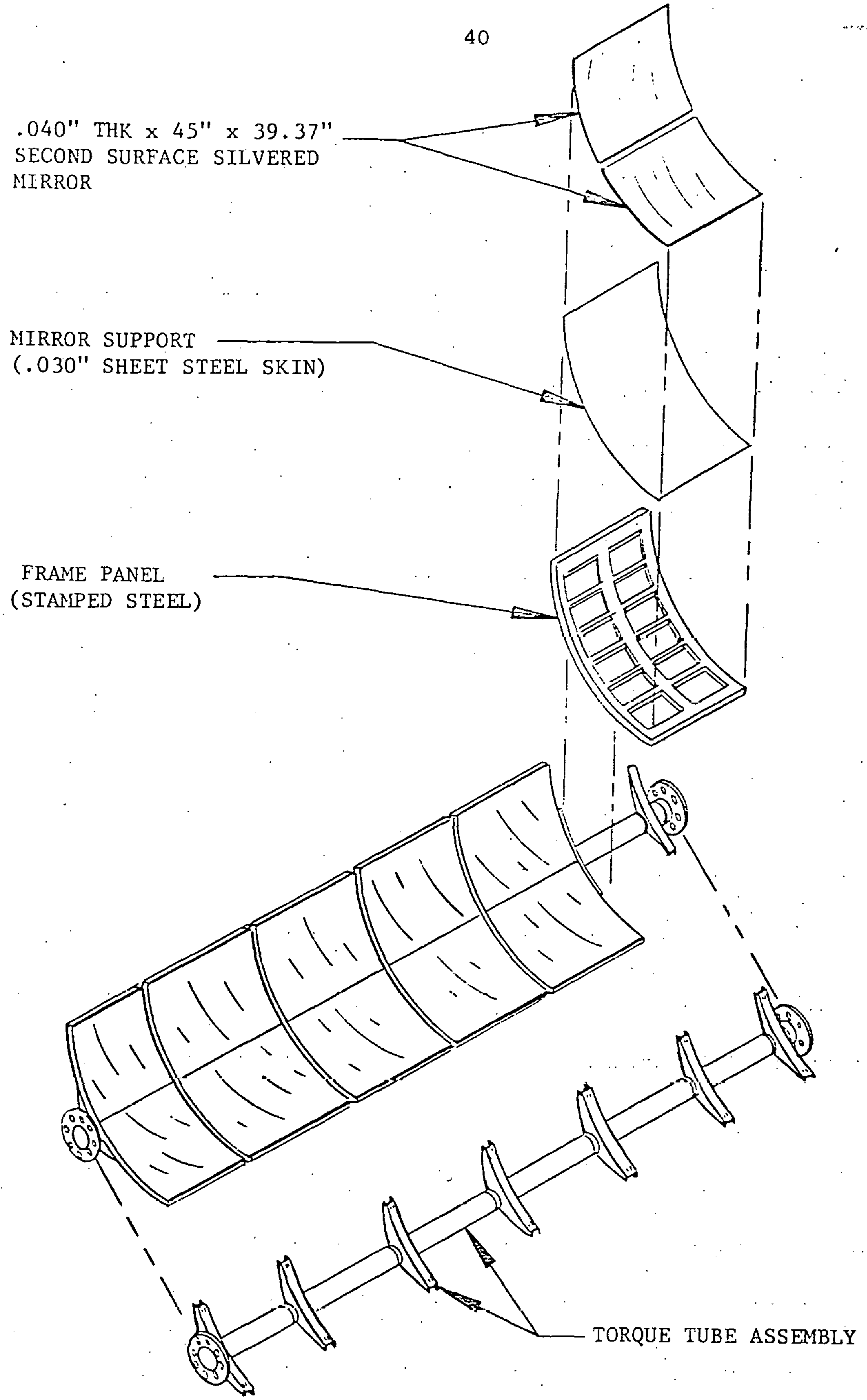


FIGURE 6.1

A

CHEMICALLY STRENGTHENED GLASS AND STEEL LAMINATE ON STEEL FRAME PANEL

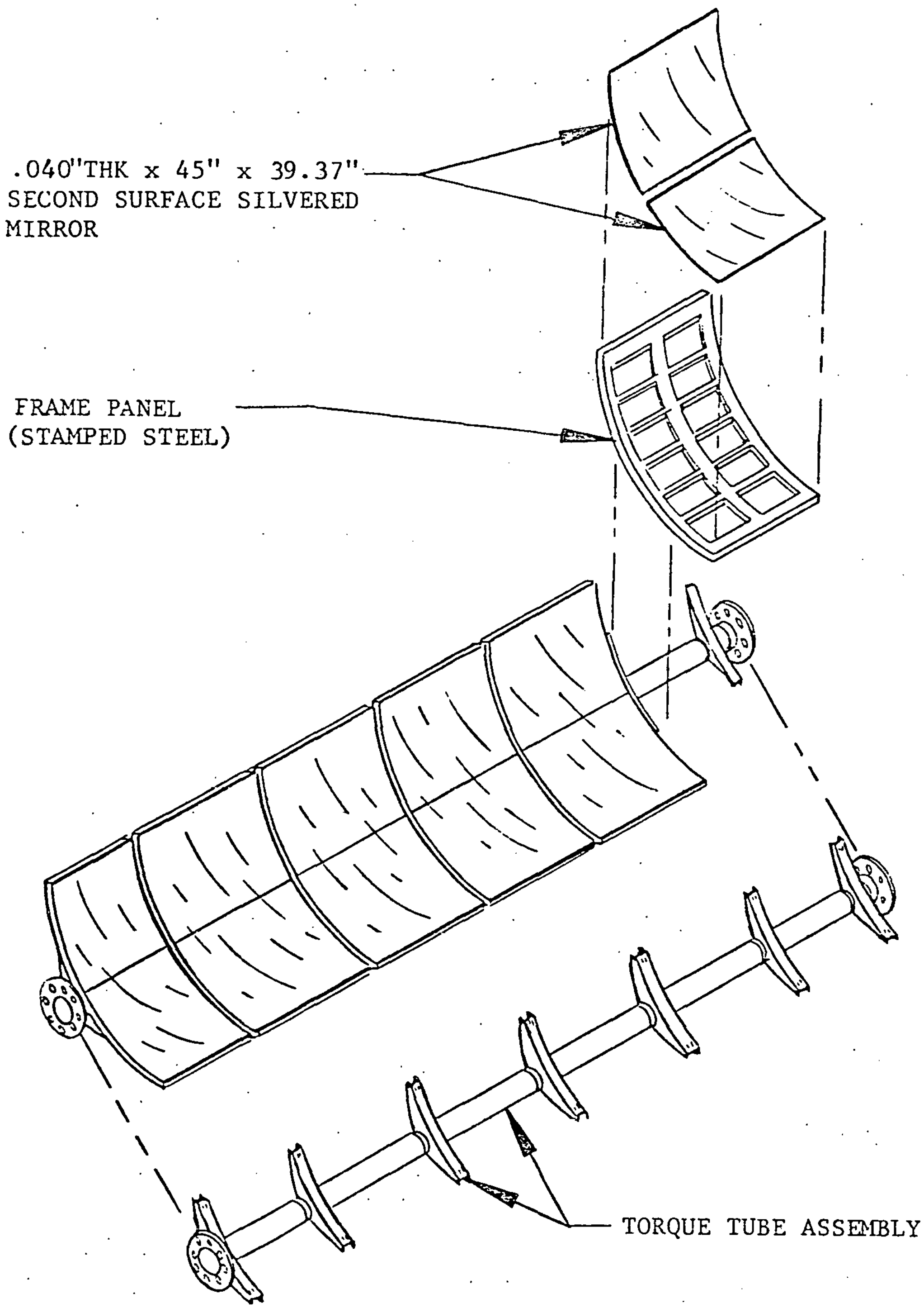


FIGURE 6.2

B CHEMICALLY STRENGTHENED GLASS ON STEEL

FRAME PANEL

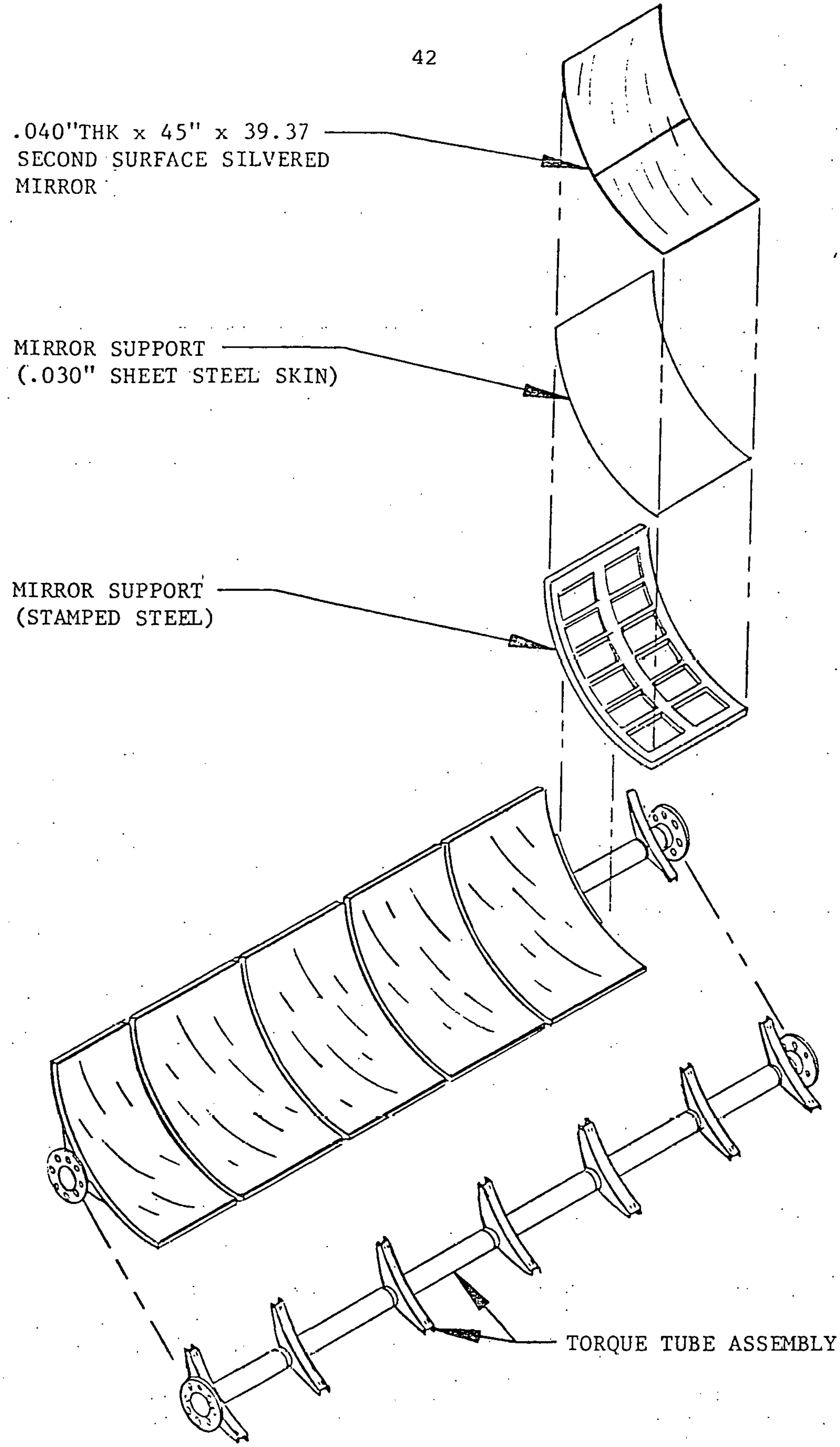


FIGURE 6.3

(C) THIN ANNEALED GLASS AND STEEL LAMINATE

ON STEEL FRAME PANEL

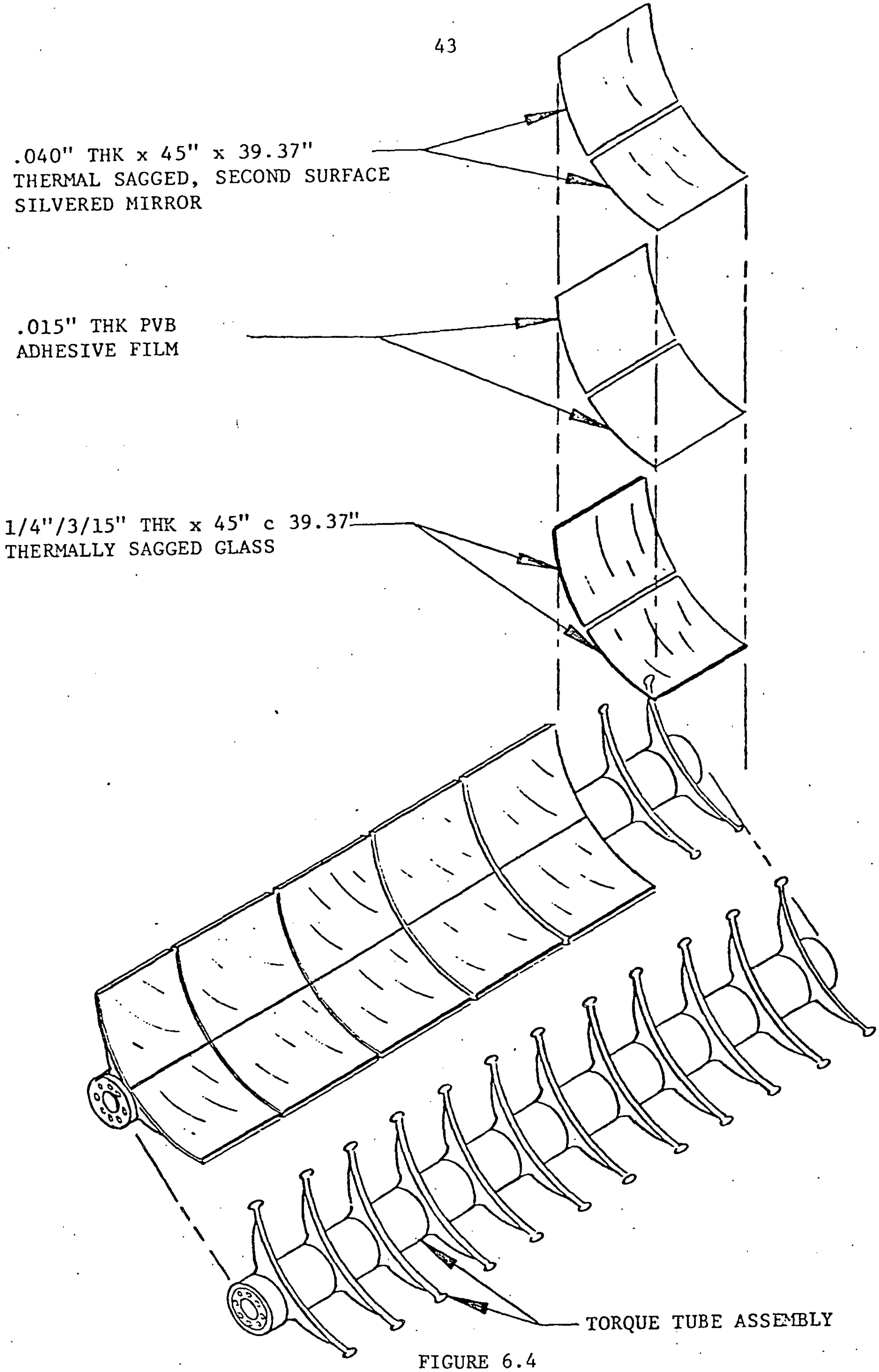


FIGURE 6.4

Ⓓ THERMALLY SAGGED GLASS AND

THIN GLASS LAMINATE

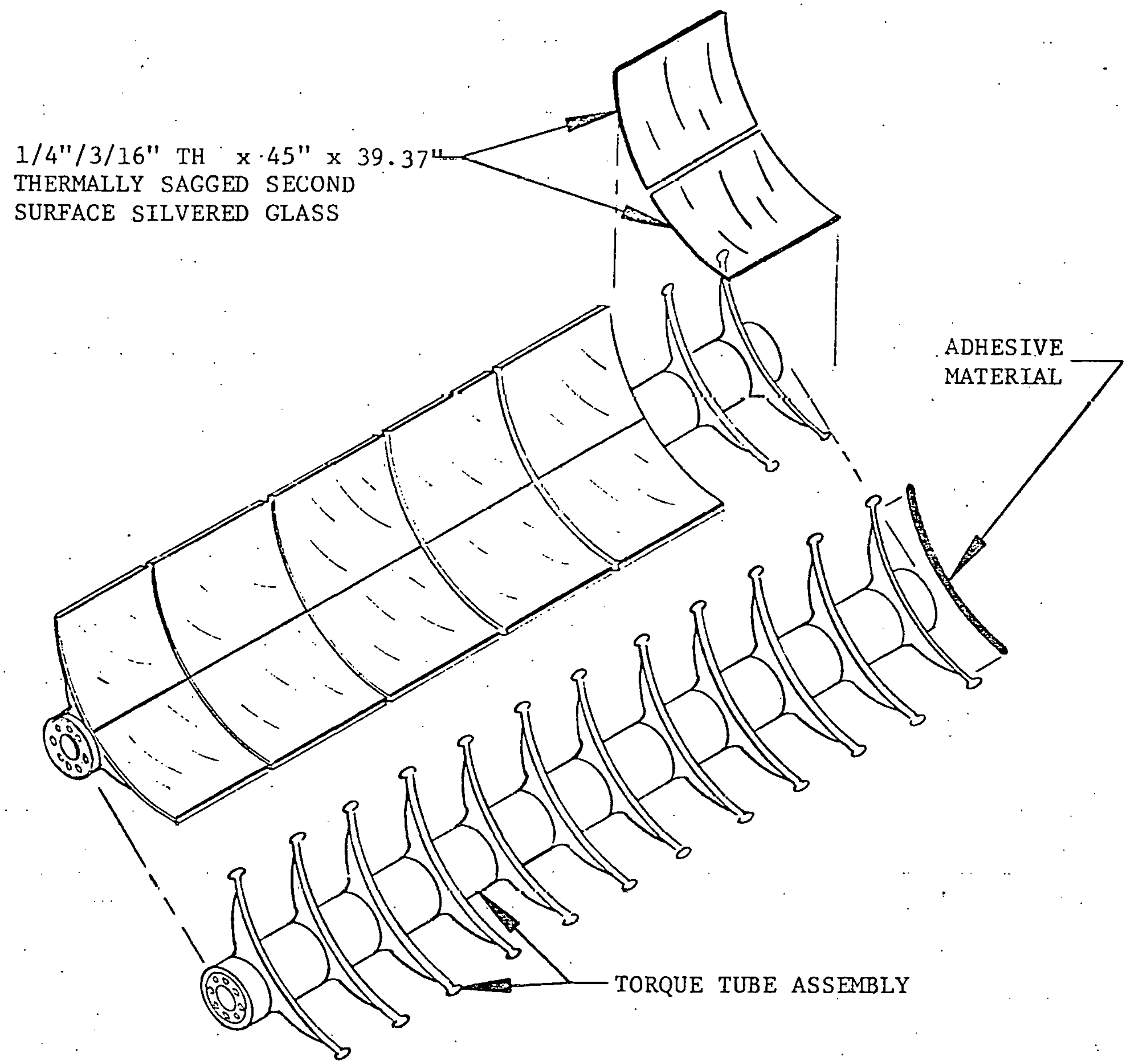


FIGURE 6.5

E THERMALLY SAGGED GLASS

(SLAB)

TABLE 6.1: NORMATIVE PRICE COMPARISON OF REFLECTOR ASSEMBLY CONCEPTS AT 1,000 MODULES/YEAR

Design	Mirror Support	Adhesive	Second Surface Silvered Glass	Torque Tube Assembly	Material Cost con- sidering Breakage	Labor & Overhead	Manufacturing Cost	
							Per Module	Per Square Foot of Aperture
A. Chemically Strengthened Glass and Steel Laminate on Steel Frame Panel	$735	$138	$2,318	$749	$3,940	$2,878	$6,818	$13.21
B. Chemically Strengthened Glass on Steel Frame Panel	474	97	2,318	749	3,638	2,622	6,260	12.13
C. Thin Annealed Glass and Steel Laminate on Steel Frame Panel	756	142	1,430	749	3,077	2,909	5,986	11.60
D. Thermally Sagged Glass and Thin Glass Laminate	568	253	4,317	789	5,927	2,321	8,248	15.98
E. Thermally Sagged Glass (Slab)	-	85	2,462	789	3,336	1,939	5,275	10.22

NOTES: 1. Solar Kleer Glass used for designs A, B, C, and D.

2. Schott's Waterwhite Glass (B270 Solarwite Glass) used for design E.

TABLE 6.2: NORMATIVE PRICE COMPARISON OF REFLECTOR ASSEMBLY CONCEPTS AT 100,000 MODULES/YEAR

Design	Mirror Support	Adhesive	Second Surface Silvered Glass	Torque Tube Assembly	Material Cost considering Breakage	Labor & Overhead	Manufacturing Cost	
							Per Module	Per Square Foot of Aperture
A. Chemically Strengthened Glass and Steel Laminate on Steel Frame Panel	$674	$138	$1,227	$541	$2,580	$523	$3,103	$6.01
B. Chemically Strengthened Glass on Steel Frame Panel	414	97	1,227	541	2,279	479	2,758	5.34
C. Thin Annealed Glass and Steel Laminate on Steel Frame Panel	687	142	582	541	1,952	484	2,436	4.72
D. Thermally Sagged Glass and Thin Glass Laminate	400	258	1,101	523	2,282	496	2,778	5.38
E. Thermally Sagged Glass (Slab)	-	85	491	523	1,099	547	1,646	3.19

NOTES: 1. Jeanettes Solar Kleer Glass used for designs A, B, C, and D.

2. Schott's Waterwhite Glass (B270 Solarwite Glass) used for design E.

6.1.2 Selecting the Recommended Design for the CSERC Study

Each of the five designs was subjected to manufacturing process and cost analyses by CSERC engineers and analysts. When this preliminary work was completed, design C (thin annealed glass and steel laminate on steel frame panel) and design E (thermally sagged glass [slab]) were chosen as the most effective designs (Figures 6.3 and 6.5). Designs C and E were selected for detailed study to determine high volume reproducibility in accordance with the task assigned to CSERC by the Department of Energy. The manufacturing processing of these designs is considered at length in the subsections that follow.

6.2 BACKGROUND ON PROCESS DATA

The manufacturing processing described in this section represents the most cost-effective processing available for the recommended design. A number of changes recommended by CSERC are embodied in the evaluated design. These recommendations permitted the use of manufacturing processes, equipment, and materials which reduce the manufacturing cost $3,000 per module (42%) in comparison with the cost of the original design.

The recommended processing meets stringent engineering tolerances. The critical requirement is that the center line of the receiver tube must lie within ± .200 in. of the perfect focal line in both the X and Y axes. Special processes and tooling are specified to accomplish this (e.g., the fixture for construction of the reflector is a solid parabolic mold whose surface is accurate within ± .002 in.)

Table 6.3 lists processes, machines, and fixtures utilized to ensure desired tolerances. These processes and equipment are described in detail on process sheets in Volume II (Appendices). Table 6.4 (Manufacturing Tolerance Study) and Figure 6.6 (Tolerance Chart) demonstrate that the processes can meet a tolerance of ± .051 in. in the Y-axis and ± .054 in. in the X-axis. These figures are well within specifications.

To focus the process descriptions in this explanatory volume and to simplify the contents, the manufacturing processing described is based on a production volume of 100,000 collector modules per year. Processing analyses for 1,000, 5,000, and 25,000 modules (design C) and 1,000 modules (design E) are included in Volume II.

Processing analyses based on the original design assumptions also appear in the Appendices. These processes were developed as part of an orderly approach to determine the potential highest cost reductions. Volume II includes as well data on the reflector alternates evaluated and costed to assist Sandia Laboratories in finding the optimum design.

Recognizing that initial concentrating collector production volumes may be well below 1,000 modules per year as new manufacturers seek to minimize capital commitments, CSERC developed a minimum investment process. This process, suitable for an annual production volume of 100 to 500 modules, is described following the processing data for 100,000 modules per year.

TABLE 6.3: PROCESSES, MACHINES, AND FIXTURES TO ENSURE DESIRED TOLERANCES

- Reflector Assembly Mold
- Torque Tube and Reflector Assembly Fixture
- Reaming of Manufacturing Holes
- Reaming and Dowelling of Holes in Critical Components
- Straightening of Receiver Tube
- Broaching/Boring of Receiver Bearing
- Providing for Linear Motion of Receiver During Thermal Expansion or Shortening of Receiver Tube to Compensate for Thermal Expansion
- Assembly Adjustments in the Plant
- Minimal Adjustments in Field
- All Welds Stress-relieved Before Machining
- Restriking and Shaving Operation Employed in Stamping

TABLE 6.4: MANUFACTURING TOLERANCE STUDY

The CSERC Tolerance Stack Study initiated in response to a request by Sandia Laboratories has established that the required tolerance of the focal length in both axes can be met with the selected manufacturing processes:

X - Axis

$\pm$ .054" (Maximum) with Standard Deviation .014"

Y - Axis

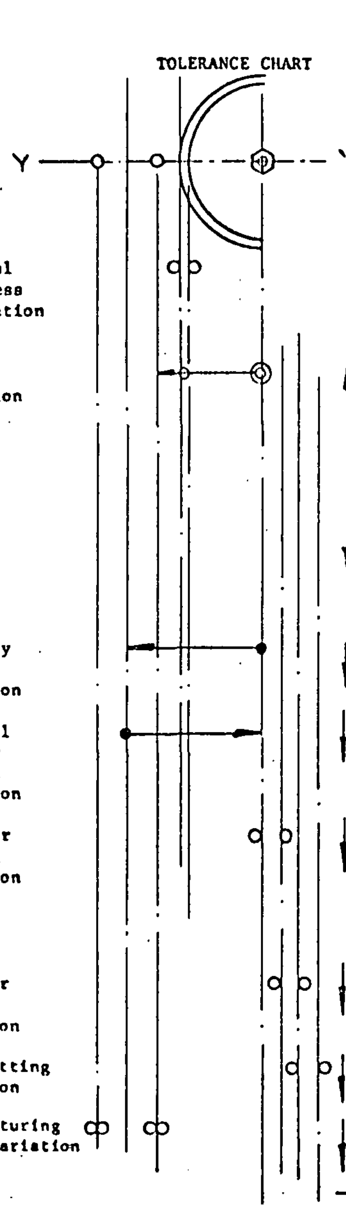
$\pm$ .051" (Maximum) with Standard Deviation .013"

These are within the allowed deviation of:

$$\sqrt{X^2 + Y^2} = .200\text{" (Maximum}$$

FIGURE 6.6: TOLERANCE CHART

TOLERANCE CHART

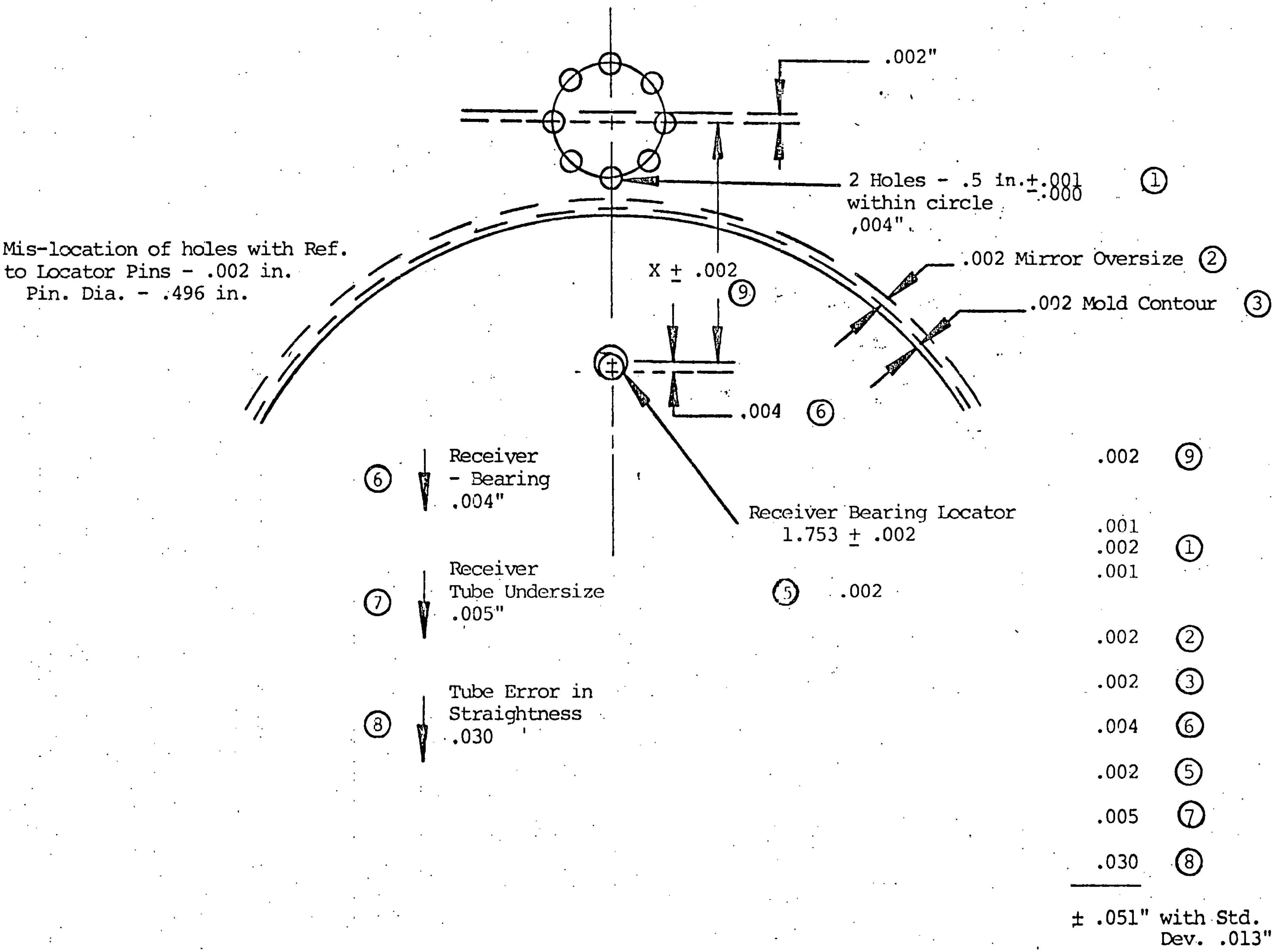


PROCESS NUMBER	PROCESS DESCRIPTION	TOLERANCE DUE TO MACHINE/ FIXTURE/ MATERIAL	WORK DIM. (INCHES)	WORK TOL. ± (INCHES)		Y-AXIS TOLERANCE STACK RESULTANT	Y-AXIS S.R.	Y-AXIS T.T.±	X-AXIS TOLERANCE STACK RESULTANT	X-AXIS S.R.	X-AXIS T.T.±
10	Receive Mirror	Mirror	.040	.002	Material Thickness Variation	±.002			±.002 ±.002		
20	Locate Mirror on Mold	Reflector Assembly Mold	19.252 Tool	.002 Dim.	Mold Variation	±.002					
30	Locate Frame Panel on Mold	"	19.252								
40	Locate Reflector on Mold	Reflector & Torque Tube Assembly Fixture	19.252	.002		±.002			±.002		
50	Locate Torque Tube & Tighten Bolts	"	26.291 Tool	.002 Dim.	Assembly Fixture Variation	±.002			±.002		
60	Locate Flexural on Fixture	Flexural & Receiver Support Fixture	26.291 Tool	.002 Dim.	Flexural Assemly Fixture Variation	±.002			±.002		
70	Locate Receiver Bearing on Fixture	"	1.753	.002	Receiver Bearing Variation	+.005 +.001	.003	±.002	+.0044 +.0016	.003	±.0014
80	Tighten 'U' Clamp Bolts & Drive Dowels	"									
90	Receive Receiver Tube	Field Assembly	1.25	.030 Straightness	Receiver Tube Variation	±.030			±.030 ±.005		
100	Place Receiver in Receiver Bearing	"	1.75	+.000 -.004	Tube Fitting Variation	+.000 -.004			±.004		
110	Assemble Torque Tube & Flexural	"	.500	+.001 -.000	Manufacturing Holes Variation	±.002 -.000			+.001		

±.051" with Std. Dev. .013"

±.0544 with Std. Dev..014"

FIGURE 6.7: PPT CONCENTRATING COLLECTOR TO ANCE STACK ANALYSIS IN Y-Y AXIS



6.2.1 Tolerance Stacking and Manufacturing Process Development

A solar device, especially a line focus concentrating collector, is particularly sensitive to tolerance stacking, which clearly is among the most important considerations affecting performance and manufacturing processes.

Solar radiation incident on a parabolic trough mirrored reflector is reflected along a line and focused to achieve a concentration of the solar energy. The efficiency of the device would attain the theoretical maximum given a perfect mirror surface, a flawless contour, exact locational and dimensional accuracy of the receiver tube, precise alignment of module sections, and the absence of adverse environmental effects.

Since these ideal conditions are improbable in the process of manufacturing a cost effective device, the designer allocates error-budgets such as the following for the PPT concentrating collector:

Error-Budget for the PPT Concentrating Collector

Type of Source		Effective Magnitude 1σ
Beam Misdirection		in mrad.
Structure		
Slope	2.5 x 2	5
Sage and Thermal		2
Tracking		
Sensor		2
Drive Nonuniformity		2
Beam Spreading		
Mirror		.25
Sun (not actually normal)		2.8

After error-budgeting, the next step is to define the tolerance on absolute design dimensions. This is accomplished by carrying out a sensitivity analysis of performance versus mislocation of the center of the receiver tube with reference to the theoretical focal line of the parabola. The results indicate that a mislocation of the focal line by .200 in. (maximum) can be tolerated.

In this study, dimensional variations in commercially available raw materials, in device components, installation, conventional manufacturing and assembly processes were analyzed and a tolerance chart made (Figure 6.6). As previously noted, the resulting tolerance stack is well within .200 in.

Every component contributing to the tolerance stack as well as each related manufacturing process, assembly toolings, and parts assembly were analyzed. The following design and manufacturing decisions were made:

1. Reflector assembly mold should have an essentially continuous surface.

2. Torque tube and reflector to be assembled in a fixture.
3. Manufacturing holes to be reamed.
4. Critical assemblies to be reamed and dowelled.
5. Receiver tube to be straightened.
6. Receiver bearing to be broached or bored.
7. Puddle welds and tack welds to be used rather than full fillet welds.
8. All welds to be stress-relieved before machining.
9. Restriking and shaving operations to be employed in stamping.
10. Receiver tube to have linear motion during thermal expansion, or the receiver tube to be shortened.
11. Assembly adjustment to be made during assembly in the plant.
12. Field adjustments to be avoided.

The application of these requirements to the collector and processes evaluated by CSERC was a key part of the development aimed at achieving mass production of a cost-effective solar device that would also meet required tolerances and performance standards. The following details concerning the above production regimen help explain the need and the results.

1. Solid Reflector Assembly Mold: Glass sheet thickness can be expected within ±.002 in. This is second surface silvered. Thus, the contour of the mold over which the glass sheet is to be formed into a parabola follows the equation:

$$y = \frac{x2}{4f} \quad [f = (482.854 - 1) \text{ mm, considering the glass thickness to be 1 mm.}]$$

The mold will have stops on two adjacent sides to reference the glass and steel laminate. The curved surface of the mold is solid. There are holes on this surface through which a vaccum pulls the glass laminate to the exact contour. The mold is manufactured from a master. Its contour accuracy can be maintained within ±.002 in. This would ensure the accuracy of the front surface y dimension within ±.002 in.

2. Torque Tube and Reflector Assembly Fixture: This fixture is 20 ft. long, 6½ ft. wide, and about 2 ft. high. Twelve pins on the apex locate 6 reflector assemblies. Unlike the reflector assembly mold, this fixture is made of pads rather than a solid surface. The torque tube is located on the manufacturing holes (2 on each flange). This ensures a distance of 26.291 in. between the center of the pitch circle diameter of the flange holes and the theoretical focus. The torque tube and reflectors are bolted together. Adjustable brackets between the two subassemblies handle variations and eliminate resulting assembly stresses.

3. Reaming Manufacturing Holes: Drilling and reaming 4 manufacturing holes (2 per flange) on the torque tube provides hole sizes that are .500 ±.001. The holes will be drilled and reamed simultaneously on a horizontal drilling head. Machine accuracy places the centers of the holes within a circle of .004 in.

4. Reaming and Dowelling Critical Subassemblies: Subassemblies such as flexurals, torque tube, receiver support, "U" bracket, receiver bearing, and drive plate are reamed and dowelled so they are positioned correctly for assembly and to transmit torque in tracking and stowing

operations. Locational clearance fits are chosen for the dowels.

5. Straightening the Receiver Tube: Tolerance on commercially available low carbon steel tubes, especially electrical welded and drawn tubes, are: O.D. ±.005 in.; wall .065 $\pm^{.004}_{.007}$; straightness .030 in. in 3 ft. length. Therefore, tolerance in straightness in 10 ft. long tube could be .100 inches. Straightening tube with 6-roll straightener can give straightness achieving ±.030 in. in 10 ft. length.

6. Broaching or Boring the Receiver Bearing: The receiver bearing can be produced by the investment casting process, which controls most dimensions. Holes in casting can be followed by a tapping operation. The bearing circular or hex hole can be controlled within ±.015 inches. Casting suppliers think this can be maintained within ±.005 in. after certain trials are conducted, but assurance of this cannot yet be given. Broaching or boring the hole is done to hold dimensions within ±.002 inches. The recommended maximum dimension is 1.753 inches. Thus, a cut within tolerance ±.002 in. would ensure a dimension of 1.751 inches to 1.755 inches. This would accommodate a tube fitting with a wall-to-wall dimension of: $1.75^{+.000}_{-.004}$.

7. Puddle and Tack Welds: Puddle welds are recommended when welding reflector supports and the torque tube. Tack welds are recommended in order to restrict deformation due to welding. Tack welds are used when welding washers and clamps to the receiver support.

8. Stress-relieving Welds Before Machining: Various parts (e.g., torque tube, flexural, pylons) are stress-relieved by the vibration method or shotblasting to stabilize them dimensionally. If machining is required, it follows the stress-relieving treatment.

9. Restriking and Shaving Operations When Stamping: In stamping, restriking may be used to achieve tolerance. The frame panel, 6½ ft. long, 3-1/3 ft. wide, 1½ ft. high, is held within ±.025 in. by restriking. Holes required in the drive plate and flexural are shaved to achieve a tolerance of ±.001 for the purpose of dowelling.

10. Linear Motion of Receiver During Thermal Expansion: Analysis showed that curvilinear motion of the receiver tube during its thermal expansion could keep it out of focus. The problem is eliminated by substituting linear motion or by shortening each receiver tube 1/2 in. so it assumes its drawing length after thermal expansion.

11. Assembly Adjustments During Assembly in the Plant: Critical assemblies, such as the reflector with the torque tube and the receiver bearing with flexural, are made on assembly fixtures. To offset variations in components, intermediate adjustable components are introduced. After being tightened, they are dowelled to the mating parts.

12. Avoiding Field Adjustments: In the field, only aligning the center of the pitch circle diameter of holes on flexural is planned. Plant quality control together with dowelling of mating components and subassemblies should ensure assembly within calculated tolerance.

6.3 MAKE/BUY ANALYSIS

Identifying the components and subsystems that can be produced cost-effectively in-plant and those that should be purchased is a critical early phase in the establishment of a manufacturing operation. The need is no less relevant or critical in the case of the PPT concentrating collector than in other production ventures. In general, parts should be manufactured in-plant when this is consistent with effective equipment utilization and when savings result. Table 6.5 contains a rundown on parts in selected design C (thin annealed glass and steel laminate on steel frame panel). For different annual production volumes, the table indicates (with the letter P) the parts and materials that manufacturers may find it economical to purchase. The blank areas, on the other hand, suggest that the manufacturer may produce these more economically in-plant. The table is a guide but not a prescription, based on CSERC analyses and the judgments of CSERC engineers.

TABLE 6.5: MAKE/BUY ANALYSIS FOR DESIGN C (THIN ANNEALED GLASS AND STEEL LAMINATE ON STEEL FRAME PANEL)

(P = Purchased)	Annual Volume (Modules)				
	100-500	1,000	5,000	25,000	100,000
REFLECTOR SUBSTRATE					
Frame Panel	P	P	P	P	
Doubler	P				
Carbon Steel Weld Nut		P	P	P	P
Weldment of Diameter Doubler	P	P	P		
"L" Shaped Angle					
MIRROR PANEL					
Reflector Skin	P	P	P	P	
Thin Annealed Glass	P	P	P	P	P
Silvering for Reflector	P	P	P		
Goodyear 6000 Series Adhesive	P	P	P	P	P
Ethanol	P	P	P	P	P
Goodyear Primer 6035	P	P	P	P	P
PYLON WELDMENT					
Pylon Top Bar					
Junior Beam					
Pylon Base Angles					
Zinc Galvanizing	P	P	P		
FLEXURAL ASSEMBLY					
Flexural Plate	P				
Sand Blasting	P				
Drive Shaft	P	P	P		
Pillow Block	P	P	P	P	P
Galvanizing	P	P	P		

(TABLE 6.5 continued)

(P = Purchased)	Annual Volume (Modules)				
	100-500	1,000	5,000	25,000	100,000
DOUBLE PYLON WELDMENT					
Cross Angle					
5-Inch Flat	P				
Pylon Top Bar					
Junior Beam					
DRIVE PYLON ASSEMBLY					
Base Plate					
"I"-Beam					
Top Plate					
Motor and Gearbox	P	P	P	P	P
Riser Assembly	P	P	P	P	P
Drive Plate	P	P	P		
Hub Casting	P	P	P	P	P
TORQUE TUBE					
Torque Tube Flange	P	P	P		
Torque Tube	P	P	P	P	P
Reflector Support	P	P	P		
Zinc Galvanizing	P	P	P		
Intermediate Receiver Support					
RECEIVER TUBE SUPPORT					
Bar	P				
Clamp	P	P			
Washer	P	P			
"U" Clamp		P			
RECEIVER					
Receiver Tube (Black Chrome Plated)	P	P	P		
Pyrex Tube	P	P	P	P	P
Silicone O-Ring	P	P	P	P	P
Fittings	P	P	P	P	P
O-Ring Support	P				
Black Chrome Plating Material				P	P
Silver Brazing Ring				P	P
I/D Grinding of Pyrex Tube	P	P	P		
Flexhose	P	P	P	P	P
RECEIVER TUBE SUPPORT BEARING					
Casting Item 2	P	P	P	P	P
Casting Item 5	P	P	P	P	P
Boring of Receiver Tube Support Bearing)	P	P			

6.4 PROCESS ANALYSIS--100,000 MODULES PER YEAR

Design: Thin Annealed Glass and Steel Laminate on Steel Frame Panel

The following pages contain process descriptions, assembly flow charts, and illustrations for a production volume of 100,000 modules. Volume II (Appendices) contains the process estimate sheets on which this information is based.

6.4.1 80 Ft. Collector Module Assembly

Figures 6.8
6.9
6.10
6.11
6.12

The following are received and unloaded from the truck using a fork truck or gantry crane:

A. Single Pylon, Receiver Tube Support and Flexural Plate Assembly
B. Double Pylon, Receiver Tube Support and Flexural Plate Assembly
C. Drive Pylon and Mechanism
D. Receiver and Receiver Tube Fittings
E. Receiver Tube Support - Midway Sheet Metal Trough
F. Torque Tube and Reflector Assembly
G. Flex Hose

Items A, B, and C are unpacked and positioned on their assigned foundations over the 2 in. spacer blocks and the foundation anchor bolt using a 2-ton fork truck with special boom attachment (Figure 6.10).

A laser/optical sighting target fixture is positioned to each flexural plate. Using laser beam instrumentation, pylons are aligned for elevation and parallelism. Equidistance between pylons is established with a spacer bar located by pins through manufacturing holes in flexural plates. Foundation bolts with two nuts are used to adjust elevation. Spacer blocks (50 mm high) are inserted between the foundation and the pylon base to permit tilting if required, so the "bottom" nut is moved to the proper height. The four 3/4 in. foundation nuts on the single pylon, the drive pylon, and the double pylon are then torqued.

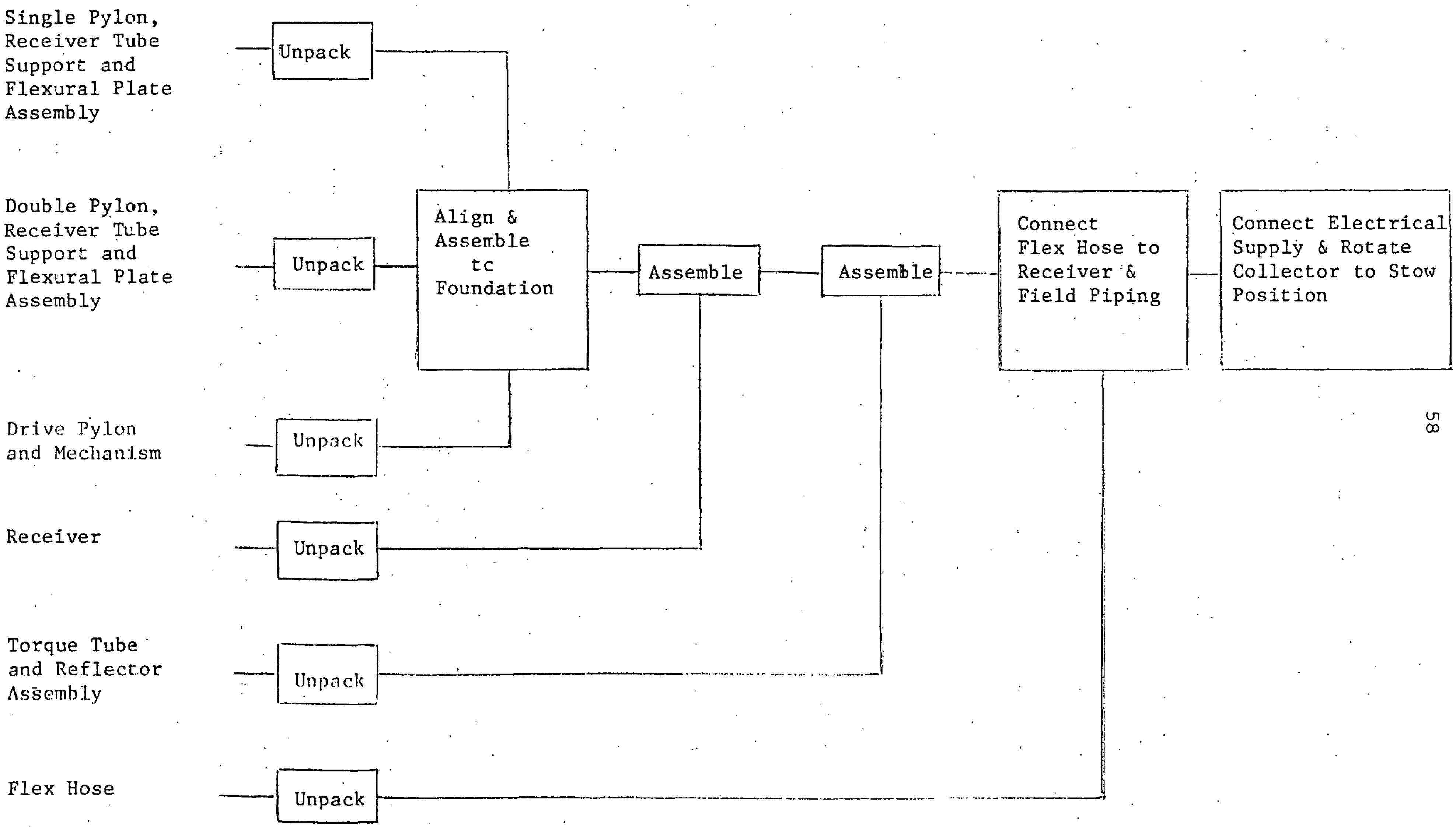
Using 16 jack screw type supports, 9 receiver sections (including the short section at the drive pylon) are prepositioned in the cradles of these supports, and the receiver tube sections are connected to each other using pipe fittings. Before connecting the sections, the fitting of each receiver section is placed in the bearing.

Using a fork truck or gantry crane with specially designed slings to raise, lower, or rotate the torque tube and reflector assembly, the two torque tube flanges are brought to the flexural plates. Dowel pins and bolts are inserted, and the bolts connecting torque tube flanges to the flexurals are torqued.

The Receiver Tube Support - Midway Sheet Metal Trough items are assembled by inserting each leg into holes on the "U" clamps. These are found on the Reflector Support Assemblies, located on the torque tube midway between the pylons. Flex hoses are connected to receivers, and the ends of terminal receivers are connected to field piping. The drive motor is connected to electricity, and the collector is rotated.

(NOTE: The same procedure is followed in the plant for one module assembly per shift, with annual production volumes of 25,000 and 100,000 modules. The procedure is followed once daily with a volume of 5,000/year and once weekly with a volume of 1,000/year. The procedure is required to establish that collector modules are functioning properly.)

FIGURE 6.8: 80 FT. COLLECTOR MODULE ASSEMBLY



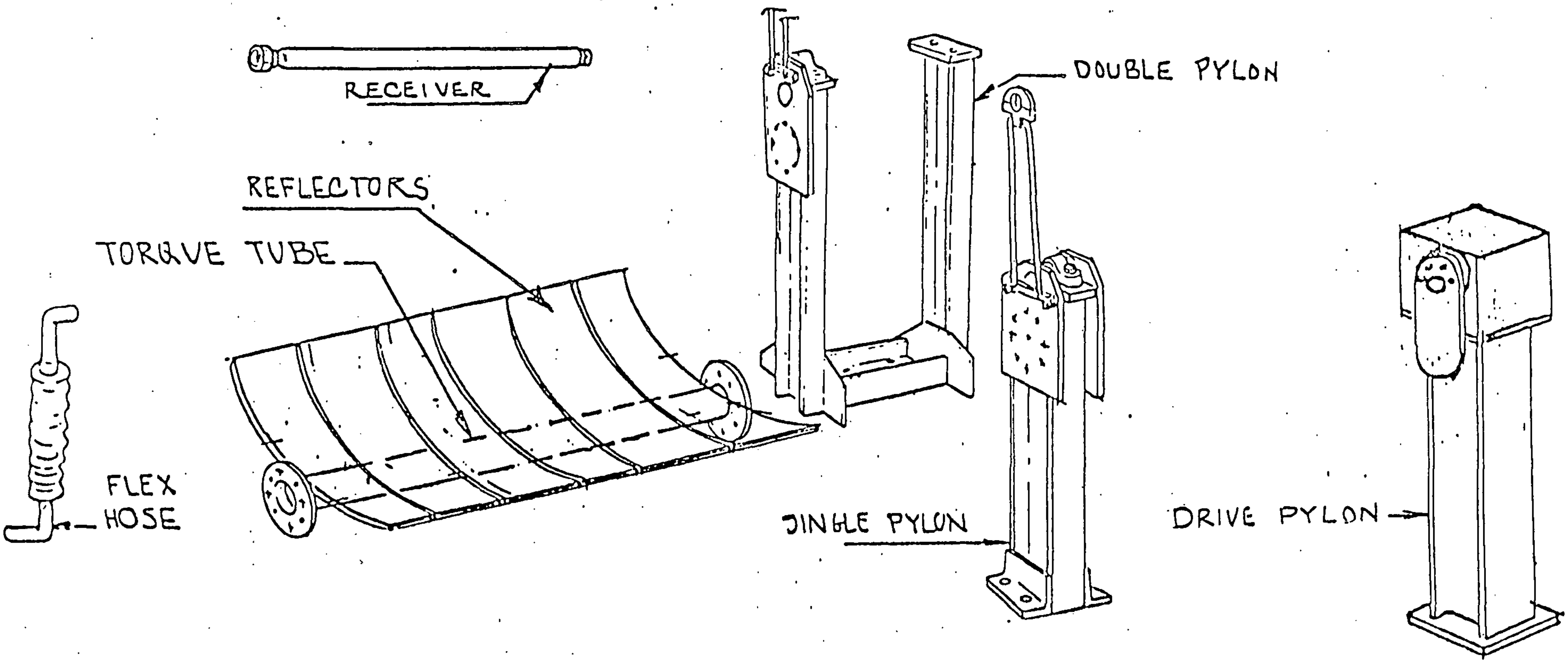


FIGURE 6.9: **80 FT. COLLECTOR MODULE ASSEMBLY.**

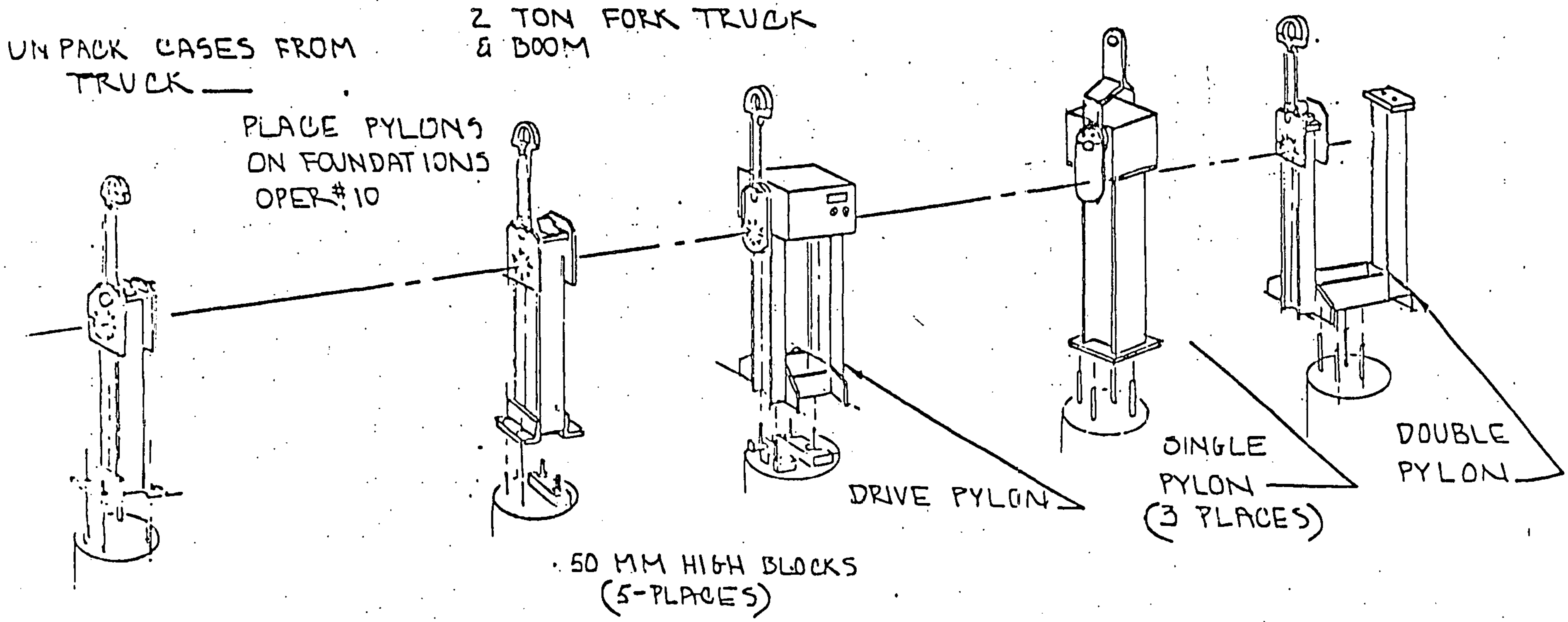


FIGURE 6.10: 80 FT. COLLECTOR MODULE ASSEMBLY

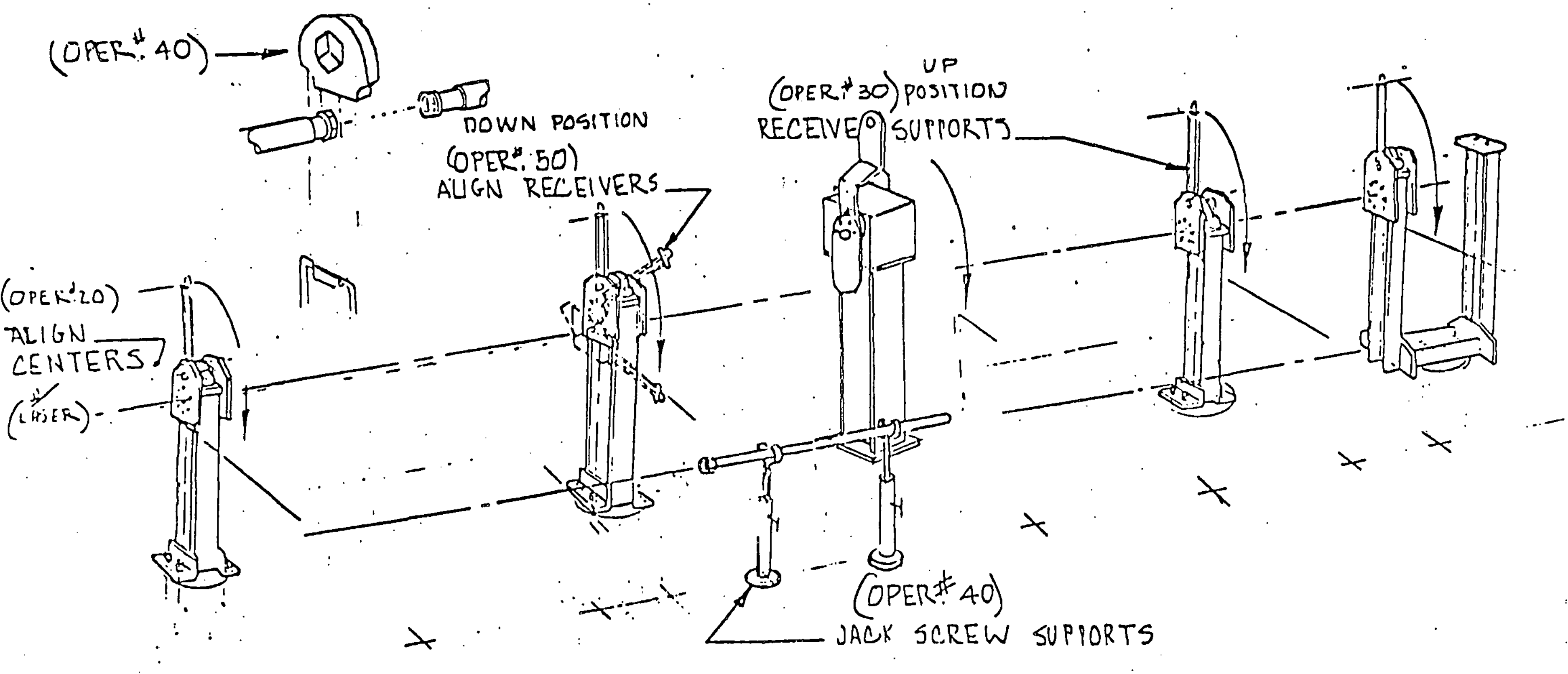


FIGURE 6.11: 80 FT. COLLECTOR MODULE ASSEMBLY

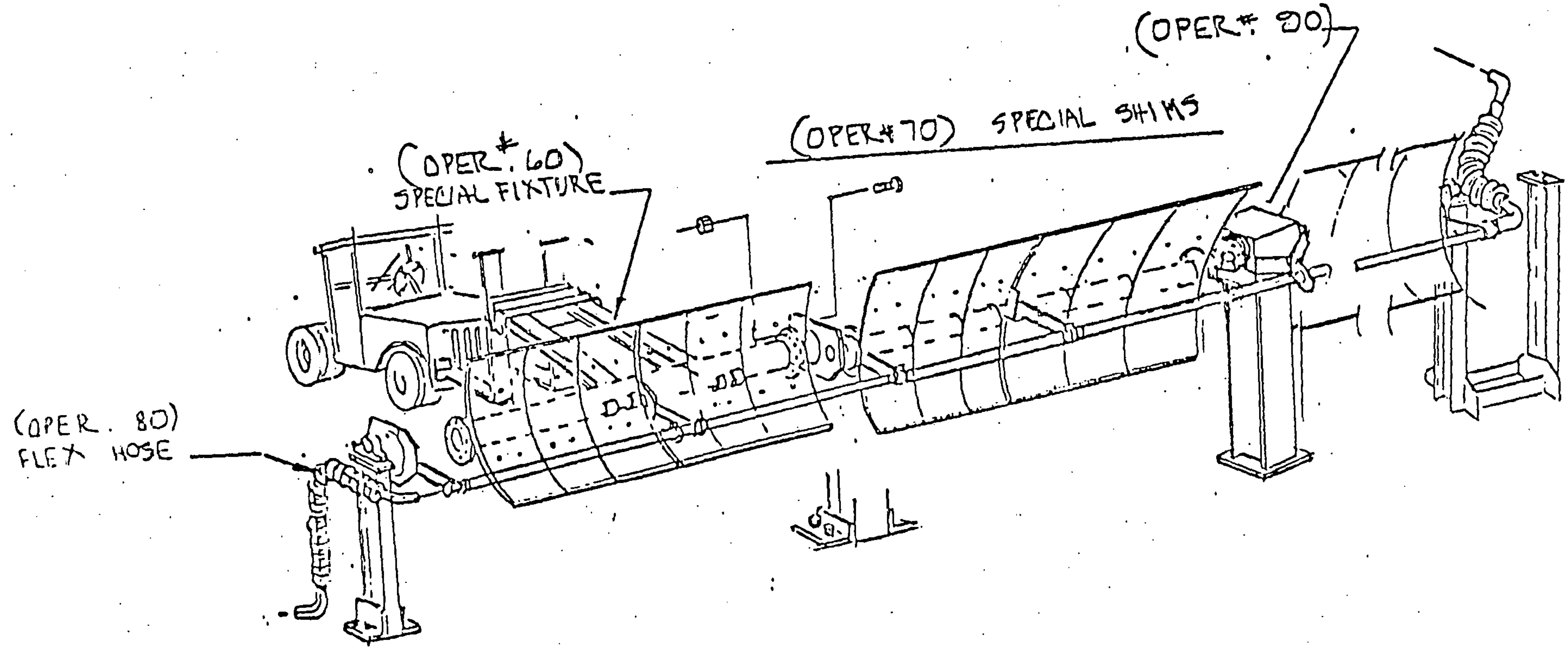


FIGURE 6.12: 80 FT. COLLECTOR MODULE ASSEMBLY

6.4.2 Single Pylon, Receiver Tube Support and Flexural Plate Assembly

Figures 6.13
6.14

Coils of .12 in. x .75 in. stainless steel for "U" clamps are transported to a 100-ton straight-side press equipped with decoiler, straightener, and feeder.

Two slots are pierced. The "U" clamps are cut to length and formed. Then the parts are transported in 4 ft. x 4 ft. x 4 ft. wire mesh bins to a five station indexing drill press where two .375 in. holes are drilled, reamed, and deburred. After random dimensional inspection, the parts are transported to in-process storage.

Driveshaft and Flexural Plate Assembly, Receiver Tube Support Assembly, and "U" clamps are taken from in-process storage to an assembly fixture.

The two manufacturing holes in the Driveshaft and Flexural Plate Assembly are located over pins. The "U" clamp is loose-assembled to the Driveshaft and Flexural Plate Assembly with two nuts and bolts. The legs of the Receiver Tube Support Assembly are assembled to the "U" clamp, and the Receiver Tube Bearing portion of the Receiver Tube Support Assembly is positioned over a pin.

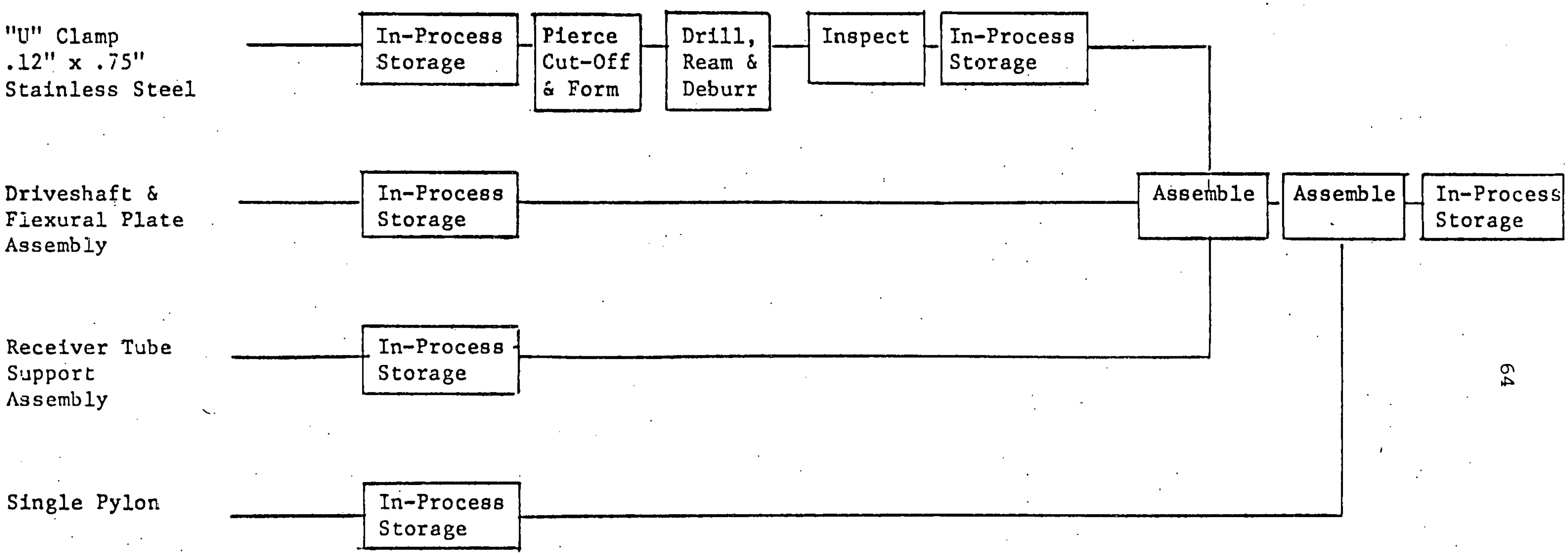
This fixture establishes the critical focal length dimension. The two nuts and bolts are torqued. Using a small drill press and drill jig, 1/8 in. dowel holes are drilled through the "U" clamp and the flexural. Two 1/8 in. dowel pins are inserted.

The assembly is then removed from the fixture and transported to in-process storage.

FIGURE 6.13:

SINGLE PYLON, RECEIVER TUBE SUPPORT

AND FLEXURAL PLATE ASSEMBLY



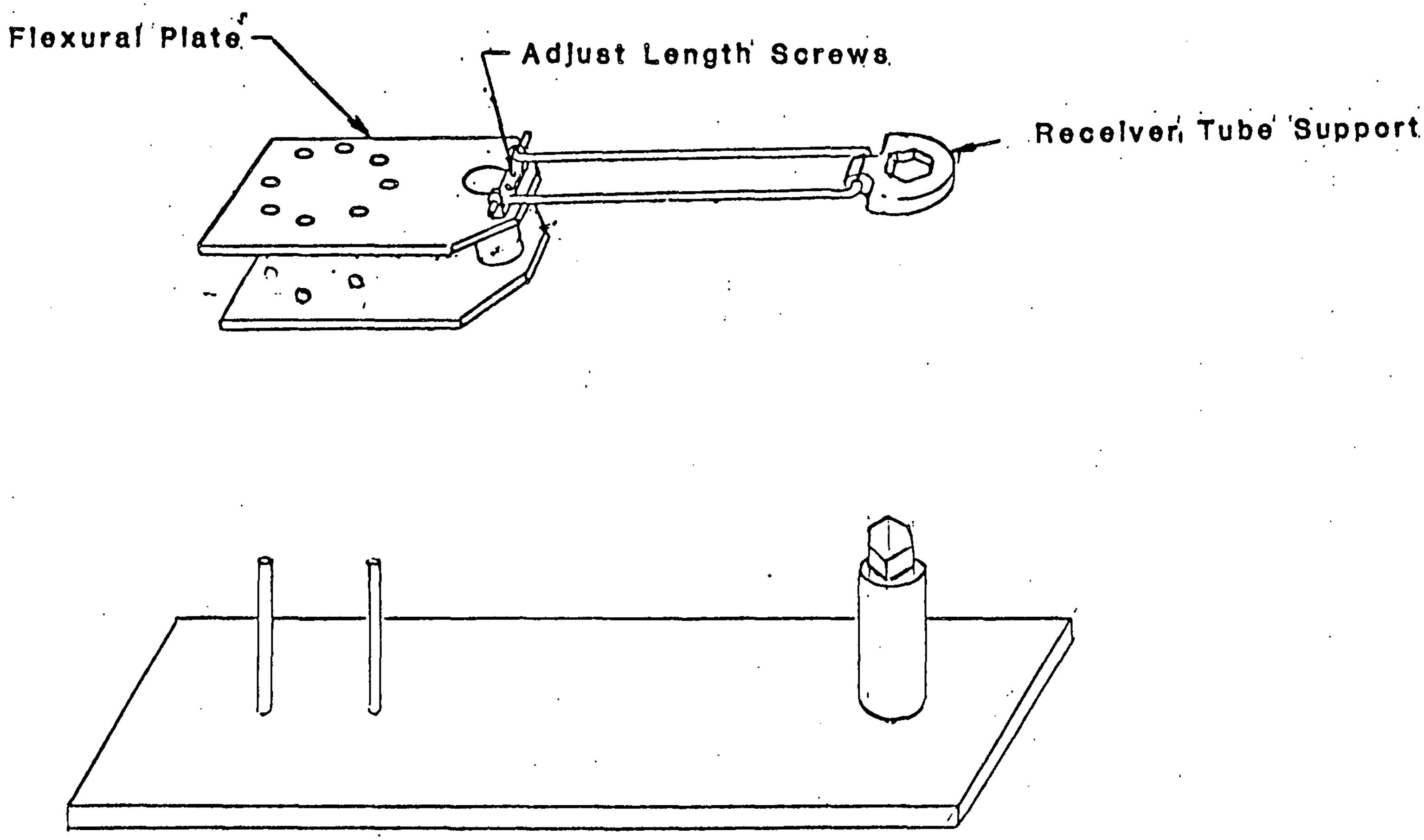


FIGURE 6.14: ASSEMBLY FIXTURE TO ESTABLISH FOCAL LENGTH DISTANCE ON RECEIVER TUBE SUPPORT.

6.4.3 Single Pylon

Figure 6.15

Material for the Base Angle, Top Bar, and Junior Beam are received in approximately 20 ft. lengths of weathering steel. This material is placed in storage and subsequently washed prior to further processing.

Pylon Base Angle material in a 19.2 ft. length is transported to a 150-ton straight-side press with an automatic feed and unload system. The bar is sheared into 25 pieces and 2 holes are pierced in each piece using a two-station progressive die. After inspection, parts are deburred and washed in a 100 cubic foot continuous deburring unit, followed by transport to in-process storage.

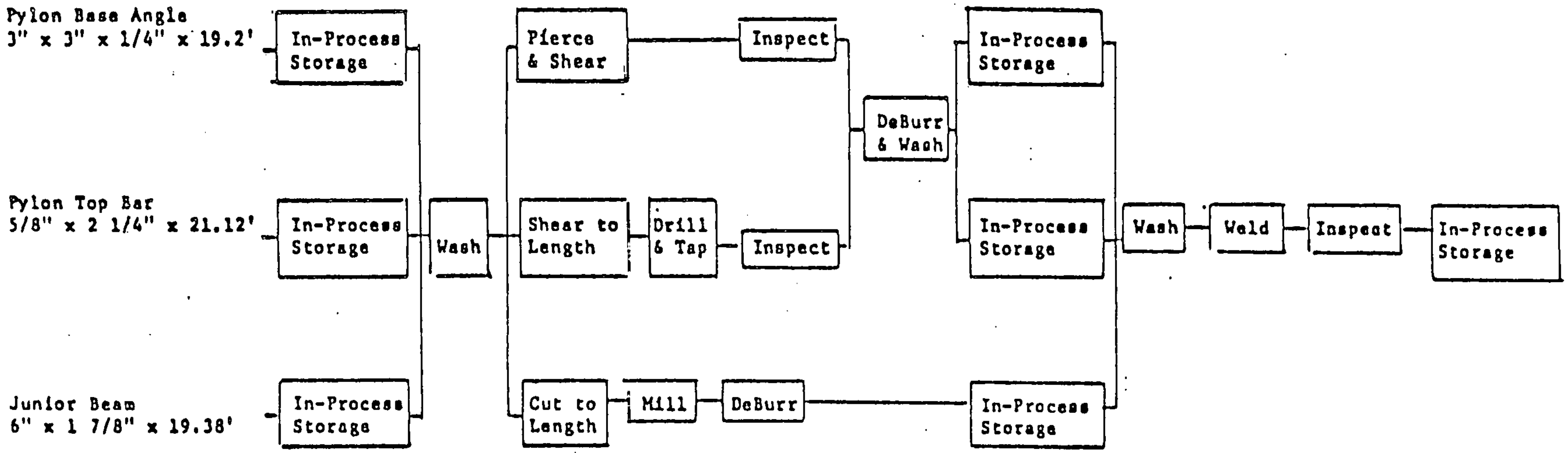
The Pylon Top Bar material in a 21.12 ft. length is taken to a 100-ton straight-side press with an automatic feed system. The bar is sheared into 30 pieces, and then taken to a 4-spindle, 4-station drill press where two 17/32 in. holes are drilled and tapped. After inspection, parts are deburred, washed in a 100 cubic foot continuous deburring and washing unit, followed by transport to in-process storage.

The Junior Beam material in a 19.38 ft. length is taken to a power saw where the bar is cut into 8 pieces. Next, the ends are milled in a horizontal milling machine. Parts are deburred using a pedestal grinder and transported to in-process storage.

The three parts are washed again in a 3-stage automatic washer and transported to a 400 amp, 440 volt, 4-station, CO_2 welder where the top bar and base angle are automatically welded to the junior beam.

After visual inspection and a nondestructive test (NDT) for welding, the parts are transported to in-process storage.

FIGURE 6.15: SINGLE PYLON



6.4.4 Driveshaft and Flexural Plate Assembly

Figure 6.16

Bars, 20 ft. long and 2-3/16 in. in diameter, are transported in special racks using a 5-ton fork truck to a Marvel saw or its equivalent. The Driveshafts are cut to length and taken in 4 ft. x 4 ft. x 4 ft. wire mesh bins with a 5-ton fork truck to a horizontal milling machine. There the ends are milled to finished length.

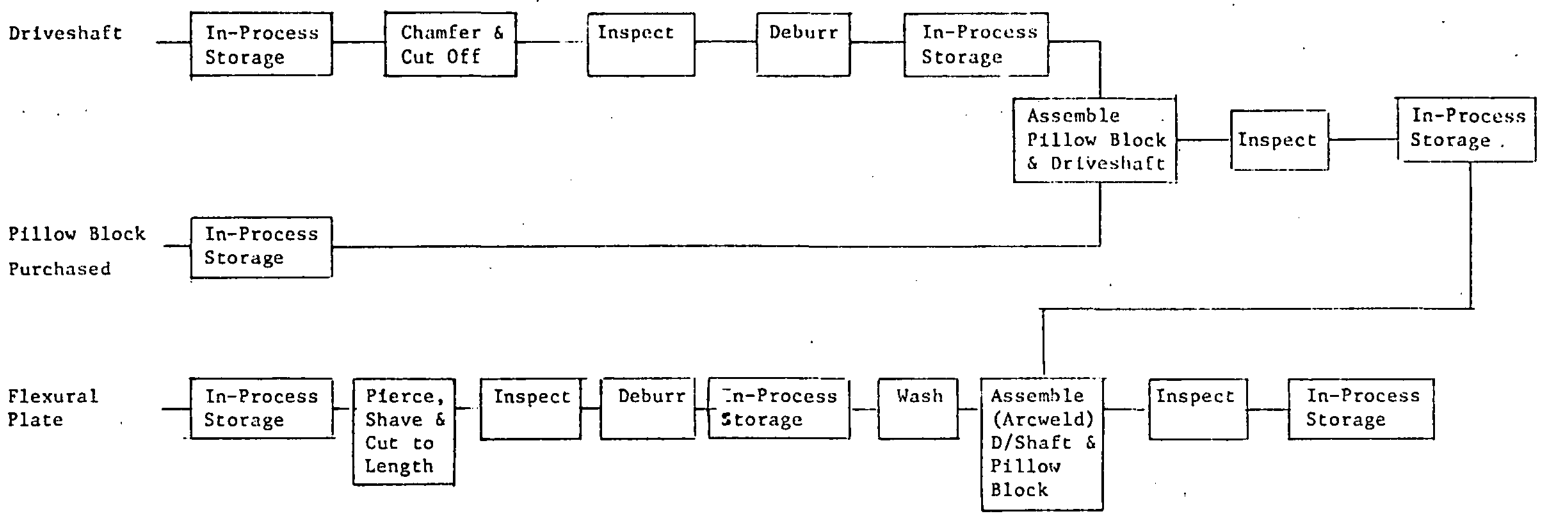
The purchased Pillow Block and the Driveshaft are transported from in-process storage to an assembly area where they are assembled.

The 20 ft. bars of 1/4 in. x 10 in. weathering Flexural Plate steel are taken from in-process storage to a 400-ton straight-side punch press with an automatic loading/unloading system. The Flexural Plates are pierced, shaved, and cut to length. Following random dimensional inspection, the plates are deburred and delivered to in-process storage.

The Pillow Block and Driveshaft, and (after washing in a 3-stage automatic washer) the Flexural Plates are transported to 2 semi-automatic MIG welding machines. There 2 Flexural Plates are welded to the Driveshaft.

After cooling in the fixture, the assemblies are 100% inspected visually and subjected randomly to nondestructive testing on an NDT machine. Following this, they are moved to in-process storage.

FIGURE: 6.16: DRIVESHAFT AND FLEXURAL PLATE ASSEMBLY



6.4.5 Receiver Tube Support Assembly

Figure 6.17

Receiver Tube Support Bar stock coils of .375 in. stainless steel are taken on a coil rack by fork truck to a 150-ton straight-side punch press equipped with automatic feed, cradle, and straightener. Parts are cut off, formed, and restruck in a 3-station transfer die. The ends are then deburred. Next the parts are washed and transported in 4 ft. x 4 ft. x 4 ft. wire mesh bins to in-process storage.

Coils of .063 in. x .62 in. stainless steel are delivered by a 5-ton fork truck to a 30-ton variable high speed press with an automatic feed system. The Receiver Support Clamps are cut off and formed in a 4-station die. After random dimensional inspection, the clamps are deburred and transported to in-process storage using 2 ft. x 2 ft. x 2 ft. wire mesh bins.

Coils of .063 in. x .62 in. stainless steel are delivered by a 5-ton fork truck to a 30-ton press where washers are pierced and blanked. Then after random inspection, they are deburred and taken to in-process storage.

The Support Bar, Clamp, and Washers are moved from in-process storage to a 2-station automatic MIG welding machine. Washers and clamps are arc tack welded to the support bar. Following this, the Receiver Tube Support Assembly is inspected visually and given non-destructive testing. Then it is washed and transported to in-process storage.

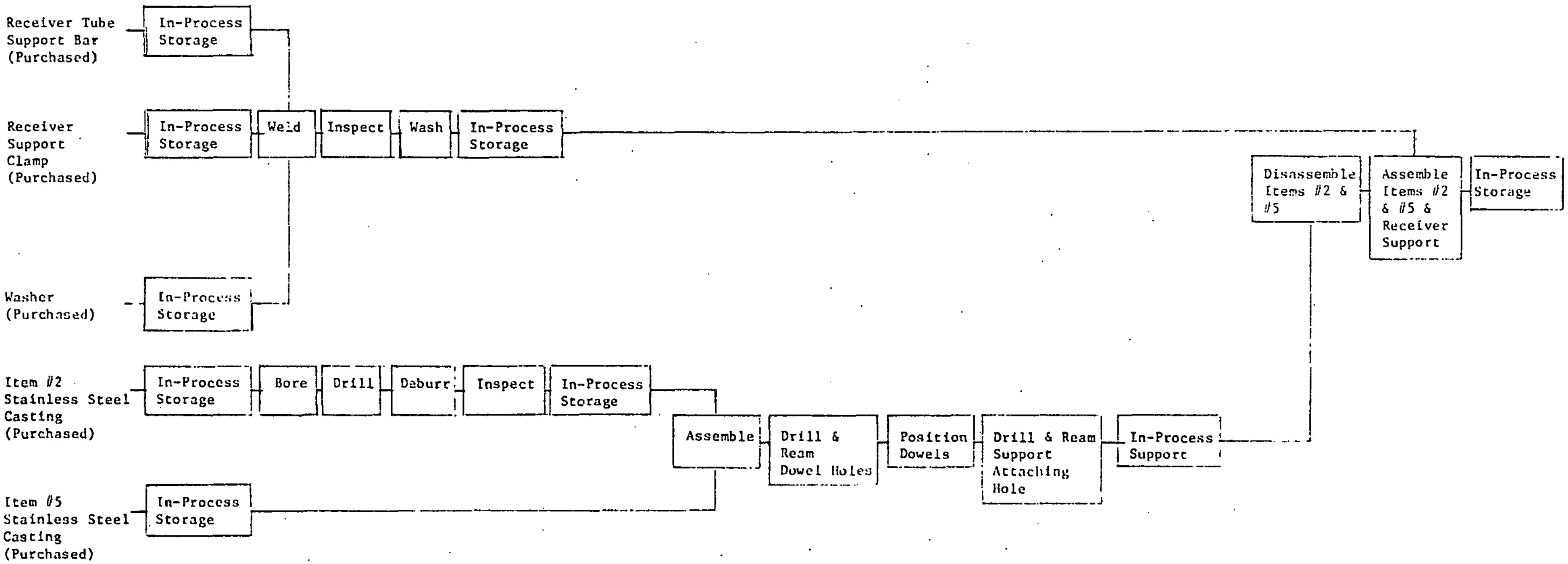
Item #2 Stainless Steel Casting is transported to a Broach where a core hole is broached to ± .002 in. tolerance. The casting is delivered to a 12-spindle 9-station index table drill press where 4 holes are drilled and tapped. The casting is inspected, deburred, and taken to in-process storage.

Items #2 and #5 (purchased) are taken to a 5-station indexing machine. They are assembled with 4 screws. The dowelling holes are drilled and reamed; then dowels are manually inserted.

Next, the transverse Receiver Tube Support Assembly Hole is drilled and reamed with reference to the broached hole. The assembly is then moved to in-process storage.

The Receiver Tube Bearing and the Receiver Tube Support are taken from in-process storage to a 2-station indexing table fixture. Items #2 and #5 are disassembled. The Receiver Tube Support is assembled to the transverse hole, and screws are automatically inserted and driven. The assembly is transported to in-process storage.

FIGURE 6.17: RECEIVER TUBE SUPPORT ASSEMBLY



6.4.6 Double Pylon, Receiver Tube Support, and Flexural Plate Assembly

Figure 6.18

Five inch Flat Weathering Steel, in 20 ft. lengths, is moved in 20 ft. x 3 ft. x 3 ft. racks by overhead crane to a 100-ton straight-side press with automatic feed. There parts are notched and cut off to length in a 2-stage progressive die.

After a random dimensional inspection, 5 in. Flats (Item #1) are deburred in a 70 cubic foot/hour vibratory deburring unit with dryer. They are then taken to in-process storage.

Twenty ft. lengths of 4 in. x 4 in. x 3/8 in. weather steel for Cross Angles (Item #3) are delivered from in-process storage in 20 ft. x 3 ft. x 3 ft. racks by overhead crane to a 150-ton straight-side press where two 1/4 in. holes are pierced and Cross Angles are cut off to length in a 2-stage progressive die. After random dimensional inspection, Cross Angles are transported in 4 ft. x 4 ft. x 4 ft. wire mesh bins to a 100 cubic foot/hour deburring and washing unit. Finally they are transported to in-process storage.

The 5 in. Flats (Item #1) and Cross Angles (Item #3) are taken from in-process storage in 4 ft. x 4 ft. x 4 ft. wire mesh bins by jib crane to a 3-stage automatic washer. They are washed and then transported to a 400 amp, 440 volt MIG welding machine where the Cross Angles are welded to the 5 in. Flats with 32 in. of weld. The assemblies are 100% visually inspected. The welds are randomly given nondestructive tests, followed by transport to in-process storage.

The Top Bar (Item #2) material in a 21.12 ft. length is taken to a 100-ton straight-side press with an automatic feed system. The bar is sheared into 30 pieces and subsequently taken to a 4-spindle 4-station drill press where two 17/32 in. holes are drilled and tapped. After inspection, the parts are deburred, washed in a 100 cubic foot continuous deburring and washing unit, and transported to in-process storage.

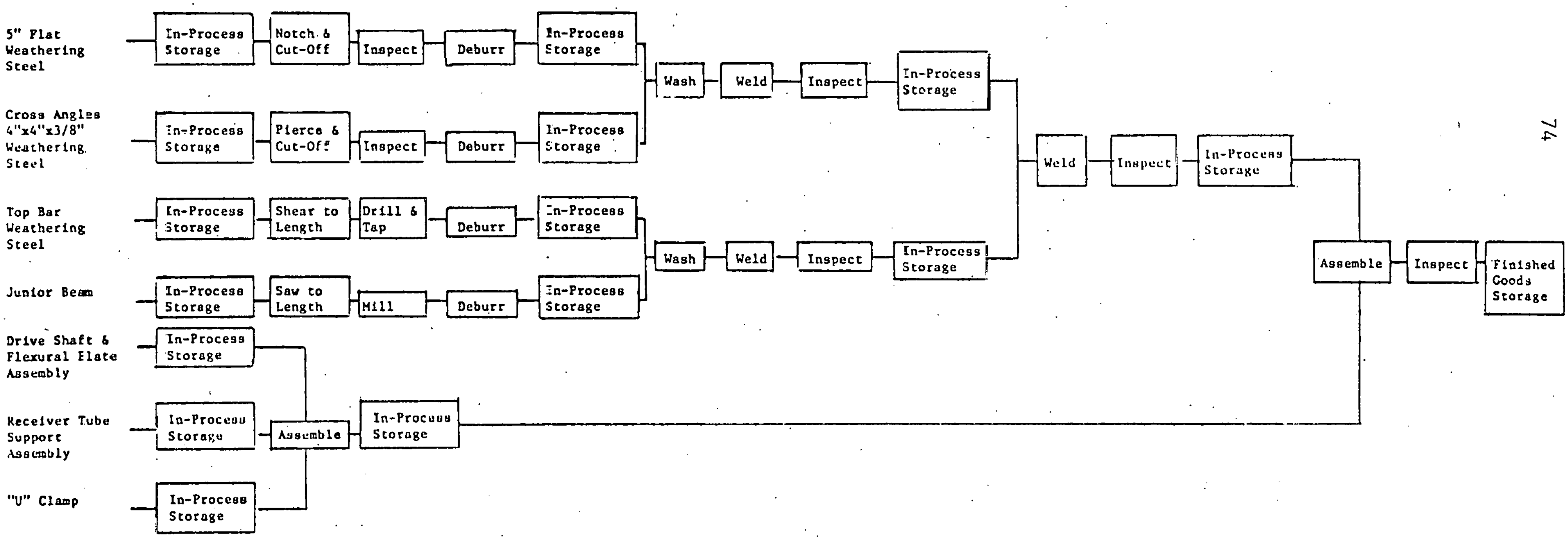
The Junior Beam (Item #4) material in a 19.38 ft. length is transported to a power saw and cut into 8 pieces. Next, the ends are milled in a horizontal milling machine. The parts are deburred using a pedestal grinder and delivered to in-process storage.

The three parts are washed again in a 3-stage automatic washer. Then they are transported to a 400 amp, 440 volt, 4-station CO_2 welder. There the top bar is automatically welded to the Junior Beam.

The weldments of the Cross Angles (Item #3), and the 5 in. Flats (Item #1), and the Junior Beam (Item #4), and the Top Bar (Item #2) are moved from in-process storage to four 400 amp, 440 volt MIG welding machines. The weldments are welded into assembly with 20 in. of 7 mm fillet weld. After 100% visual inspection and random nondestructive weld testing, the assemblies are transported to in-process storage.

The Double Pylon Weldment and the Flexural, Pillow Block and Receiver Support Assembly are taken from in-process storage to a 4-station indexing table assembly fixture. There the Flexural, Pillow Block and Receiver Support Assembly is attached to the Double Pylon Weldment using two 5/8 in. screws. Following random inspection, the assemblies are taken to finished goods storage.

FIGURE 6.18: DOUBLE PYLON, RECEIVER TUBE SUPPORT, AND FLEXURAL PLATE ASSEMBLY



6.4.7 Drive Pylon Assembly

Figure 6.19

Weathering steel (Corten or equivalent), 3/4 in. x 12 in., in 20 ft. lengths is transported in special racks by overhead crane to an 800-ton punch press. There the Bottom Plates are cut off and pierced in a 2-stage die. Next, the Bottom Plates in 4 ft. x 4 ft. x 4 ft. wire mesh bins are taken to a disc grinder where they are deburred and then transported to in-process storage.

"I" Beams, made from 36 in. S-10 structural weathering steel, are brought from in-process storage to a Marvel saw or equivalent, where they are cut to rough length. They are next delivered to a horizontal milling machine, and their ends are milled square. The "I" Beams are then transported to in-process storage.

The Top Plates, 3/4 in. x 12 in. weathering steel, are processed in the same way as the Bottom Plates.

Bottom Plates, "I" Beams, and Top Plates are loaded into weld fixtures and assembled using 40 ft. of arc welding. The assembly subsequently goes to in-process storage.

Weathering steel Drive Plates, 1/4 in. x 10 in., removed from in-process storage, have 16 holes pierced and shaved and the corners trimmed off in a progressive die. Next, the Drive Plates are deburred and taken to in-process storage.

Modular iron (ASTM-A-339-55 annealed) Hub Castings are transported from in-process storage to an automatic chucker. The front and the rear of the front flange of the Hub are faced, and the 2.6 in. diameter hole is drilled and reamed.

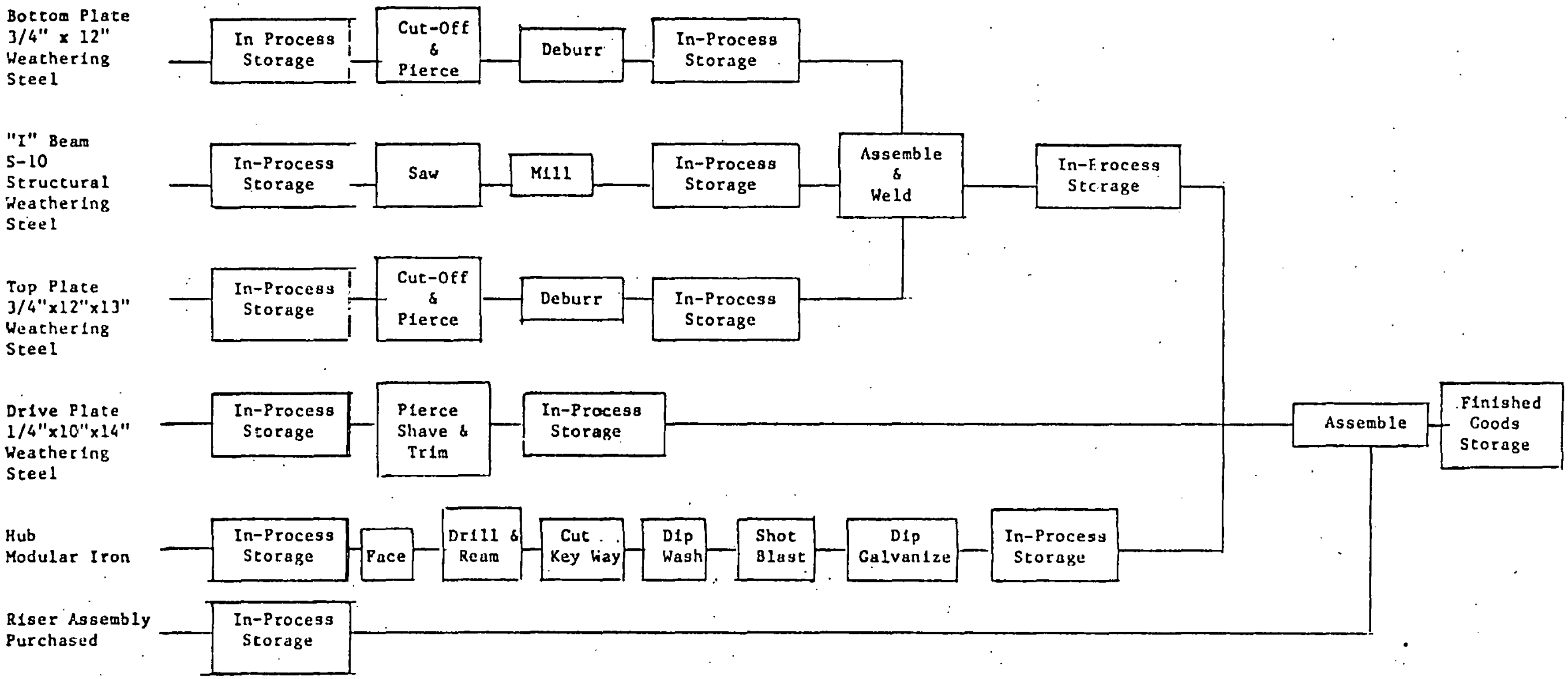
The Hub is next transported to a #4 Natco where 8 holes are drilled and 3 are reamed. Then the keyway is cut on a keyway slotter. Afterward it is dip-washed, shot-blasted,dip galvanized, and taken to in-process storage.

The Drive Pylon Assembly, Gear Box, Drive Plates, Hubs, Risers, and standard parts are delivered to a subassembly fixture where the following work occurs:

- Using a jib crane, position the Gear Box on the Top Plate of the Pylon. Insert 4 bolts/washers/nuts and torque.
- Position Hubs on each end of the gearbox shaft and insert keys.
- Position Drive Plates and Riser to Hubs. Drive dowels using a special hydraulic tool on the inside of the Riser and outside of the Hub. Attach with nuts and bolts.

Finally, send the Drive Pylon Assembly to finished goods storage.

FIGURE 6.19: DRIVE PYLON ASSEMBLY



6.4.8 Receiver

Figures 6.20
6.21

Low carbon welded steel Receiver Tubes, 1-1/4 in. O.D. x .065 in. wall x 10 ft. long, are transported in special racks by a 5-ton fork truck to a 6-roll straightening machine (Kane and Roche or equivalent). There Receiver Tubes with a tolerance of ± .010 in. per lineal foot as received are straightened to a tolerance of ± .003 in. per lineal foot. The special rack is then delivered to in-process storage from where it is subsequently drawn for plating.

Receiver Tubes are sent from in-process storage to a 3-stage automatic washer. The tubes are washed, followed by vapor cleaning and grit blasting on a batch basis. Next, the tubes are positioned on special 10 ft. x 3 ft. x 3 ft. plating racks (holding 10 tubes per rack). The plating racks in turn are positioned on the plating overhead conveyor. In this procedure, the Receiver Tubes pass through 10 preparation tanks, 4 nickel plating tanks, and 8 black chrome tanks. The racks are then automatically unloaded; the parts are randomly inspected for absorptance and emittance; and they are then transported by fork lift to the induction brazing furnace area.

Coils of .015 in. x 3.5 in. stainless steel "O" Ring Support material are transported on skids from in-process storage to a transfer press punch press, automatic feed, and straightener. There the blanks are stamped and subsequently drawn and redrawn in a 6-station transfer press. Parts are then transported in 4 ft. x 4 ft. x 4 ft. wire mesh bins to a 44 cubic foot per hour continuous deburring unit. The parts are deburred, washed, and transported in 4 ft. x 4 ft. x 4 ft. wire mesh bins to in-process storage by fork truck.

The glass tube is brought from in-process storage to a grinding lathe where the inside diameter of each end of the tube is ground from a 55.2 ± 0.5 mm diameter to a 55.7 ± .025 mm diameter for a length of 1 in. at each end. After washing, the tubes are transported in special racks to the assembly area by fork truck.

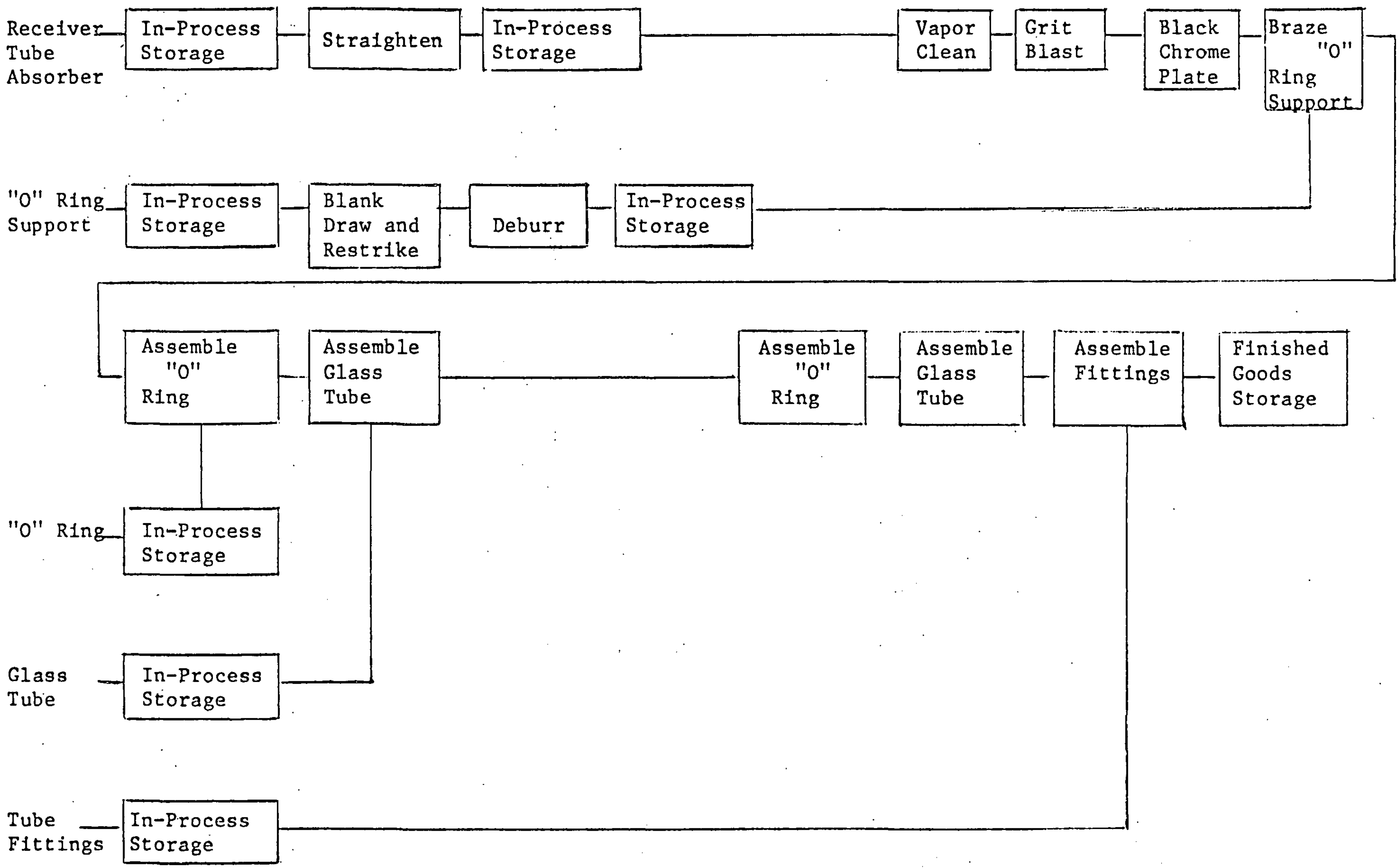
The Receiver Tube, Glass Tube, "O" Rings, and "O" Ring Supports are brought from in-process storage to an induction brazing unit where an "O" Ring Support and a Silver Brazing Ring are positioned to the ends of the Receiver Tube. Then the "O" Ring Support is induction-brazed to the Receiver Tube with the Receiver Tube in a vertical position.

Next, the Receiver Tubes are transported by indexing conveyor to a 4-position indexing capstan head assembly fixture area. There the "O" Ring is positioned on the previously brazed Receiver Tube, and the Receiver Tube is automatically loaded to the first mandrel position on the capstan fixture. In the second position the glass tube is automatically slid over the "O" Ring. In the third position a second "O" ring is automatically positioned on the other end of the tube.

Then the glass tube is slid and automatically unloaded from the fourth position.

Finally, assemblies are put in an automatic fitting assembly fixture where a fitting is assembled to one end. The assemblies are next transported to finished goods storage.

FIGURE 6.20: RECEIVER



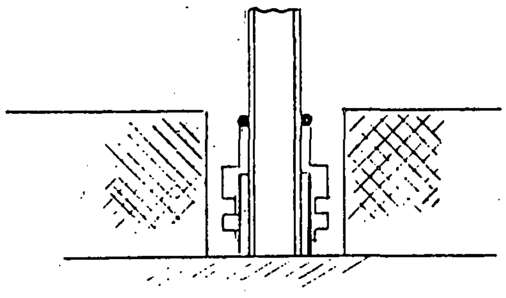
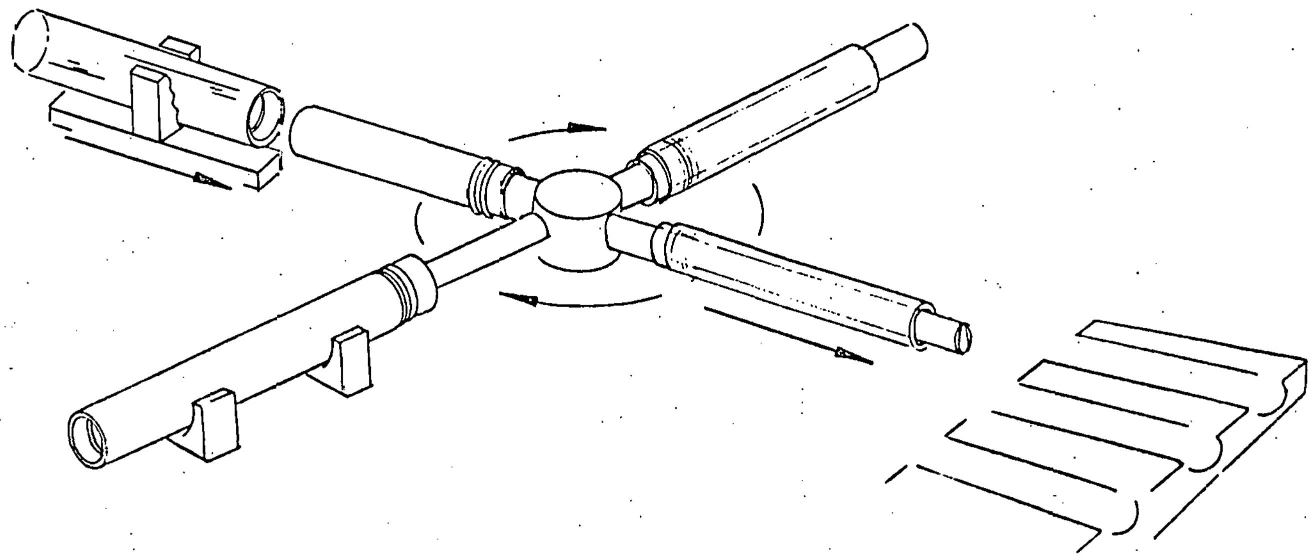


FIGURE 6.21: FITTING "O" RING SUPPORTS AND GLASS TUBE IN THE RECEIVER ASSEMBLY PROCESS



6.4.9 Torque Tube and Reflector Assembly

Figures 6.22
6.23

The Torque Tube Assembly is transported from in-process storage by conveyor. The Reflector Assembly is brought in specially-designed 7 ft. x 5 ft. racks on a fork truck. Both assemblies at a 5-station indexing conveyor are processed as follows:

Station #1 - Load the Reflector in fixture using "Versatran-Type FB" or equivalent and locate on 2 pins.

Station #2 - Load Torque Tube and Reflector Support Assembly with automation, and then automatically insert locating pins in the Torque Tube flange tooling holes.

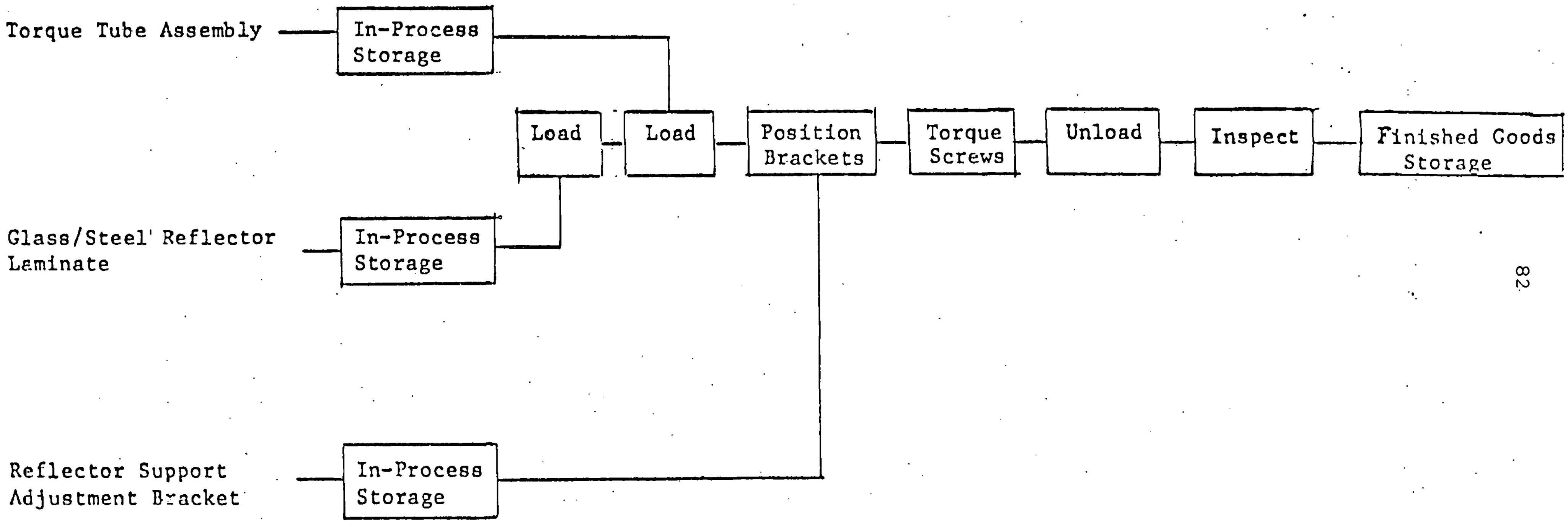
Station #3 - Position "L" adjustment brackets until they flush automatically with doubler surface on frame panel. Automatically insert screws and torque screws to doubler surface.

Station #4 - Insert screws automatically and torque the "L" adjustment bracket to Reflector Support.

Station #5 - Automatically retract the locating pins and unload automatically onto a conveyor.

After random laser ray tracer inspection of slope error and focal lengths, transport the Torque Tube and Reflector Assemblies using overhead cranes to finished goods storage.

FIGURE 6.22: TORQUE TUBE AND REFLECTOR ASSEMBLY



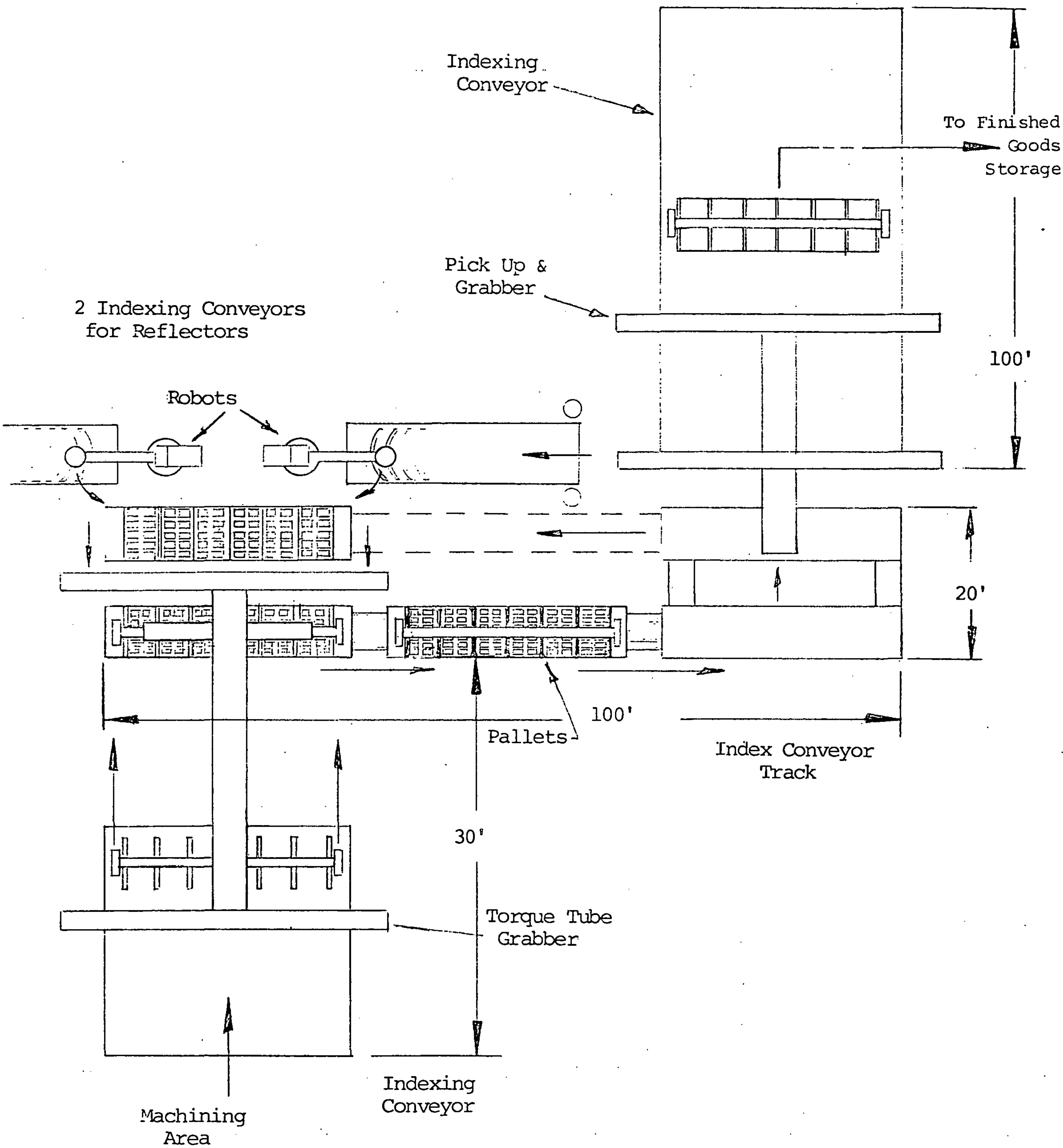


FIGURE 6.23: REFLECTOR TORQUE TUBE ASSEMBLY

6.4.10 Glass/Steel Reflector Laminate

Figures 6.24
6.25

The Thin Annealed Glass sheets are transported from in-process storage on skids using a 5-ton fork truck to a washer where they are loaded by robot. The sheets are washed and dried and unloaded by robot to a skid. Then the sheets are transported to the bonding area.

The Sheet Steel Skin Panels are taken from in-process storage on skids by a 5-ton fork truck to an indexing conveyor. The Skin panels are loaded by robot, on which they are washed, dried, and mechanically cleaned with Ethanol to prepare for bonding. They are mechanically primed with Primer 6025 and dried in an infrared oven. Two-component adhesive (Goodyear 6000 and 6010 G Series or equivalent) is mechanically applied on two glass sheets.

Next, using a robot, the Skin Panel is positioned on glass sheets. They are bonded under the pressure of nip rollers and heat-cured for 3 minutes. The edge is mechanically scraped for adhesive squeezeout. The sheets are unloaded from the conveyor to a skid by robot which places a paper separator between each sheet. The skid is then transported to the bonding area.

On a separate continuous belt conveyor the Frame Panel is loaded by robot, washed and dried, mechanically cleaned with Ethanol, dried, mechanically primed with Primer 6025, and dried again. The Frame Panels are unloaded by robot to skids, which are transported to the assembly area.

Using robots, the Glass/Steel Laminate is located on a stationary fixture. A 2-component adhesive (Goodyear 6000 and 6010 G Series or equivalent) is applied automatically to the steel surface of the Laminate. Then, using a robot, the Frame Panel is located over the Glass/Steel Laminate. The assembly is heat-cured for 3 minutes at 250^{o} Fahrenheit. After this it is unloaded to a skid and taken by fork truck to in-process storage.

FIGURE 6.24: GLASS/STEEL REFLECTOR LAMINATE

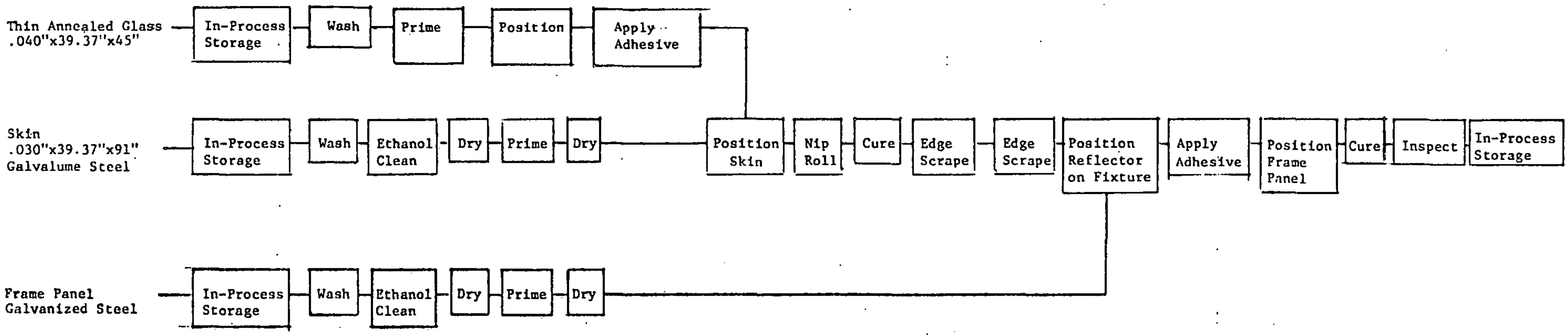
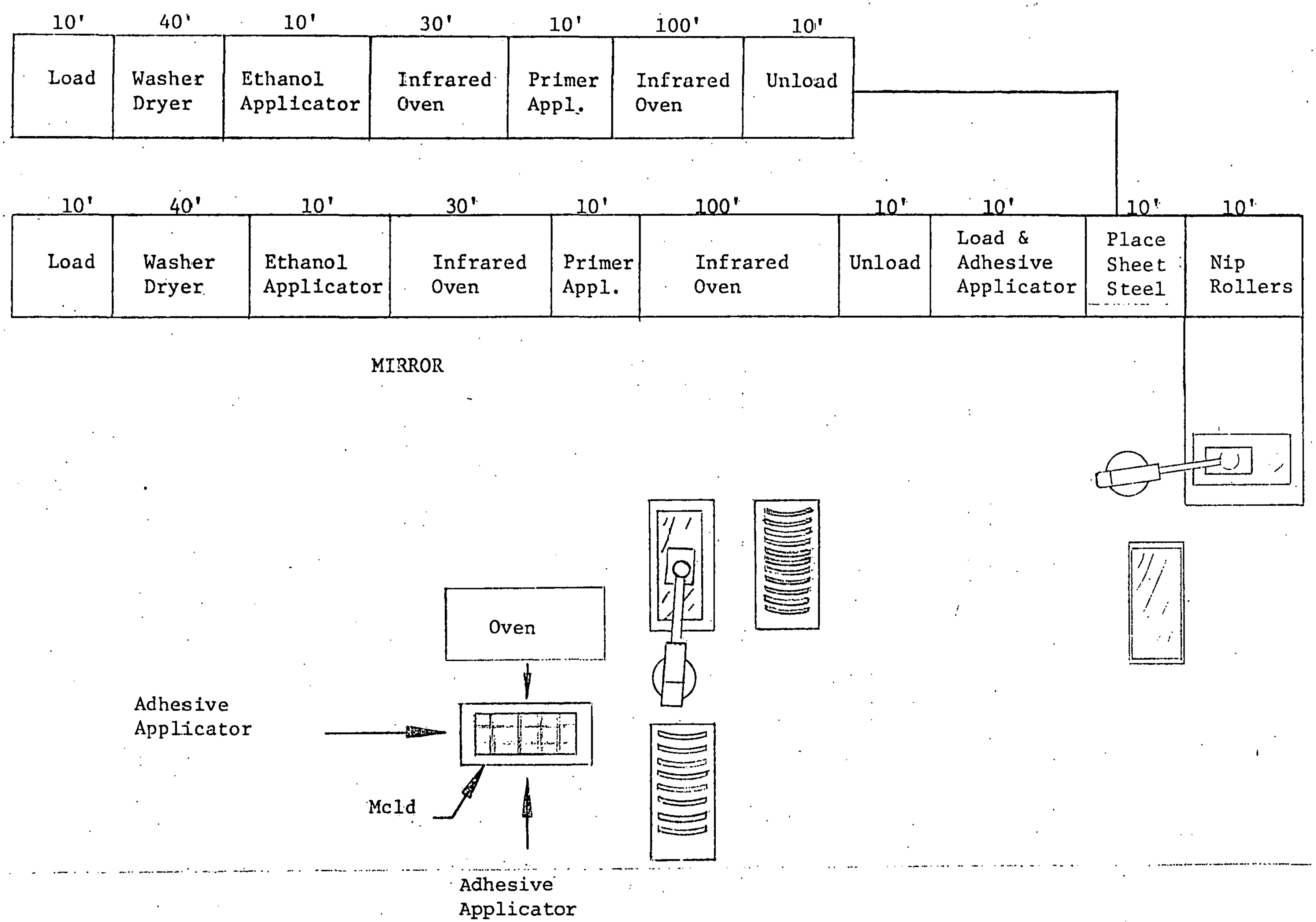


FIGURE 6.25: REFLECTOR ASSEMBLY



6.4.11 Mirror

Figures 6.26
6.27

Glass sheets in special racks are brought from in-process storage to the silvering line using a 5-ton fork truck. The Glass is loaded by robot to a continuous belt conveyor silvering line. The glass, in turn, is mechanically scrubbed and rinsed. Next, sensitizer and silver are sprayed to the top surface followed by a rinse; then comes an iron filing and copper application. After infrared curing, paint is sprayed over the copper and dried. Finally the glass is cleaned, rinsed, and air-dried.

The silvered glass is unloaded by robot to a skid which is transported by fork truck to the bonding area.

FIGURE 6.26: MIRROR

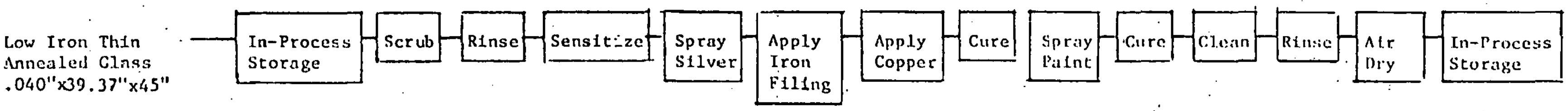
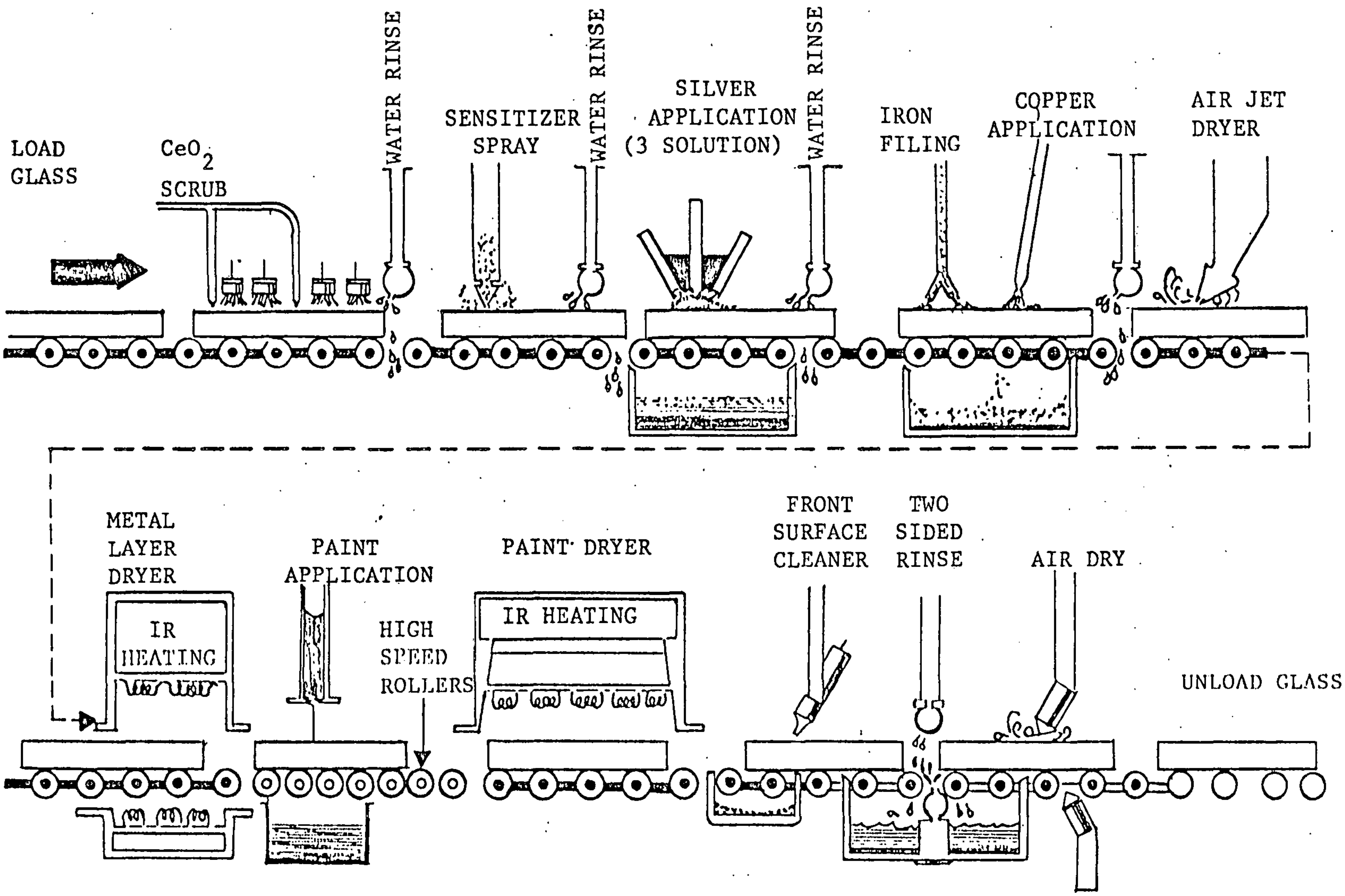


FIGURE 6.27: MIRRORING OF GLASS



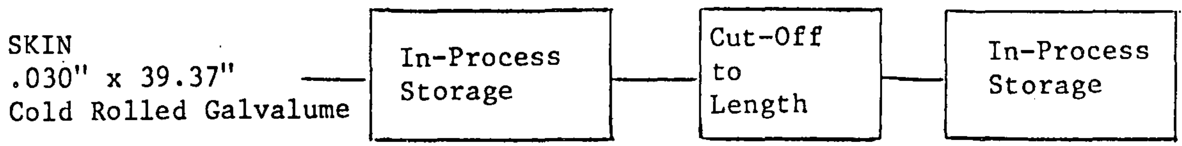
6.4.12 Skin

Figure 6.28

Coils of .030 in. x 39.37 in. wide cold rolled Galvalume steel are transported to a "cut off to length" system, consisting of a coil peeler, straightener, roll reel, crop shear, and high speed sheet stacker.

The sheets are cut off to 91.5 in. x 39.37 in. wide. They are stacked on a skid and delivered to in-process storage.

FIGURE 6.28: SKIN



6.4.13 Torque Tube Assembly

Figures 6.29
6.30

Weathering angle steel, 1/8 in. x 1-1/4 in. x 1-1/4 in., in 20.5 ft. lengths, is transported to a roll forming machine where the Torque Tube Flanges are formed and cut off. Next, the ends are formed in a 30-ton press and butt-welded. After butt welding and flash removal on a milling machine, the Flanges are deburred in a 100 cubic foot/hour machine. The Flanges are then taken to in-process storage.

Torque Tubes in 20 ft. x 3 ft. x 3 ft. racks are delivered to the torque tube welding and assembly transfer line (Figure 6.30). The tubes are removed from the racks using a 10-ton overhead crane and loaded into an 8-tube storage device. This device feeds each tube into the load station of the flange welder.

The Flanges are transported from in-process storage to hopper feeds at either end of the torque tube flange welding station. There the Flanges are automatically welded by overhead MIG torches. After the Flanges are welded, the tube is automatically loaded into a pallet.

Support brackets are brought from in-process storage in 4 ft. x 4 ft. x 4 ft. wire mesh bins and manually loaded onto a magazine chain conveyor.

A pallet with tube and support brackets moves into the first weld station where the pallet is pumped up off the conveyor and positioned by register pins into control holes on the Flanges. An overhead equalizing clamp unit holds the support in position for welding. Three puddle welds are made in each of 4 supports at the first station. The remaining 4 supports are welded in the next station. Welds are stress-relieved.

Torque tubes are transferred to the following station where both Flanges are faced off to assure parallelism. The top surface of the Receiver Support Block--Midway Sheet Metal Trough is milled to provide a precision surface for subsequent assembly of the "U" clamp.

The next station drills 8 holes in each Flange to be followed by boring of 2 tooling holes. Exposed surfaces are touched up. Then the assemblies are delivered to in-process storage.

FIGURE 6.29: TORQUE TUBE ASSEMBLY

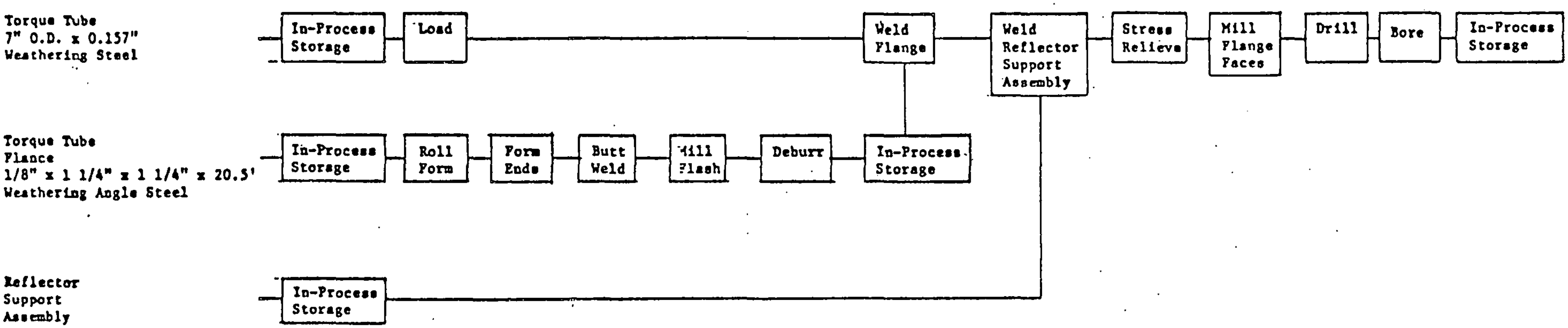
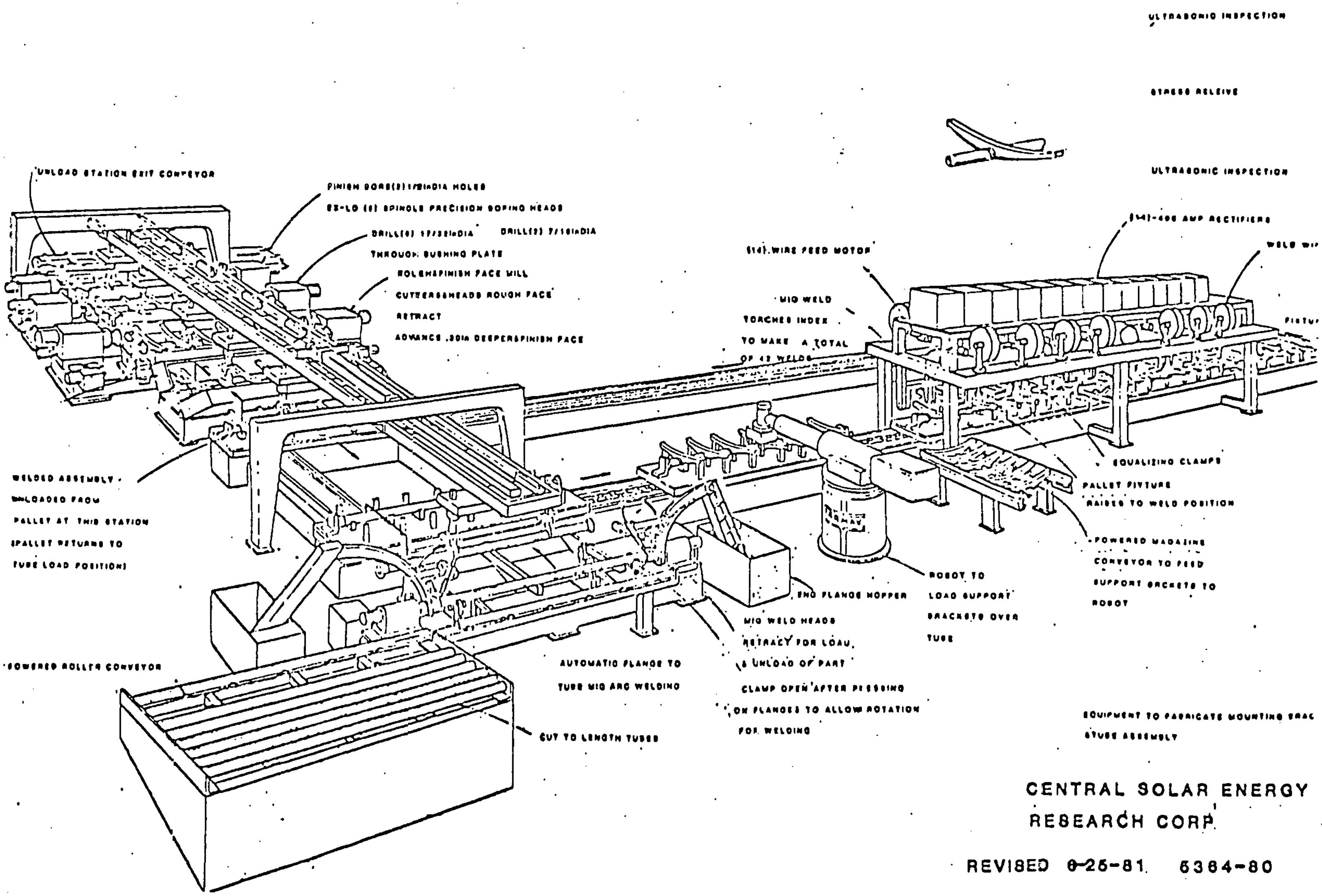


FIGURE 6.30: TORQUE TUBE ASSEMBLY



6.4.14 Receiver Support Assemblies--Midway Sheet Metal Trough

Figures 6.31
6.32

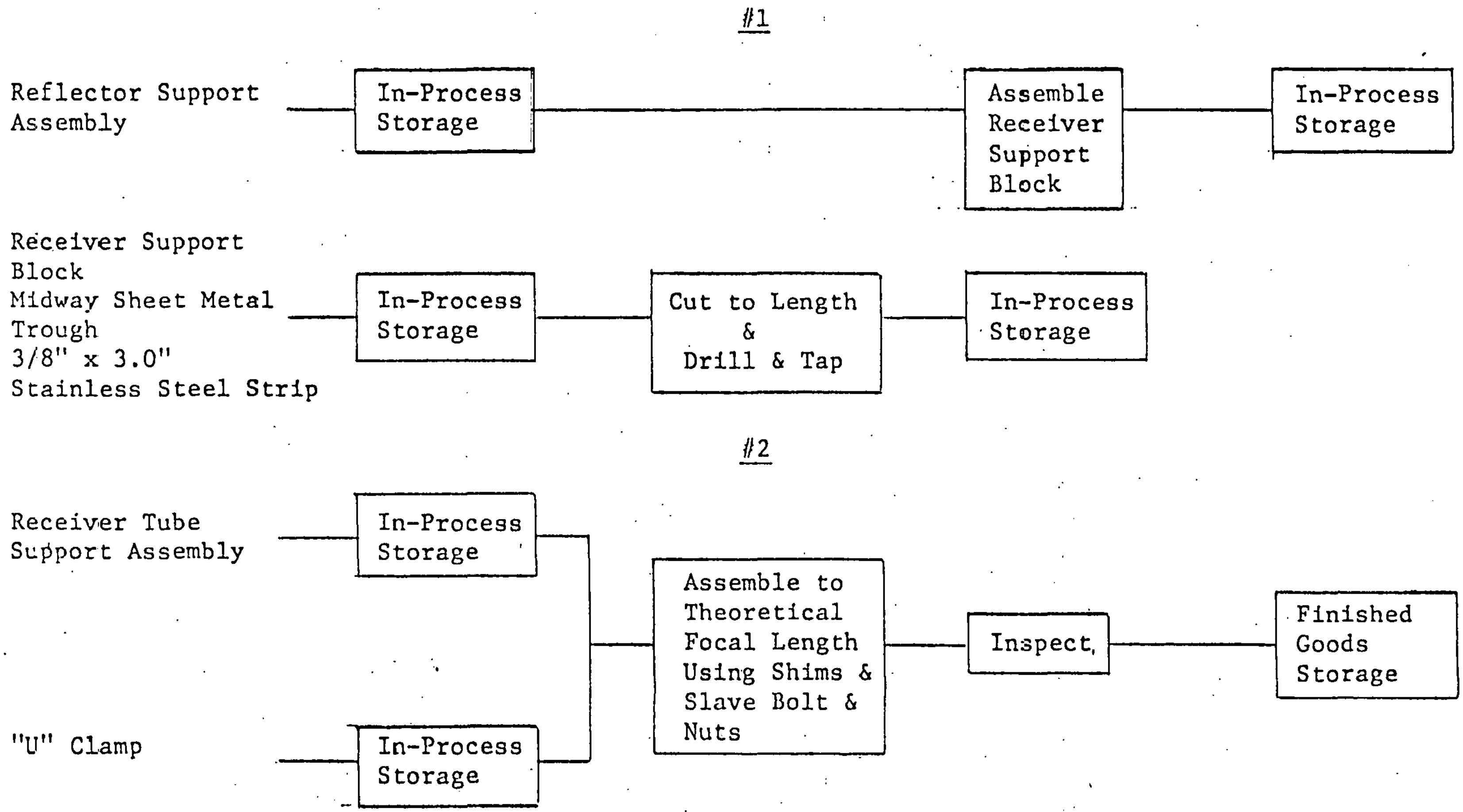
Coils of 3/8 in. x 3.0 in. stainless steel strip are taken from in-process storage using a 7.5-ton fork truck to a Marvel saw, equipped with automatic feed as well as a bar unscrambler and loader. The steel strip is cut into 5.5 ft. lengths for use as connections to Frame Supports. The 5.5 ft. lengths are delivered to a 6-station transfer drill press where eight 1/4 in. diameter holes are drilled and tapped. Next, the parts are deburred and transported to in-process storage.

Reflector Support Assemblies and Trough Receiver Support Blocks--Midway Sheet Metal are trucked to a 4-station assembly machine where they are assembled using 4 automatically fed and torqued screws. The assemblies then are taken in 4 ft. x 4 ft. x 4 ft. wire mesh bins using a 5-ton fork truck to in-process storage.

"U" clamps and Receiver Tube Support Assemblies go from in-process storage to a subassembly fixture. The broached bearing hole of the Receiver Tube Support Assembly is located over the fixture pin. The "U" clamp is positioned within stops which establish its side-to-side relationship with the theoretical axis of the Support Assembly and the theoretical focal length.

Appropriate shims are chosen to bridge the gap between the stop and the "U" clamp. The "U" clamp is clamped in this position, and the 2 mounting holes and shims are drilled and reamed. The shims are then assembled to the "U" clamp with slave bolts and nuts, which will be removed and discarded after field assembly.

FIGURE 6.31: RECEIVER SUPPORT ASSEMBLIES
NOS. 1 AND 2
MIDWAY SHEET METAL TROUGH



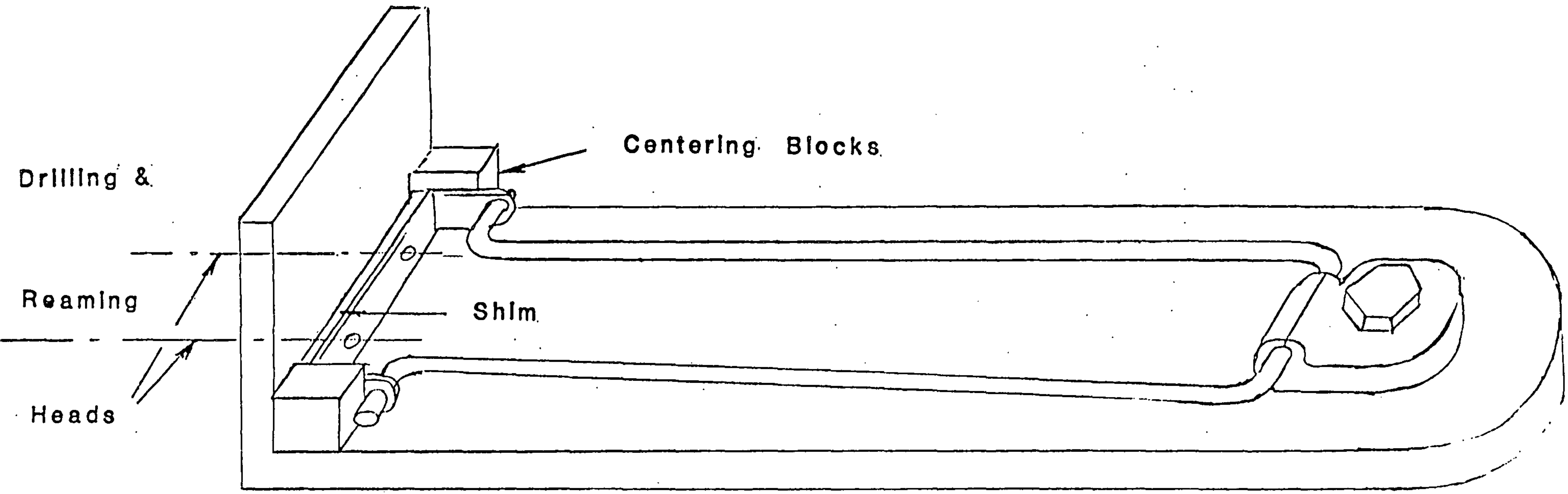


FIGURE 6.32: ASSEMBLY FIXTURE TO ESTABLISH FOCAL LENGTH DISTANCE ON RECEIVER TUBE SUPPORT - MIDWAY STEEL TROUGH

6.4.15 Reflector Support Assembly

Figure 6.33

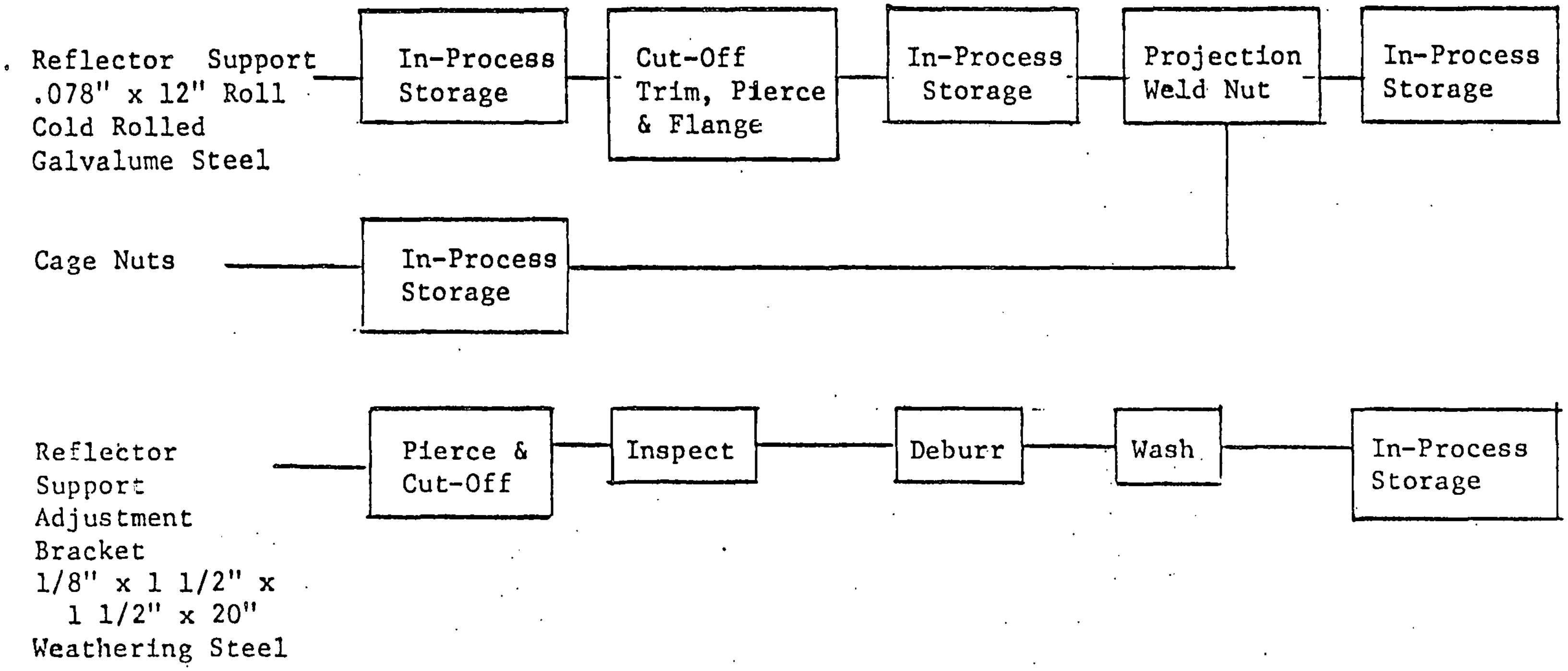
Rolls of .078 in. x 12 in. cold rolled Galvalume steel, drawn quality are taken from in-process storage to a 750-ton straight-side punch press equipped with a decoiler/straightener. There Reflector Supports are cut off, trimmed, pierced, and flanged in a 5-stage progressive die. Finished parts are delivered in 4 ft. x 4 ft. x 4 ft. wire mesh bins by fork truck to in-process storage.

Reflector Supports and Cage Nuts from in-process storage go to an indexing welding fixture conveyor where the nuts are fed automatically into position on the Reflector Supports and projection-welded. They return by fork truck in 4 ft. x 4 ft. x 4 ft. wire mesh bins to in-process storage.

Twenty foot lengths of 1/8 in. x 1-1/2 in. x 1-1/2 in. "L" shaped weather steel are transported to a 100-ton straight-side punch press equipped with a bar unscrambler and loader. There Reflector Support Adjustment Brackets are pierced and cut off in a 3-stage progressive die.

After a sample dimensional inspection, parts are delivered in wire mesh bins to a 100 cubic foot/hour deburring and washing unit. After passing through this unit, they go in bins using a fork truck to a galvanizing line. Following this process, the parts are taken to in-process storage.

FIGURE 6.33: REFLECTOR SUPPORT ASSEMBLY



6.4.16 Frame Panel Assembly

Figures 6.34
6.35
6.36

Drawn quality galvanized steel in .03 in. x 55 in. coils is transported to a 300-ton press where Frame Panel material is sheared to 110 in. length.

Pallets, 8 ft. x 4 ft., of blanks are taken to a 4-press line where the panels are drawn to parabolic shape. Reinforcing ribs are formed, 18 lightening holes are pierced, and the Frame Panels are restruck and unloaded. Following inspection, they are transported to in-process storage.

Coil racks, 4 ft. x 5 ft., of 1.5 mm x 41 mm cold rolled steel are transported from in-process storage to a 30-ton high speed/variable speed punch press with a roll feed cradle straightener. There Frame Panel Doublers are blanked and pierced in a 2-station progressive die. After random dimensional inspection, doublers in 4 ft. x 4 ft. x 4 ft. wire mesh bins go to a 30 horsepower, 70 cubic foot/hour deburring unit. They are deburred, washed, and dried, followed by in-process storage.

Doublers and Weld Nuts are moved in 4 ft. x 4 ft. x 4 ft. wire mesh bins from in-process storage to a 3-stage automatic washer. Using a 1-ton jib crane, they are loaded on a washer conveyor. After washing, they are transported to a 150 kVA semiautomatic projection welding machine. The parts are manually loaded and welded 2 at a time, then automatically unloaded. After a 100% visual and random nondestructive test, the parts are carried in wire mesh bins to be galvanized. Finally they are returned to in-process storage.

Frame Panels and Doublers with Nuts go to a 120 kA, 440 Volt projection weld press welder where the doublers are fed automatically into position. The Frame Panel is positioned by robot and 4 doublers per panel are welded. The Frame Panel Assembly is then taken to in-process storage.

FIGURE 6.34: FRAME PANEL ASSEMBLY

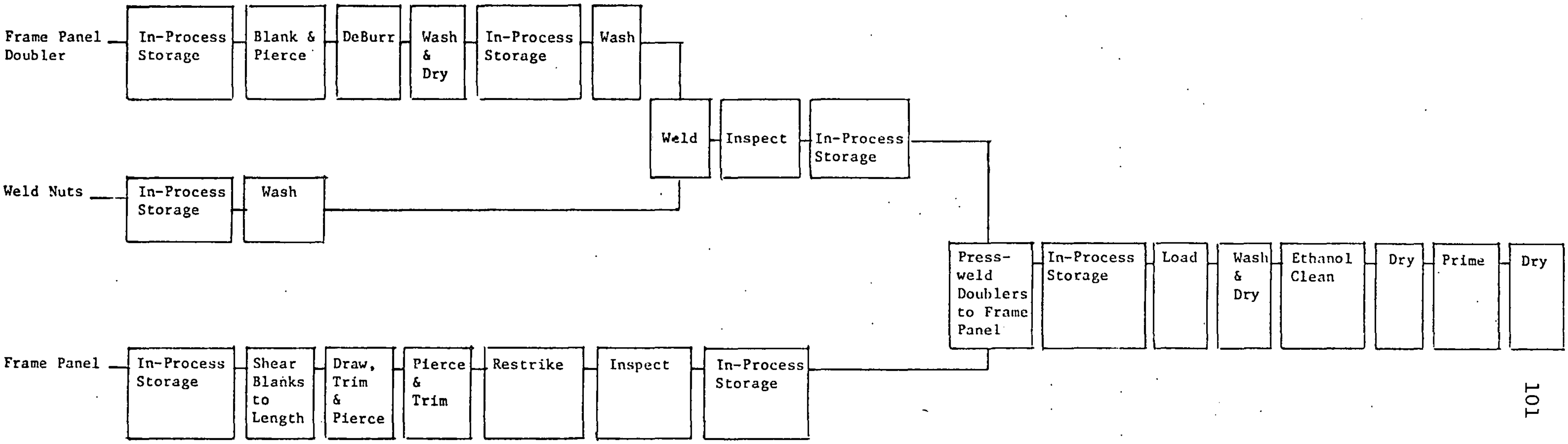
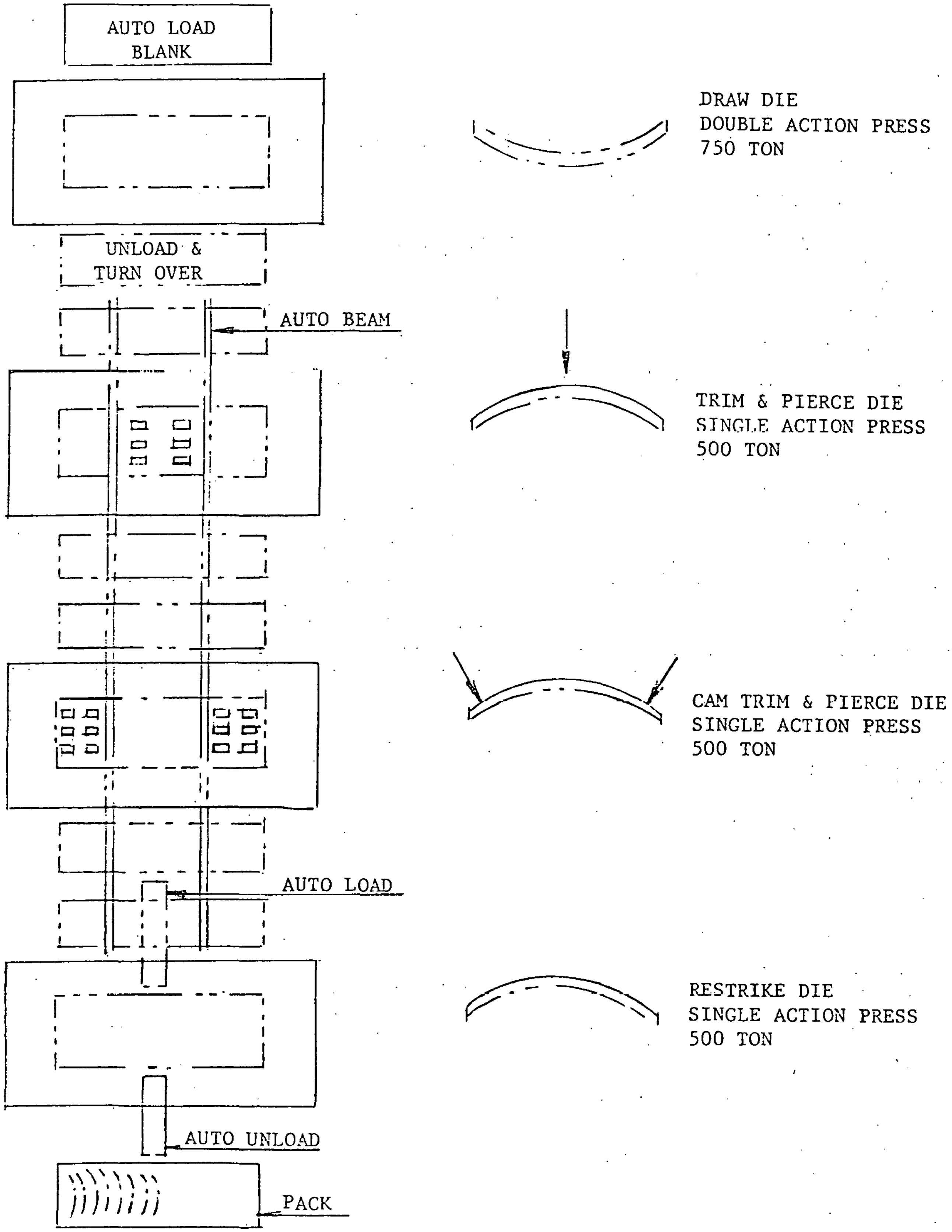


FIGURE 6.35: FRAME PANEL
PRESS LINE & AUTOMATION



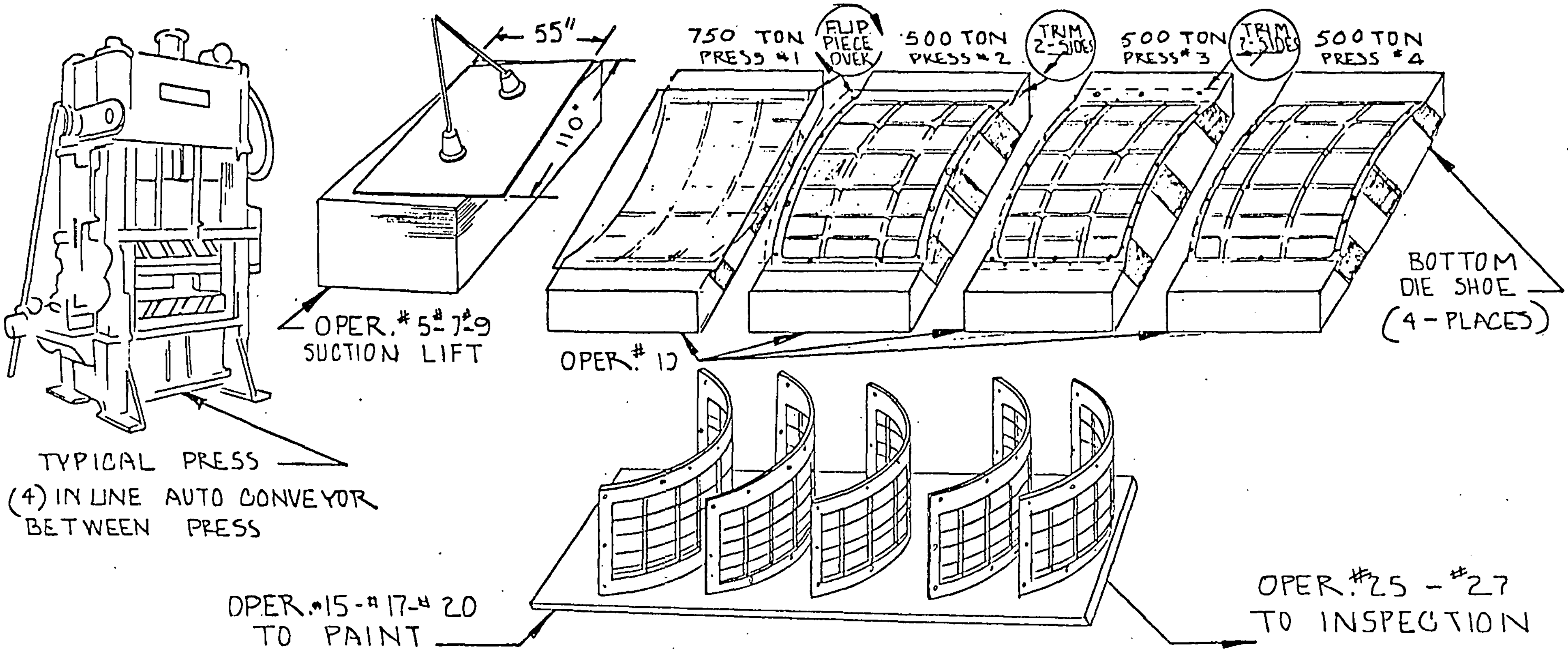


FIGURE 6.36: FRAME PANEL STAMPING

6.5 PROCESS ANALYSIS--100,000 MODULES PER YEAR

Design: Thermally Sagged Glass (Slab)

The process for the Slab Glass alternate is given in this subsection.

To avoid repetition, processes common to both the Thin Annealed Glass and Steel Laminate on Steel Frame Panel design and the Thermally Sagged Glass (Slab) design have not been duplicated.

Table 6.6 follows as a convenient reference guide to the common and unique processes for the two designs.

TABLE 6.6: REFERENCE GUIDE FOR COMMON AND UNIQUE PROCESSES IN PRODUCTION OF THE TWO SELECTED DESIGNS

Component	Unique To Design C*	Unique To Design E*	Common To Both
80 ft. Collector Module Assembly			X
Single Pylon Receiver Tube Support and Flexural Plate Assembly			X
Single Pylon Weldment			X
Flexural Plate and Receiver Tube			X
Driveshaft and Flexural Plate Assembly			X
Receiver Tube Support Assembly			X
Double Pylon, Flexural and Receiver Support Assembly			X
Drive Pylon Assembly			X
Receiver			X
Torque Tube and Reflector Assembly	X	X	
Glass/Steel Reflector Laminate	X		
Slab		X	
Mirror[1]	X	X	
Skin	X	NR*	
Torque Tube Assembly[2]	X	X	
Reflector Support Assembly[3]	X	X	
Frame Panel Assembly	X	NR*	

* Design C = Thin Annealed Glass and Steel Laminate on Steel Frame Panel
Design E = Thermally Sagged Glass (Slab)
NR = None Required

NOTES:

1. Silvering Process Differences: a) Thin annealed glass is silvered flat. b) Slab is silvered as a curved surface.
2. Welding Differences: Differences in reflector supports require different welding methods.
3. Configurations are different. The support for the thin annealed glass design requires an adjustment bracket.

6.5.1 Torque Tube and Reflector Assembly--Slab Glass

Figures 6.37
6.38

The Torque Tube Assembly is removed with an overhead gantry crane from the belt conveyor coming from the welding and machining operation. The assembly is transported to an indexing conveyor whose first station is a washer where the Torque Tube Assembly is washed and dried.

In subsequent stations, the surfaces of the Cross Frames are Ethanol-cleaned and dried, following which primer (Goodyear #6035 or equivalent) is applied automatically with a cam-operated dispenser, and cured in an infrared oven.

The Mirrors are washed and primed. They are then positioned on the parabolic mold fixture where a 2-component adhesive (Goodyear #6000 and #6010 G Series or equivalent) is applied automatically with a cam-operated dispenser which restricts applications to the surface area. This surface area will be bonded to the Cross Frames.

Next the Torque Tube Assembly is positioned over the Mirrors using a gantry crane. The assembly is heat-cured for three minutes. The Torque Tube and Reflector Assembly is then loaded to a conveyor which carries it to finished goods storage.

During this processing, random inspection of slope error and focal length is made once daily.

FIGURE 6.37: TORQUE TUBE & REFLECTOR ASSEMBLY - SLAB GLASS

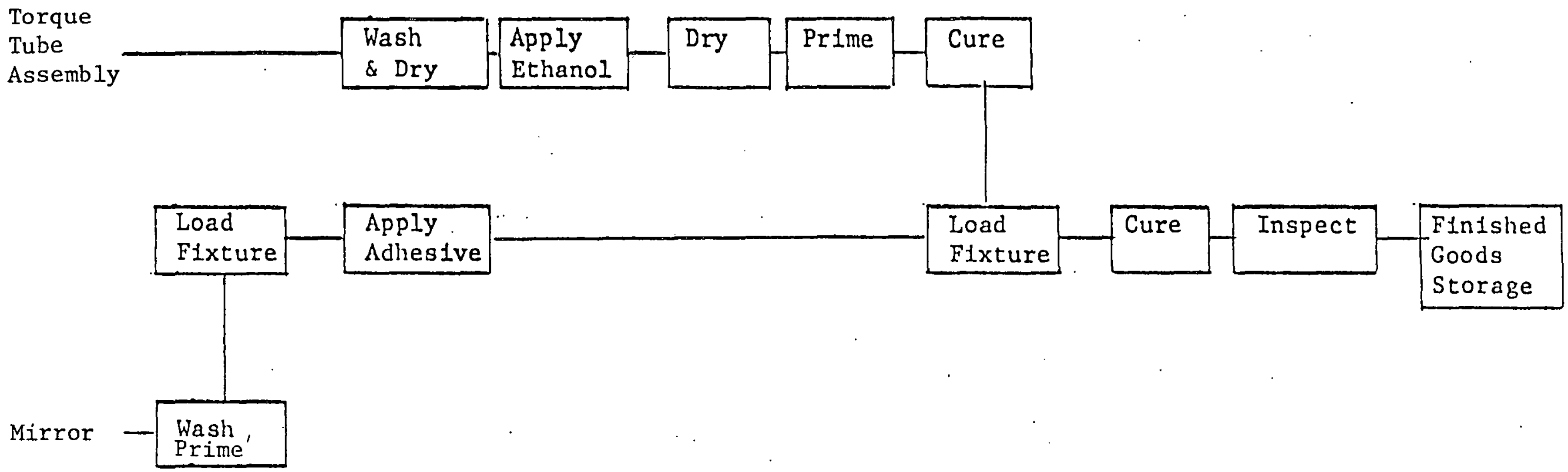
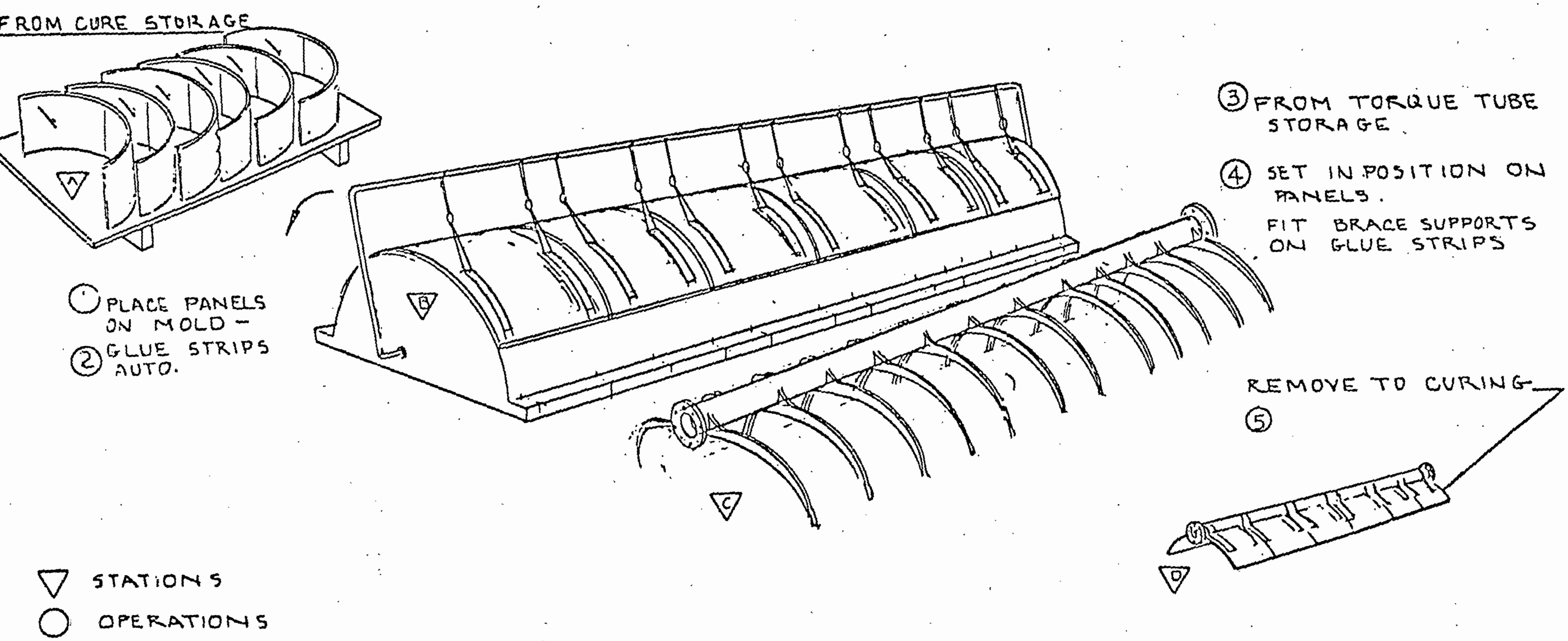


FIGURE 6.38: TORQUE TUBE & REFLECTOR ASSEMBLY
SLAB GLASS



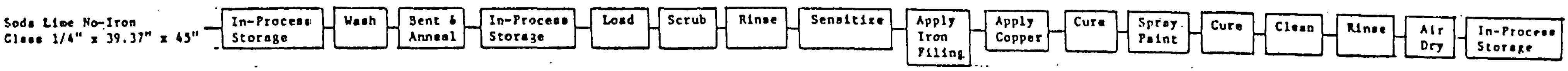
6.5.2 Mirror--Slab Glass

Figures 6.39
6.40
6.41

Sodalime no-iron glass in .200 in. x 39.37 in. x 45 in. slabs is transported from in-process storage to the washer area. There each piece of glass is manually removed from its crate, loaded onto the washer conveyor, and washed. After washing and drying, the glass is sent to a bending and tempering furnace where it is thermally sagged on solid parabolic contour fixtures. Daily checks of the contour are made using a checking fixture and feeler gauge. After bending, the slab glass is transported to the silvering operation.

Each of seven continuous belt conveyor silvering lines is loaded using robots; and the slabs are then mechanically scrubbed and rinsed. Next, sensitizer and silver are sprayed to the top surface followed by a rinse, iron filing, and copper and dried. Then the glass is cleaned, rinsed, and air-dried. The silvered glass is unloaded by robot to a skid which is transported by fork truck to the bonding area.

FIGURE 6.39: MIRROR - SLAB GLASS



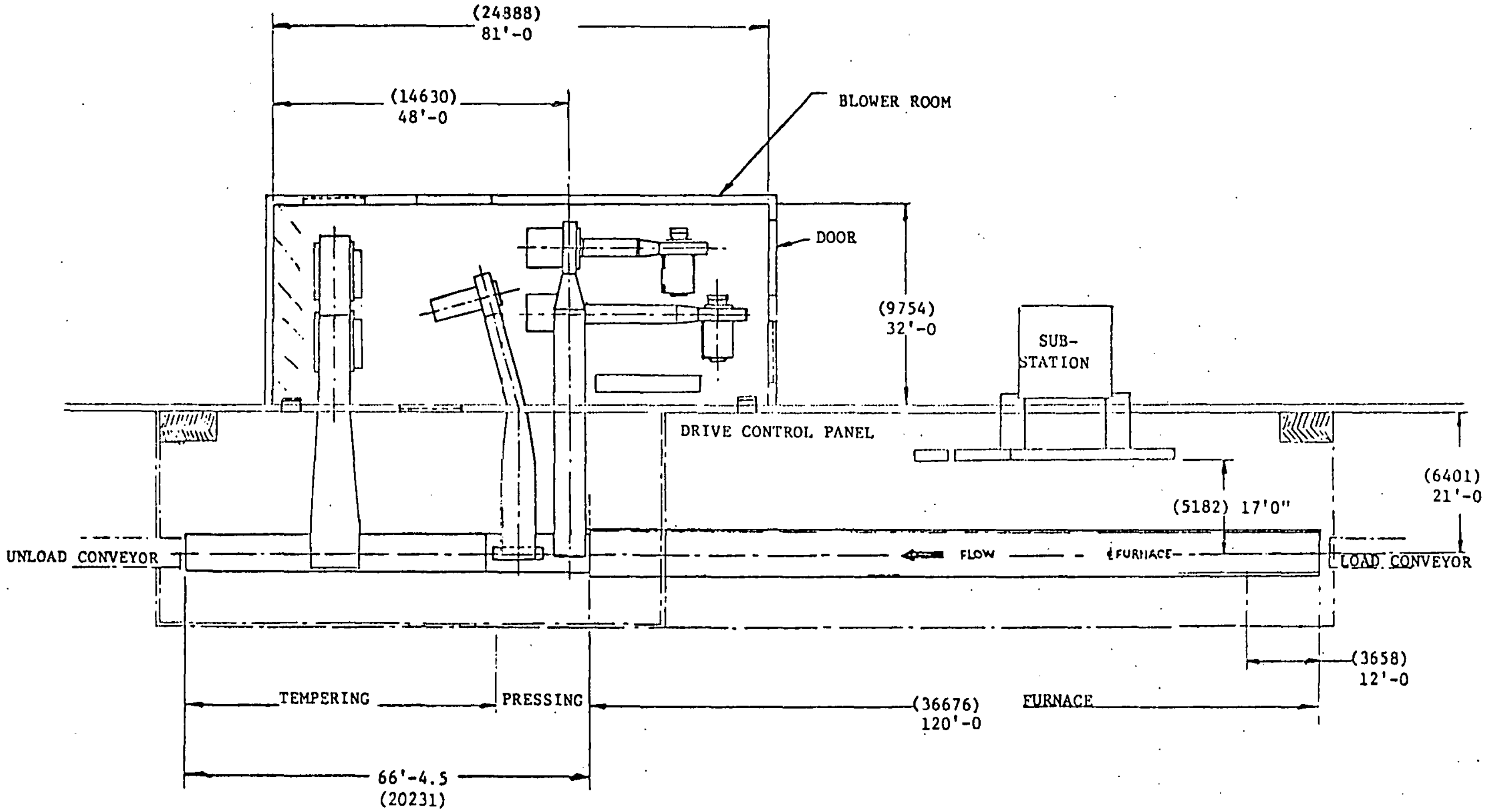
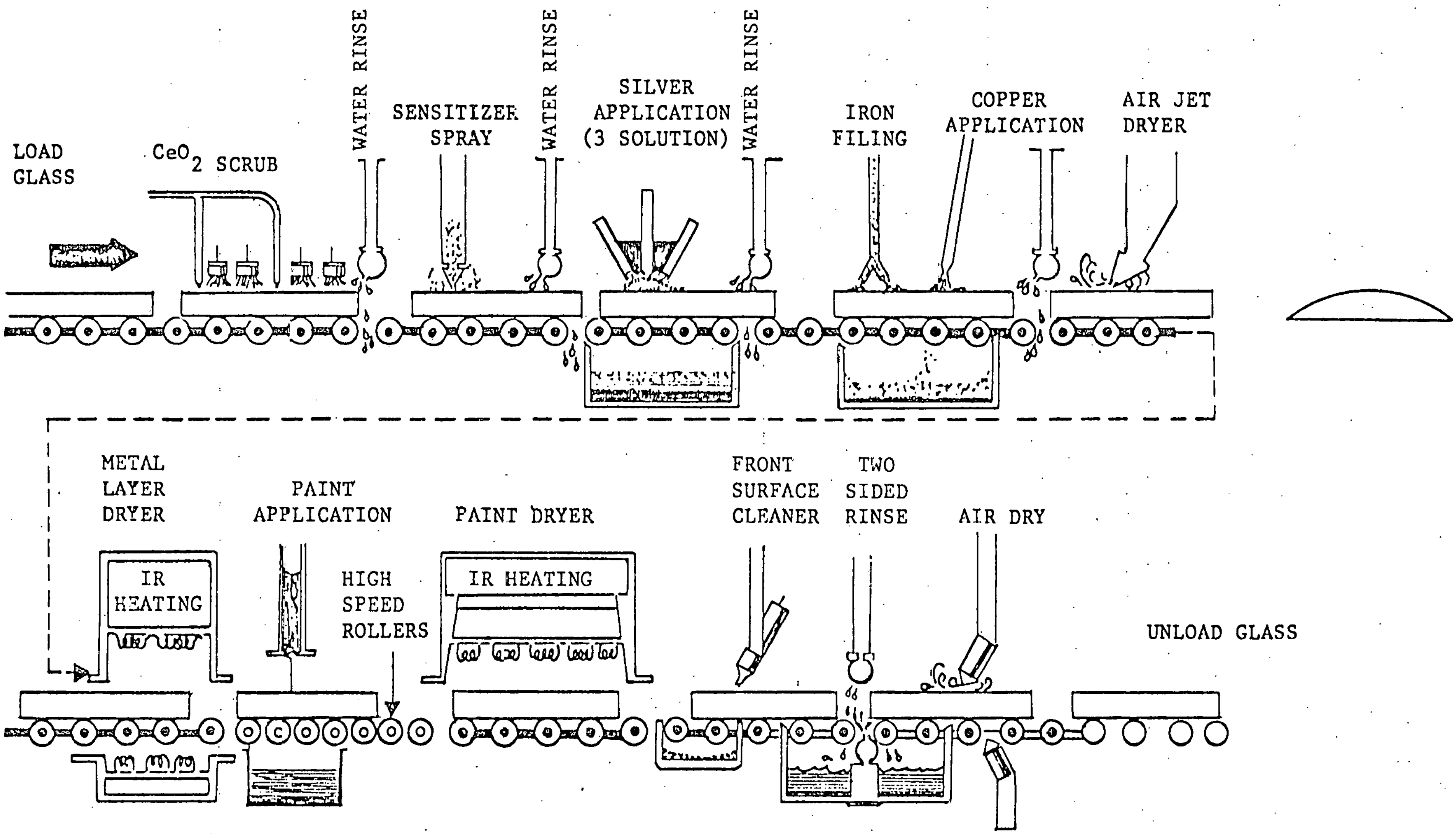


FIGURE 5.40: THERMAL FORMING OF GLASS

FIGURE 6.41: MIRRORING OF GLASS



6.5.3 Cross Frame Saddle

Figure 6.42

Coils of .035 in. x 9 in. Galvalume drawn quality steel are transported from in-process storage to a 500-ton straight-side press with decoiler and straightener.

At the press, Cross Frame Saddles are blanked, flanged, formed, restruck, and cam-trimmed in a 5-stage progressive die. Following random dimensional inspection, Cross Frame Saddles are returned to in-process storage.

6.5.4 Cross Frame - Sheet Steel

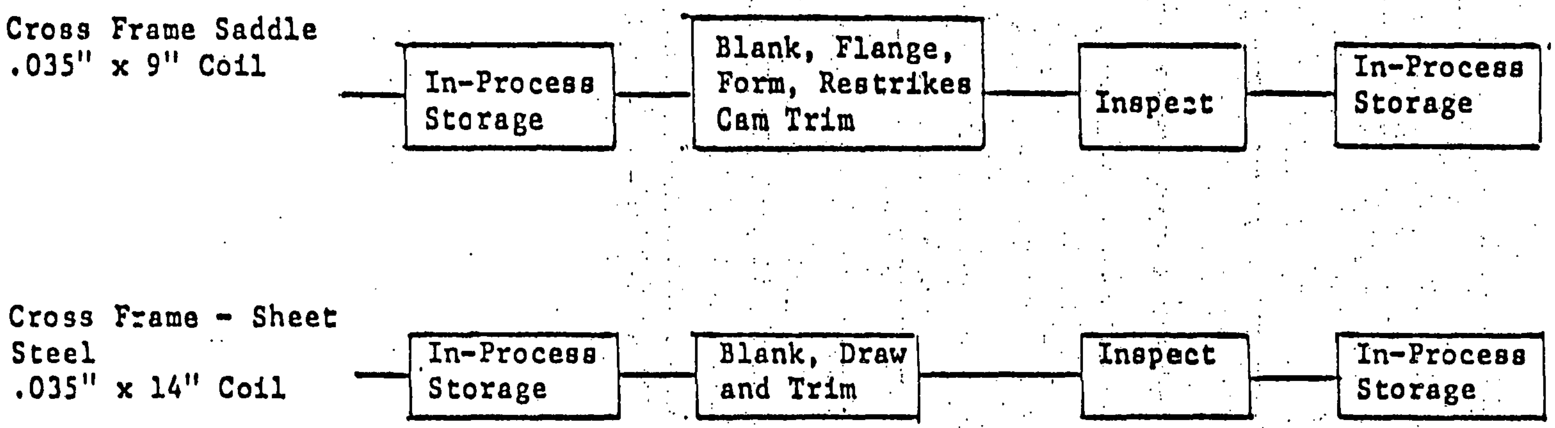
Figure 6.42

Coils of galvalume drawn quality steel, .035 in. x 14 in., are delivered by special fork truck to an 800-ton straight-side punch press with decoiler and straightener.

There Cross Frames--Sheet Steel are blanked, drawn, and trimmed in a 3-stage progressive die. After the frames are randomly inspected, they are transported in 6 ft. x 6 ft. wire mesh bins to in-process storage.

FIGURE 6.42: CROSS FRAME SADDLE

CROSS FRAME SHEET STEEL



6.5.5 Receiver Support--Midway (Glass Laminate or Slab Trough)

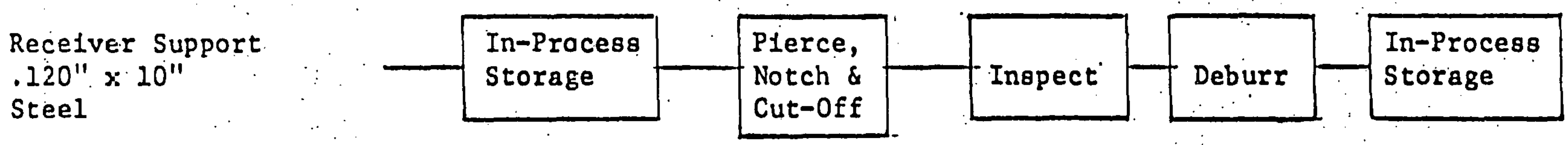
Figure 6.43

Coils of .120 in. x 10 in. Galvalume steel are transported by fork truck to a 100-ton punch press with decoiler and straightener.

At this punch press, Receiver Supports are pierced with 3 slots, given a semicircular notch (10 in. radius), and cut off to length.

After random inspection, the Receiver Supports are taken to a 100 cubic foot/hour deburring unit, where they are deburred, and then the Receiver Supports are delivered to in-process storage.

FIGURE 6.43: RECEIVER SUPPORT - MIDWAY (GLASS LAMINATE OR SLAB TROUGH)



6.6 PROCESS ANALYSIS--100 TO 500 MODULES PER YEAR (LOW VOLUME)

Design: Thin Annealed Glass and Steel Laminate on Steel Frame Panel

NOTE:

As previously indicated in subsection 6.2, it is recognized that initial concentrating collector production volumes are likely to be less than 1,000 modules per year, since new and even established manufacturers may seek to minimize their capital commitments.

Although 1,000 modules per year was the lowest volume specified for the CSERC study, CSERC also developed a minimum investment process to meet the anticipated need for startup assistance in producing small volumes.

This process, appropriate for production of 100 to 500 modules per year, is covered in the following subsection.

The process for low volume production includes operations which must be performed in-plant because of their critical importance to the efficient functioning of the concentrating collector in the field. These operations are:

- Lamination of the reflective surface (mirror) to the frame panel.
- Assembly of the frame panel supports to the torque tube.
- Assembly of the frame panel with reflective surface to the torque tube assembly.

The low volume process contains operations for which only a small investment is required to achieve maximum value-added benefits and profits. Typical of components/processes are pylon and frame panel support weldments, utilizing arc welding equipment that requires a relatively modest investment.

Prospective manufacturers are encouraged, of course, to integrate any applicable facilities or equipment they have available such as punch presses and milling machines.

6.6.1 80 Ft. Collector Module Assembly

Figure 6.44

The following are received and unloaded from the truck using a fork truck or gantry crane:

A. Single Pylon, Receiver Tube Support and Flexural Plate Assembly
B. Double Pylon, Receiver Tube Support and Flexural Plate Assembly
C. Drive Pylon and Mechanism
D. Receiver and Receiver Tube Fittings
E. Receiver Tube Support - Midway Sheet Metal Trough
F. Torque Tube and Reflector Assembly
G. Flex Hose

Items A, B, and C are unpacked and positioned on their assigned foundations over the 2 in. spacer blocks and the foundation anchor bolt using a 2-ton fork truck with special boom attachment (Figure 6.10).

A laser/optical sighting target fixture is positioned to each flexural plate. Using laser beam instrumentation, pylons are aligned for elevation and parallelism. Equidistance between pylons is established with a spacer bar located by pins through manufacturing holes in flexural plates. Foundation bolts with two nuts are used to adjust elevation. Spacer blocks (50 mm high) are inserted between the foundation and the pylon base to permit tilting if required, so the "bottom" nut is moved to the proper height. The four 3/4 in. foundation nuts on the single pylon, the drive pylon, and the double pylon are then torqued.

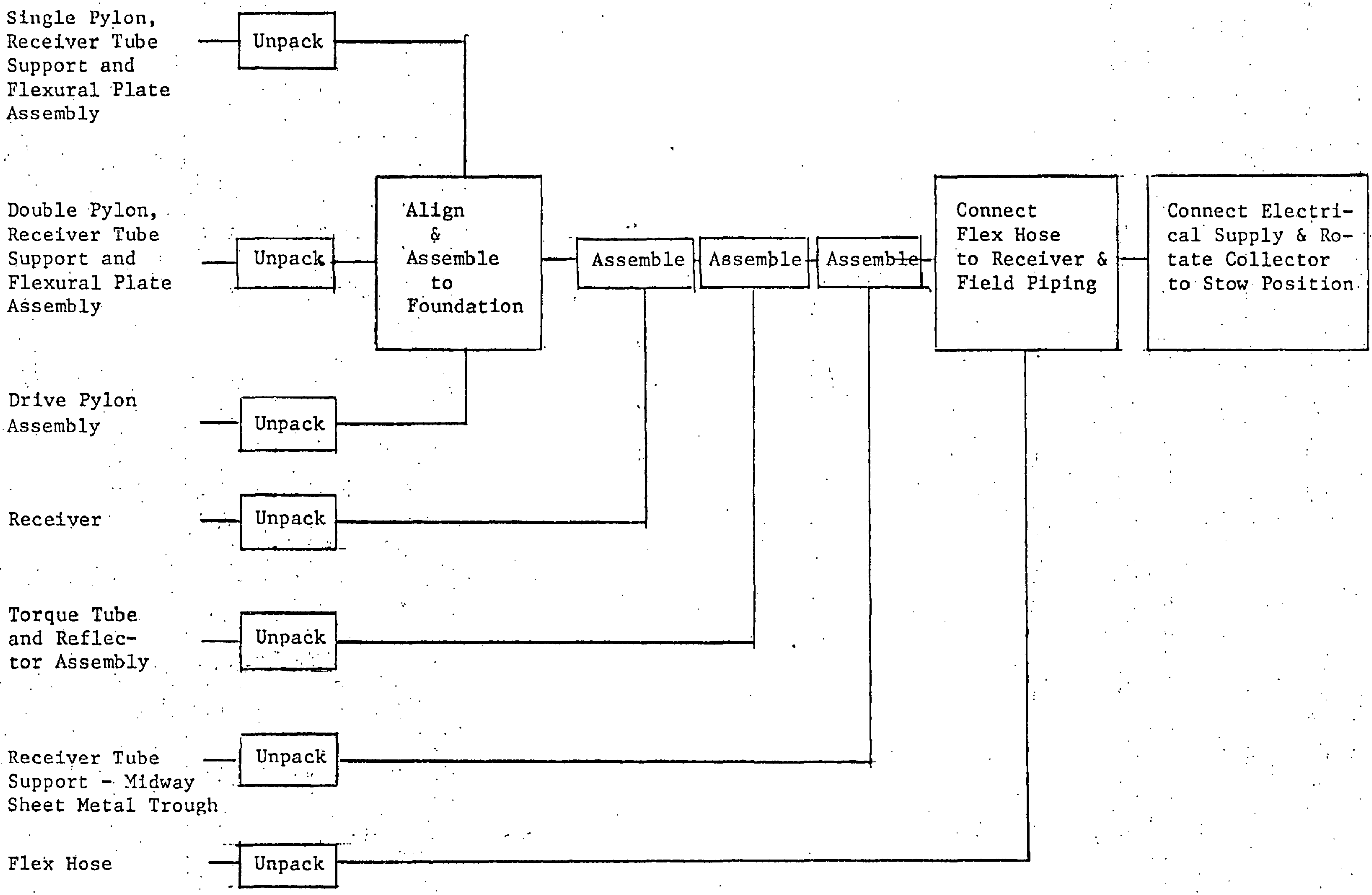
Using 16 jack screw type supports, 9 receiver sections (including the short section at the drive pylon) are prepositioned in the cradles of these supports, and the receiver tube sections are connected to each other using pipe fittings. Before connecting the sections, the fitting of each receiver section is placed in the bearing.

Using a fork truck or gantry crane with specially designed slings to raise, lower, or rotate the torque tube and reflector assembly, the two torque tube flanges are brought to the flexural plates. Dowel pins and bolts are inserted, and the bolts connecting torque tube flanges to the flexurals are torqued.

The Receiver Tube Support - Midway Sheet Metal Trough items are assembled by inserting each leg into holes on the "U" clamps. These are found on the Reflector Support Assemblies, located on the torque tube midway between the pylons. Flex hoses are connected to receivers, and the ends of terminal receivers are connected to field piping. The drive motor is connected to electricity, and the collector is rotated.

(NOTE: In the 100-500 modules per year process, this procedure is followed in the plant for one module assembly each week. The same weekly frequency is maintained up to a production volume of 1,000 modules per year. When 5,000 modules are produced annually, the procedure is followed daily. With volumes of 25,000 and 100,000 per year, the same procedure occurs each work shift.)

FIGURE 6.44: 80 FT. COLLECTOR MODULE ASSEMBLY



6.6.2 Glass/Steel Reflector Laminate

Figure 6.45

Silvered glass sheets, .040 in. x 39.37 in. x 45 in., of annealed low iron glass (mirrors) are transported in their shipping container by fork truck to the bonding area. Similarly, .030 in. x 39.37 in. x 91.5 in. sheets of cold rolled Galvalume steel (skin panels) are taken on skids by fork truck to the bonding area. Frame panels are also transported on skids by fork truck to the bonding area. Mirrors, skin panels, and frame panels are washed and dried in a washer.

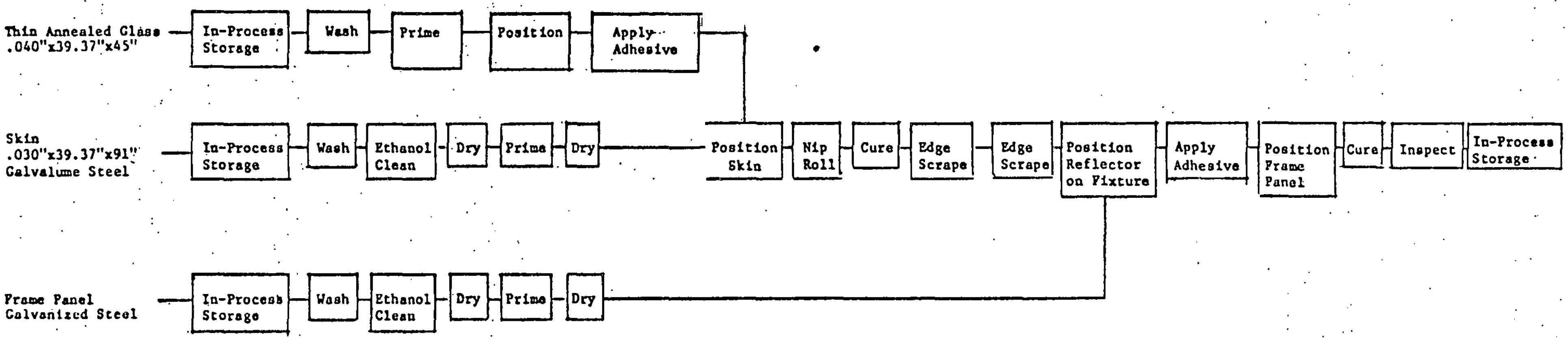
Next, the bonding surface areas of the skin and frame panels are cleaned with Ethanol. They are then hand spray primed with Goodyear Primer #6025 (or equivalent) and dried in an infrared oven. A 2-component adhesive (Goodyear 6000 and 6010 G Series or equivalent) is sprayed to the mirror panels.

Steel sheet is positioned to mirror panels, and the laminate is passed through nip rollers. Each laminate is then heat-cured in an infrared oven for 3 minutes, after which the adhesive squeeze-out is scraped manually from the edges.

The laminates are positioned on a solid parabolic fixture. The steel skin surface of the laminate is hand sprayed with a 2-component adhesive (Goodyear 6000 and 6010 G Series or equivalent). Using a hoist, the frame panels are located over the laminate. An infrared oven heats the assembly, which is allowed to remain for 3 minutes to cure the adhesive.

The assemblies are then unloaded to a skid and delivered to in-process storage.

FIGURE 6.45: GLASS/STEEL REFLECTOR LAMINATE



6.6.3 Torque Tube Assembly

Figure 6.46

Torque tube flanges (purchased), 20 ft. lengths of 7 in. x .157 in. wall low carbon welded steel tube (purchased), and reflector support weldments are transported to the welding fixture area.

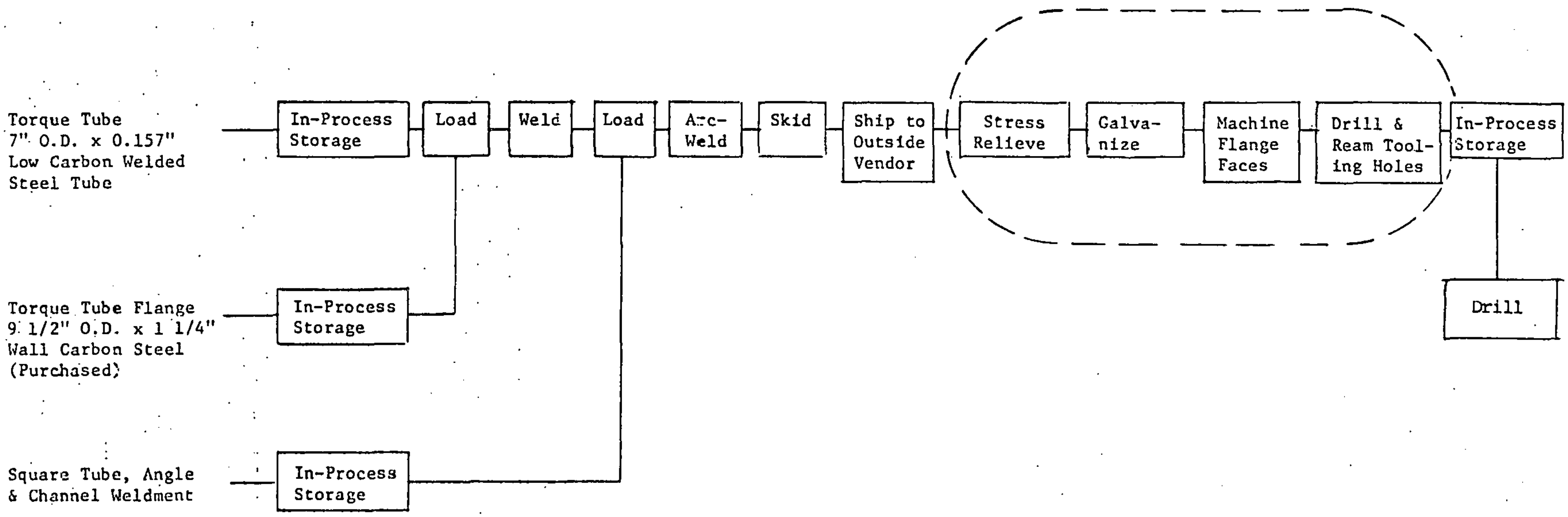
One torque tube flange is positioned to each end of the torque tube. The fixture is rotated and the flanges are arc-welded by hand to the torque tube around its circumference.

Next, the seven frame panel support weldments are positioned to locating pads and clamped. A 6 in. bead arc-weld is made with a manual torch on each side of the channels on the seven supports. The midway sheet metal trough receiver supports are assembled to the frame panel supports with 4 screws prior to welding.

The assembly is removed to a special shipping skid for shipment to outside vendors. In that position, the assembly is sand blasted and galvanized. The faces of the flanges are machined to assure parallelism. Two holes are drilled and reamed in each flange to provide manufacturing locating holes for subsequent operations. Using these holes as locators for a drill fixture, the remaining 6 holes are drilled.

The assembly is then returned to in-process storage until needed for its assembly to the reflector.

FIGURE 6.46: TORQUE TUBE ASSEMBLY



6.6.4 Torque Tube and Reflector Assembly

Figure 6.47
Figure 6.48

The glass-steel reflector laminates are transported from in-process storage and loaded onto a parabolic fixture which uses pads in a parabolic contour. The torque tube assembly is brought from in-process storage.

Using an overhead hoist, the torque tube assembly is lowered to a position where two locating pins on either end can be inserted into the manufacturing/locating holes in the flanges.

The frame panel support weldments are attached to the frame panel cage nuts in the doublers with 4 screws per panel, using .005 in. shims where required to eliminate gapping.

After the locator pins are withdrawn, the slope error and the focus point and focus line are inspected using a Laser Ray Tracer. After this inspection, the assembly is transported to the final assembly area with an overhead crane or fork trucks with special forks.

FIGURE 6.47: TORQUE TUBE & REFLECTOR ASSEMBLY

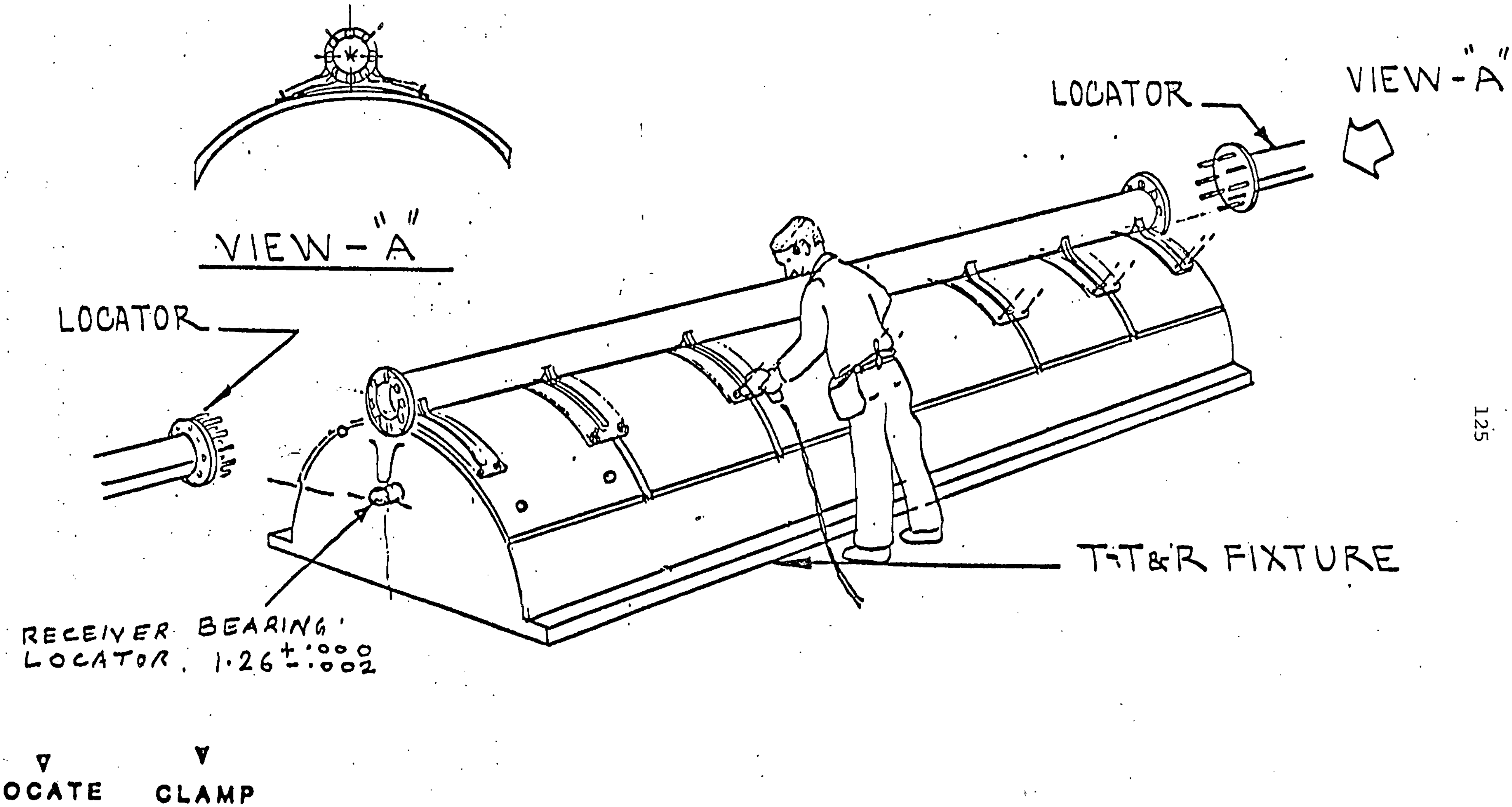
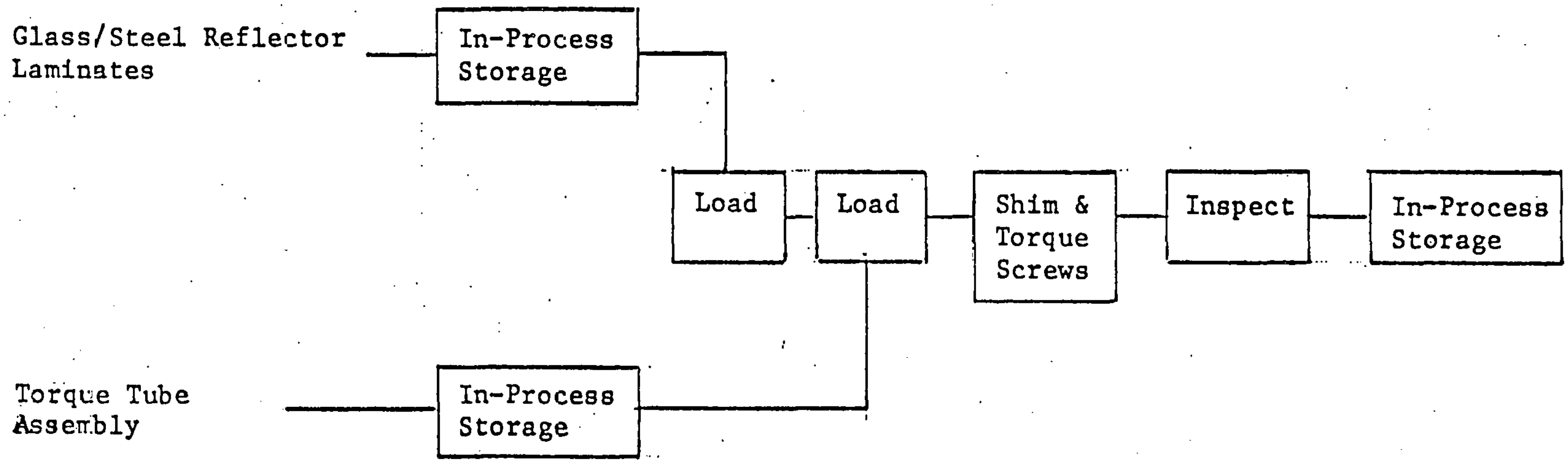


FIGURE 6.48: TORQUE TUBE AND REFLECTOR ASSEMBLY



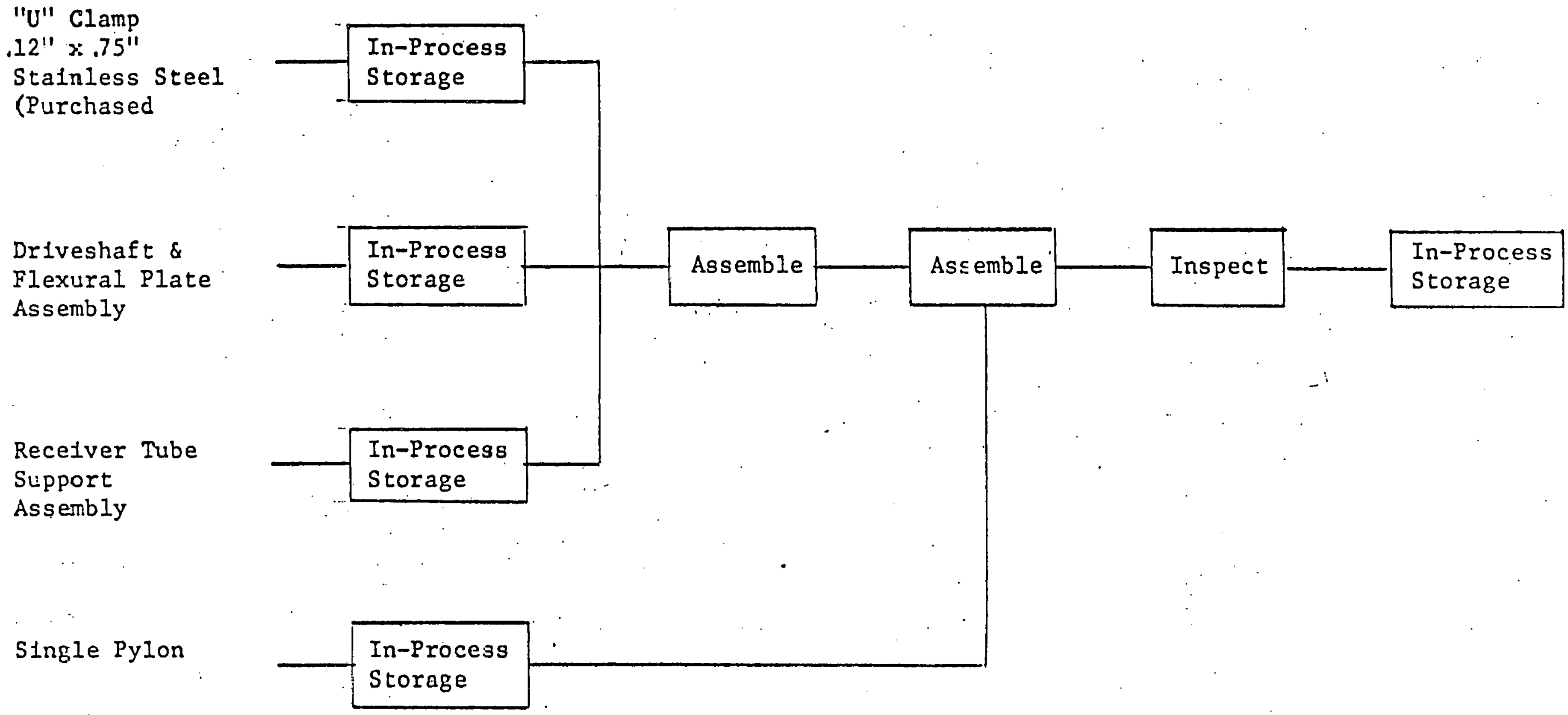
6.6.5 Single Pylon, Receiver Tube Support and Flexural Plate Assembly

Figure 6.49

The Receiver Tube Support, the Driveshaft and Flexural Assembly, and the "U" clamp are taken to an assembly fixture. There the "U" clamp is loose-assembled to the Flexural Assembly with 2 nuts and bolts through oversize holes. The Receiver Tube support legs are inserted into holes in the "U" clamp. After the dimension from the manufacturing tooling holes to the Receiver Tube Support Bearing hex hole is established, the bolts are torqued, 2 dowel pins are driven, and the assembly is transported to in-process storage.

The Single Pylon and the Flexural Assembly with Receiver Tube Support are moved from in-process storage to an assembly fixture. Then the pillow block is secured to the pylon with two 5/8 in. screws. After assembly, a torque check is randomly made, and the assembly is transported to finished goods stores.

FIGJRE 6.49: SINGLE PYLON, RECEIVER TUBE SUPPORT AND FLEXURAL PLATE ASSEMBLY



6.6.6 Single Pylon

Figure 6.50

ASTM-A36 Angle steel, 3 in. x 3 in. x 1-1/4 in., in 19.2 ft. lengths, is transported to a power saw. The steel is cut into 25 angles and deburred in a 100 cubic foot/hour continuous deburring unit followed by drilling. The steel angles are then taken to in-process storage.

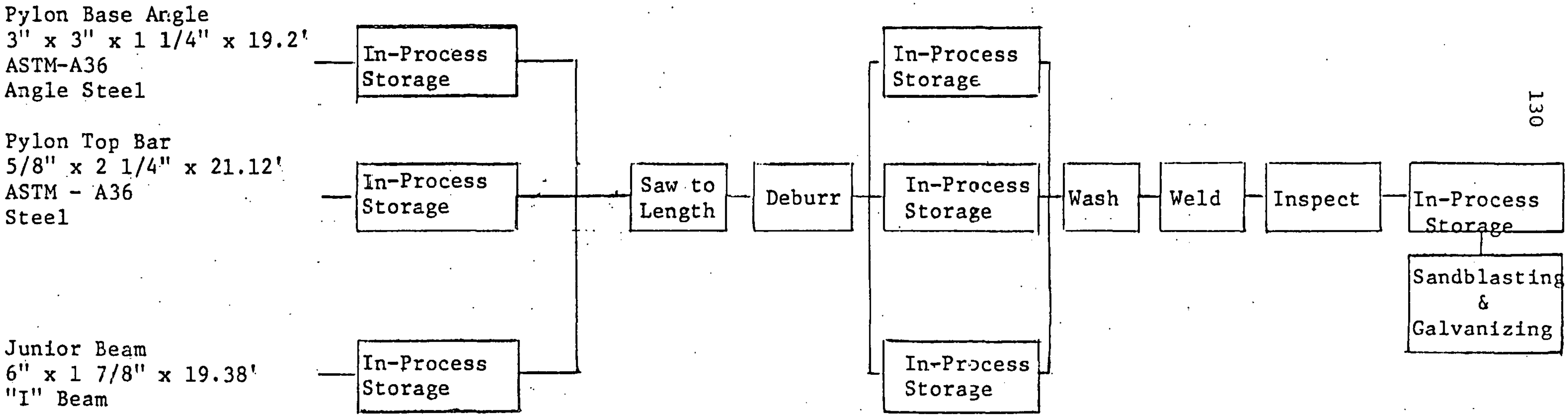
Top Bar ASTM-A36 steel, 5/8 in. x 2-1/4 in., in 21.1 ft. lengths, is transported to a power saw and cut into 30 pieces. The Top Bars in wire mesh bins are delivered to a drill press where two 5/8 in. holes are drilled and tapped with a 11-UNC thread. The Top Bars next are taken to a 100 cubic foot/hour deburring unit. After deburring, they are sent to in-process storage.

"I" beam Junior Beam ASTM-A36 steel, 6 in. x 1-7/8 in., in 19.38 ft. lengths, is transported to a power saw and cut into 8 pieces. Next, both ends are milled and deburred on a pedestal grinder. The finished parts are carried in 4 ft. x 4 ft. x 4 ft. wire mesh bins to in-process storage.

All the above parts go from in-process storage to a 3-stage washer. After washing, they are taken to the welding area. The parts are located and clamped in a fixture and manually arc-welded with fillet weld. Finished single pylon weldments are returned to in-process storage. From there they are shipped to an outside vendor for hot dip galvanizing (2.0 oz. per square foot).

When the galvanized weldments return, they are delivered to in-process storage.

FIGURE 6.50: SINGLE PYLON



6.6.7 Driveshaft and Flexural Plate Assembly

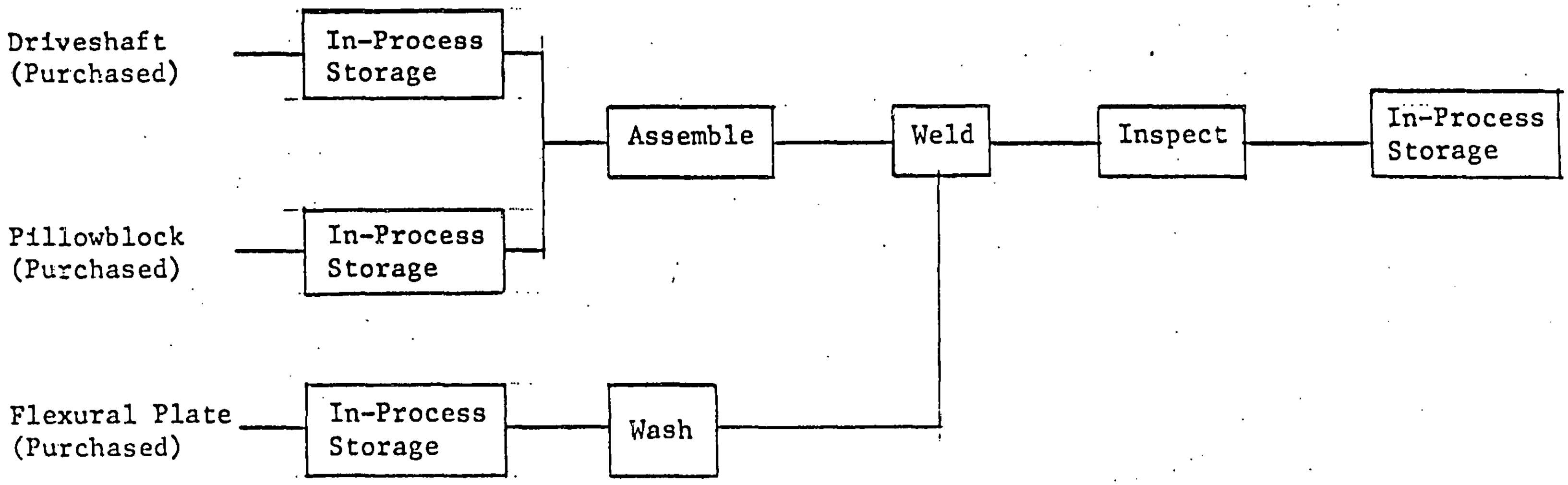
Figure 6.51

The Pillow Block and the Driveshaft, and (after washing in a 3-stage automatic washer) the flexural plates are transported to a welding fixture where 2 flexural plates are hand arc-welded to the driveshaft.

After welding, the assemblies are 100% inspected visually and subjected to nondestructive testing on an NDT machine. The assemblies then go to in-process storage. From in-process storage, the assemblies are shipped to an outside vendor for sandblasting and galvanizing.

When the galvanized assemblies return from the outside vendor, 6 holes are hand-drilled and reamed using a fixture.

FIGURE 6.51: DRIVESHAFT AND FLEXURAL PLATE ASSEMBLY



6.6.8 Receiver Tube Support Assembly

Figure 6.52

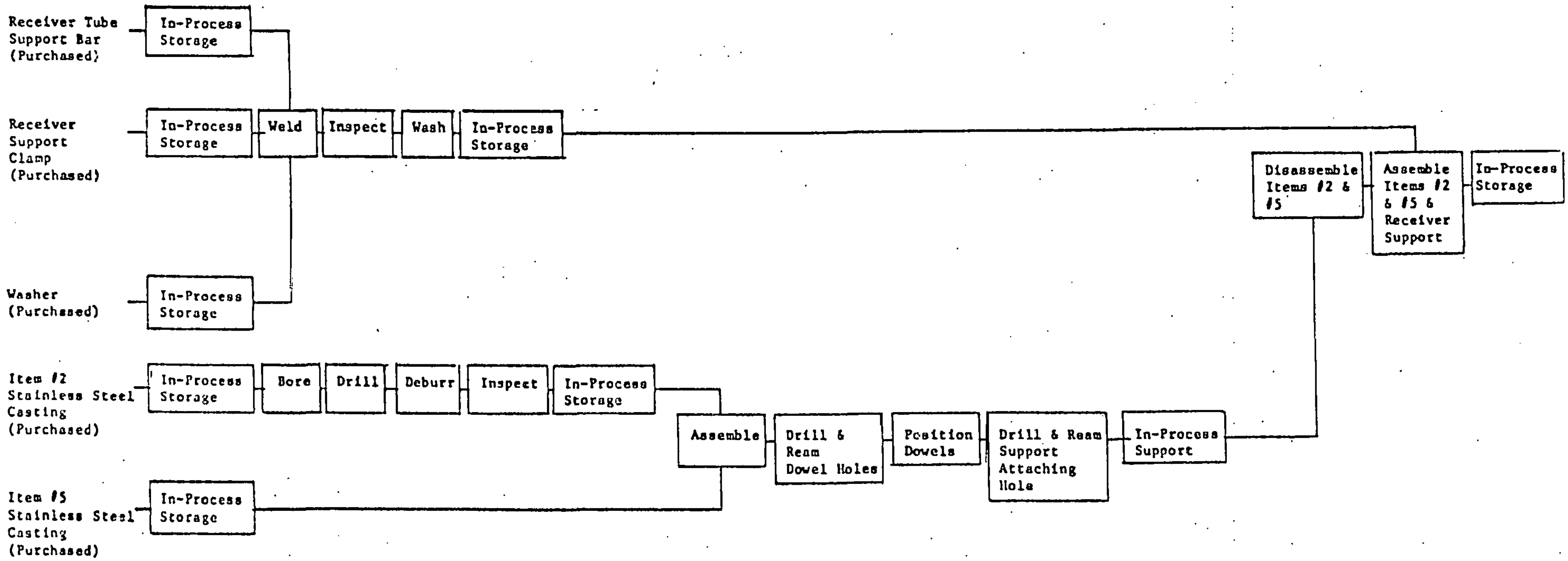
The support bar, clamp, and washers are transported from in-process storage to an assembly fixture where washers and clamps are hand arc-welded to the support bar. Then the Receiver Tube Support Assembly is inspected visually and by nondestructive testing. Following washing, the assembly is transported to in-process storage.

Item #2 stainless steel casting is taken to a lathe where a hole is bored to ± .002 in. tolerance. The casting next goes to a drill press where 4 holes are drilled and tapped. The casting is inspected, deburred, and sent to in-process storage.

Items #2 and #5 (purchased) are assembled with 4 screws. Dowelling holes are drilled and reamed on a drill press and dowels are inserted manually. Next, the transverse Receiver Tube Support Assembly hole is drilled and reamed on a drill press. Afterward, the assembly is taken to in-process storage.

The Rotating Receiver Tube Bearing and the Receiver Tube Support are moved from in-process storage to a 2-station indexing table fixture. There Items #2 and #5 are disassembled. The Receiver Tube Support is assembled to the transverse hole and screws are inserted automatically and driven. The assembly then is transported to in-process storage.

FIGURE 6.52: RECEIVER TUBE SUPPORT ASSEMBLY



6.6.9 Double Pylon Weldment

Figure 6.53

ASTM-A36 steel, 3/8 in. x 4 in. x 4 in., in 20 ft. lengths, is taken to a power saw and cut into 21 in. long cross angles. In 4 ft. x 4 ft. x 4 ft. wire mesh bins, the cross angles are transported to a drill press where two 1/4 in. holes are drilled. The parts are then delivered to a 100 cubic foot/hour deburring and washing unit. After deburring and washing, the parts go to in-process storage.

The 5 in. flats (purchased) and the cross angles are taken from in-process storage to a welding fixture. The cross angles are hand arc-welded to the 5 in. flats with 32 in. of weld. Following 100% visual inspection and random nondestructive testing, the assemblies are returned to in-process storage in 4 ft. x 4 ft. x 4 ft. wire mesh bins.

ASTM-A36 steel, 5/8 in. x 2-1/4 in., in 21.12 ft. lengths, for use as top bars, is transported to a power saw. The steel is cut into thirty 8-1/2 in. lengths. Next, the top bars are transported in 4 ft. x 4 ft. x 4 ft. wire mesh bins to a drill press. Then two 17/32 in. holes are drilled and tapped (11 UNC). The parts are deburred and washed in a 44 cubic foot/hour continuous deburring and washing unit. Finally the parts are transported to in-process storage.

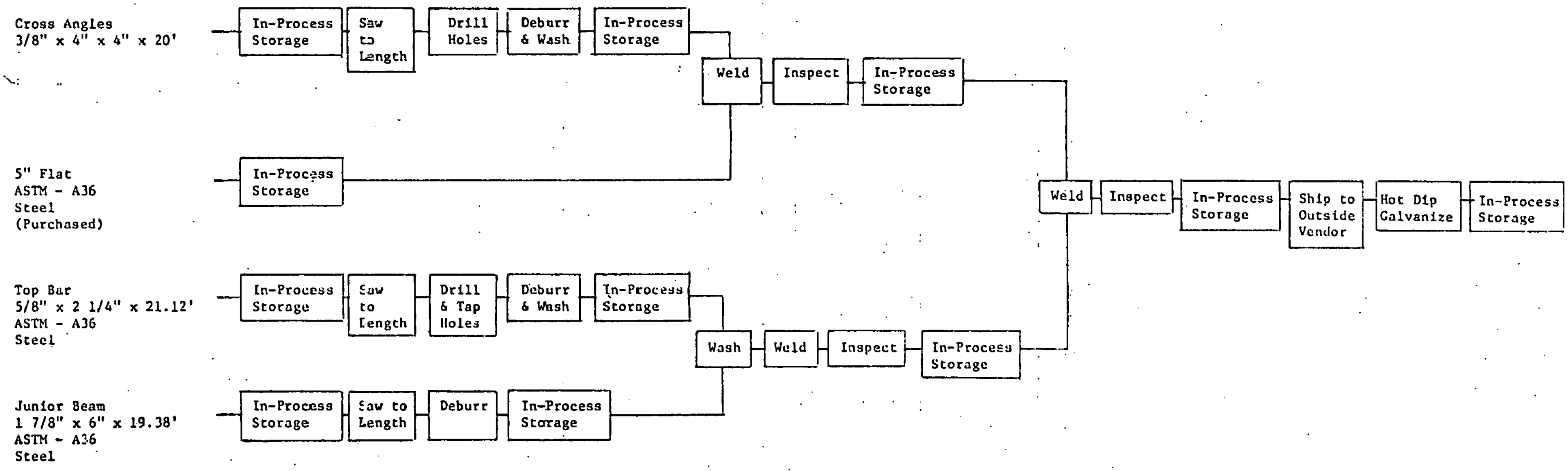
"I" beam Junior Beam ASTM-A36 steel, 6 in. x 1-7/8 in., in 19.38 ft. lengths, goes to a power saw where it is cut into 8 pieces. Next, both ends are deburred on a pedestal grinder. The parts in 4 ft. x 4 ft. x 4 ft. wire mesh bins are delivered to in-process storage.

The top bar and the junior beam go from in-process storage to a welding fixture where the top bar is manually arc-welded to the junior beam. After a 100% visual inspection and a random nondestructive weld test, the weldments return to in-process storage.

The 5 in. flat/cross angle weldment and the top bar/junior beam weldment move from in-process storage to a welding fixture. Then they are clamped and manually arc-welded with 34 in. of fillet weld. Following 100% visual inspection and random nondestructive inspection, the Double Pylon Weldment goes to in-process storage. From there it is shipped to an outside vendor for hot dip galvanizing (2.0 oz. per square foot).

When they are returned from galvanizing, the weldments once more go to in-process storage.

FIGURE 6.53: DOUBLE PYLON WELDMENT



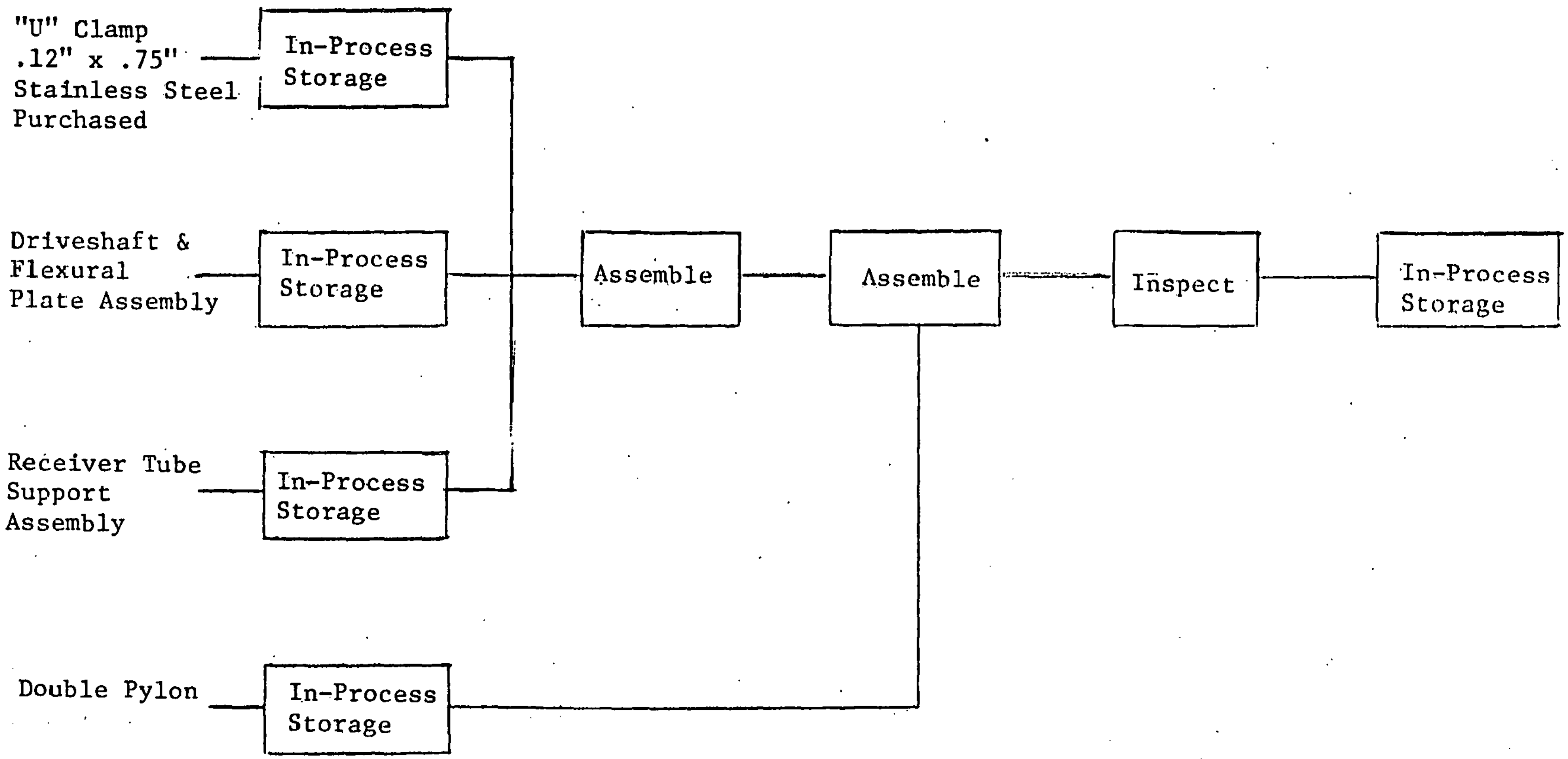
6.6.10 Double Pylon, Receiver Tube Support and Flexural Plate Assembly

Figure 6.54

The Double Pylon Weldment and the Flexural, Pillow Block and Receiver Support Assembly are transported from in-process storage to an assembly fixture. There the Flexural, Pillow Block and Receiver Support Assembly is attached to the Double Pylon Weldment with two 5/8 in. screws.

After random inspection, the assemblies are delivered to finished goods storage.

FIGURE 6.54: DOUBLE PYLON, RECEIVER TUBE SUPPORT AND FLEXURAL PLATE ASSEMBLY



6.6.11 Drive Pylon Assembly

Figure 6.55

Transport 3/4 in. x 12 in. x 13 in. Hot Rolled Steel Top and Bottom Plates (purchased with ground surfaces) to a radial drill. Drill eight 1 in. diameter holes in the plates, deburr manually, and then transfer the plates to in-process storage using 4 ft. x 4 ft. x 4 ft. wire mesh bins.

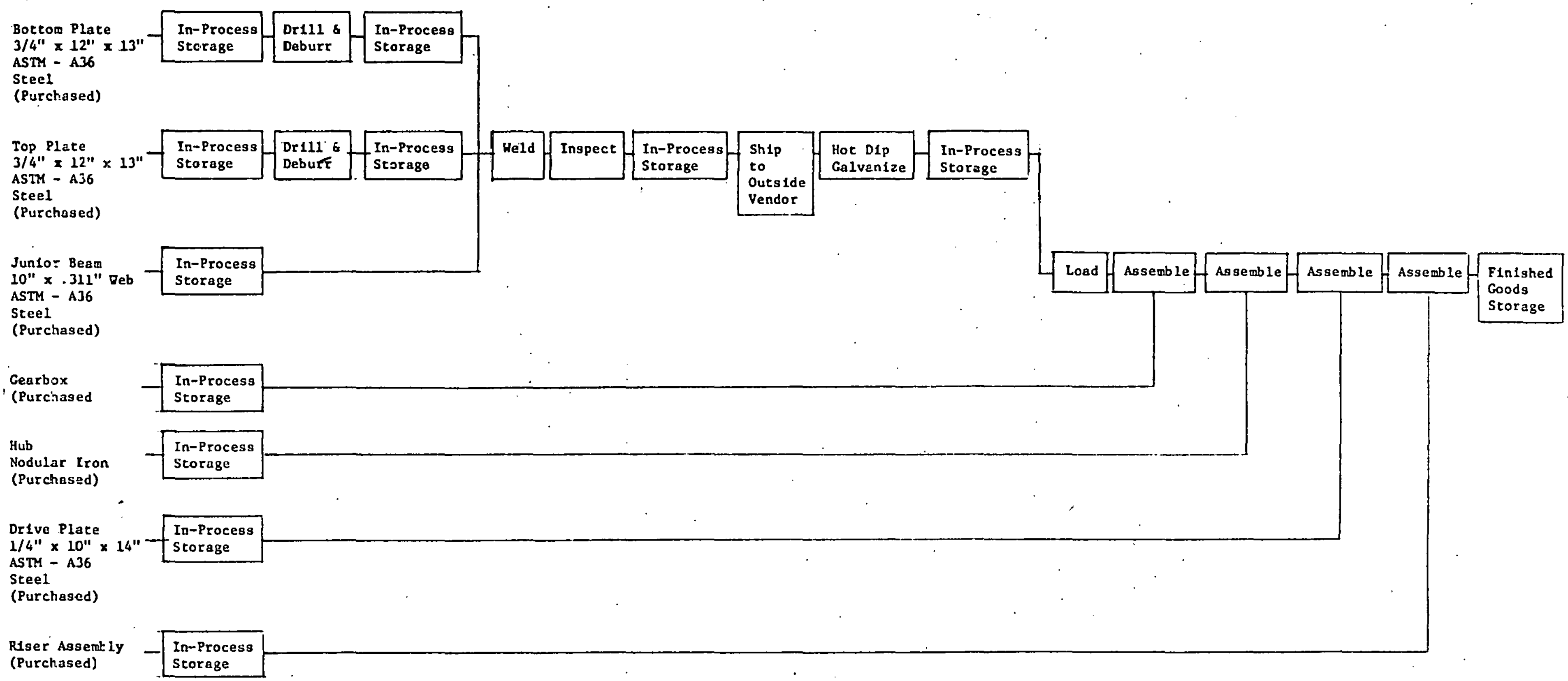
Transport Top and Bottom Plates and 10 in. x 10 in. x 36 in. (.311 in. web) Junior Beam to a welding fixture. Locate and clamp the parts on the fixture and hand arc-weld with 40 in. of weld. After 100% visual and random nondestructive inspection, deliver the weldments to in-process storage. From there, ship them to an outside vendor for galvanizing (2 oz. per square foot). When the weldments return, they are taken again to in-process storage.

The Drive Pylon Assembly, gear box, drive plates, hubs, risers, and standard parts are transported to a subassembly fixture for the following work:

- Position in fixture using a jib crane.
- Use a jib crane to position the gear box to the top plate of the pylon. Insert 4 bolts/washers/nuts and torque.
- Position hubs on each end of the gearbox shaft and insert keys.
- Position drive plates and riser to hubs. Using a special hydraulic tool, drive dowels on inside of riser and outside of hub, then attach with nuts and bolts.

When this work is accomplished, transport the Drive Pylon Assembly to finished goods storage.

FIGURE 6.55: DRIVE PYLON ASSEMBLY



6.6.12 Square Tube, Angle and Channel Weldment

Figure 6.56

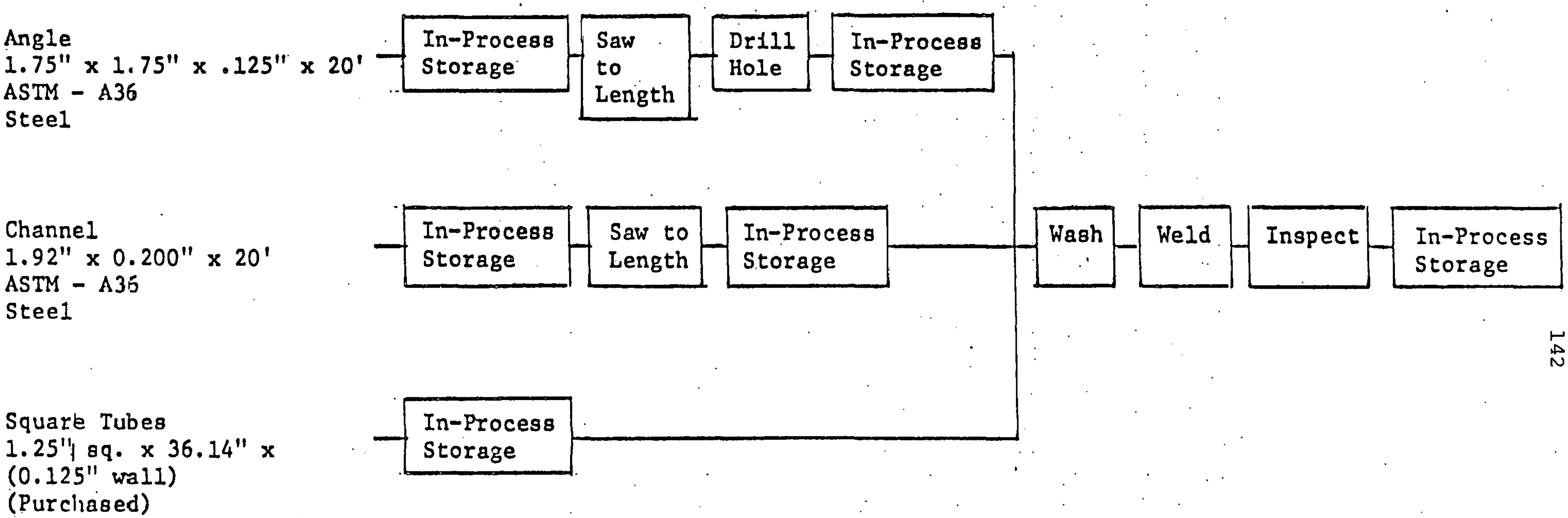
Angles are made from 20 ft. sections of 1.75 in. x 1.75 in. x 0.125 in. ASTM A36 steel. The steel is taken to a Marvel saw (or equivalent) and sawed to length. Next, two 3/16 in. holes are drilled into one leg of each angle, and the angles are transported in tote pans to the assembly area.

Twenty foot sections of channel, 1.92 in. x .200 in., are taken to a Marvel saw (or equivalent) and sawed into 8 in. lengths. These pieces are delivered in wire mesh bins to the assembly area.

Square tubes (1.25 in. sq. x 36.14 in. x 0.125 in. wall [purchased]) are brought to the assembly area in shipping containers.

The parts are washed in a 3-stage washer and transported to the welding area. The parts are located and clamped in fixture and hand arc-welded into an assembly. The weldments are then taken in wire mesh bins to in-process storage.

FIGURE 6.56: SQUARE TUBE, ANGLE AND CHANNEL WELDMENT



7.0 COSTING AND SELLING PRICE ESTIMATES

7.1 THE COSTING APPROACH

One objective of this study is to derive realistic cost estimates for manufacturing and installing the PPT Concentrating Collector as described in preceding sections. Direct equipment, material, and labor requirements were derived as an integral part of the manufacturing process analysis. The manufacturing process analysis also provides direct manufacturing floor space and material handling requirements for each annual volume.

These direct manufacturing requirements together with current unit prices (costs) provide the necessary input to the Solar Array Manufacturing Industry Costing Standard (SAMICS), a computerized methodology which generates detailed as well as summary estimates of all direct, indirect, and capital costs. SAMICS also calculates a "normative selling price" which yields a predetermined rate of return on investment.

Freight and installation charges per collector are estimated manually and are added to the manufacturer's selling price to obtain an estimated installed cost.

7.2 INTRODUCTION TO SAMICS COSTING

SAMICS methodology, developed at the Jet Propulsion Laboratory, has been convincingly documented and well-reviewed. (1.2) SAMICS has been effectively applied to the costing of concentrating collectors by CSERC and Pacific Northwest Laboratory. (3,4) Annotated references on SAMICS will be found in the final References section of this report.

CSERC in its original application of SAMICS used the methodology to assess manufacturing costs of alternative systems and processes and also to help prove the validity of SAMICS in this application. Reducing costs and expanding production in the solar industry are twin goals that have become an important part of the U.S. energy program. SAMICS offers a valuable tool to help design cost-effective processes and to introduce the efficiencies of mass production and automation. Before the solar manufacturing industry can expand on the scale projected, sophisticated production costing, design engineering, budgeting, and pricing must take place to give potential manufacturers the facts and figures required for major capital investments and go-ahead production decisions.

The CSERC experience with SAMICS shows that this methodology has the flexibility, versatility, and accuracy needed in the solar industry. SAMICS facilitates decision-making and helps in the generation of analytically correct data. It guides developing production operations in avoiding mistakes, thus saving money and time.

Developed as part of the Low-Cost Solar Array Project at the Jet Propulsion Laboratory, SAMICS has proven applicable to any process industry. It is especially helpful to new industries with limited experience in commercial scale production, since it supplies an effective way to evaluate and compare different processes or sequences.

7.3 THE SAMICS MODEL

SAMICS is designed to assess the relative costs of alternative processes or process sequences in manufacturing. This was particularly relevant in carrying out the CSERC assignment to determine mass production feasibility of concentrating collectors.

The SAMICS model consists of the following four components:

1. The Manufacturing Process model translates descriptions of specific manufacturing processes required to produce a single product into direct capacity requirements for a specific volume of output in a steady state or long-run scale of operation. The required input data are given in the Process Description (see Volume II).

2. The Factory Construction and Staffing Algorithm generates the indirect facilities and staff requirements by skills on the basis of the direct requirements determined by the manufacturing process model.

3. The Capital Requirements model estimates the value of land, facilities, equipment, and working capital on the basis of each firm's direct and indirect requirements.

4. The Financial model approximates annual operating and overhead expenses of the firm (including profits and taxes) for a steady state manufacturing year.

The final step is a culmination of the foregoing steps. SAMICS applies a set of standard financial parameters to compute the market price required to provide a reasonable return on equity investment.

7.4 SAMICS CRITERIA

SAMICS requires that direct requirements for each manufacturing process step be determined and made available as external input to the SAMICS program. Direct requirements include:

- floor space and other facilities
- machine operators and service personnel
- utilities and plant services
- materials and supplies

In effect, the program substitutes precision for guesswork. SAMIS (acronym for Standard Assembly-Line Manufacturing Industry Simulation based on Release 3) is the computer program for SAMICS. Rather than apportioning indirect requirements on the basis of crude "rule-of-thumb" ratio-to-direct requirements, SAMIS substitutes "stepwise continuous power function" algorithms for inputting indirect requirements on the basis of given direct requirements.

The market price calculated by the program is a normative product price, determined so that the present value of all revenues is equal to the present value of all costs. This is an application of the required rate of return on equity criteria used in making investment decisions. The required rate of return is interpreted as profit which is treated as a cost in the net required revenue calculations.

7.5 IPEG PROGRAM

SAMICS methodology can be broadened to give additional useful information. In addition to assistance with the manufacturing process, direct and indirect requirements, make/buy decisions, costing, and pricing, SAMICS through a recent extension shows improved capability for performing sensitivity analyses and plotting the results. (5,6,7)

The new program, Improved Price Estimation Guidelines (IPEG), allows the user to complete sensitivity analyses at minimal cost.

One worthwhile application of this SAMICS extension is the ability to analyze for the response of total cost and selling price to changes in major material prices and financial parameters such as the rate of return on investment, interest, inflation rates, and taxes.

7.6 CSERC APPLICATION OF SAMICS

The SAMIS Release 3 program which implements SAMICS methodology was adapted by the CSERC staff (2,3) to study mass production of concentrating collectors and to cost the process effectively by adding necessary commodity and personnel requirements to the cost account catalog and by modifying some existing accounts. (See Appendices, Volume II for details.)

The manufacturing requirement for warehouse floor space, for example, was modified to be consistent with the design engineers' plant layout. Warehouse forklift space requirements were altered to include 5- and 7.5-ton trucks in appropriate positions. Overhead cranes were added as a new requirement.

An important modification was made in the in-process inventory time multiplier to avoid overestimating the working capital requirements. Overestimation of working capital will also result in overestimating amortized one-time costs, return on investment, and income taxes. Such overestimating may occur because SAMICS was designed for an assembly-line production plant, whereas in the concentrating collector plant several subassemblies utilize simultaneous processes and their in-process times are not cumulative.

CSERC staff made assumptions and established parameters pertinent to the special requirements of the assignment and the apparatus selected for evaluation. Table 7.1 summarizes the nondefault parameters specified in the analysis for a Southeastern Michigan plant site.

TABLE 7.1: NONDEFAULT PARAMETERS
SOUTHEASTERN MICHIGAN PLANT SITE

Description	Condition
a. Annual volumes (concentrating collectors per year)	1,000 5,000 25,000 100,000
b. Base year	1981
c. Manufacturing Year	1983
d. Construction lead time (1,000 and 5,000 collectors)	1.25 years
e. Construction lead time (25,000 and 100,000 collectors)	2.50 years
f. Useful lifetime of all machinery (no salvage value after 10 years)	10 years
g. Raw material inventory time	.055 years (20 days)
h. In-process inventory time multiplier (1,000 and 5,000 collectors)	.09
i. In-process inventory time multiplier (25,000 and 100,000 collectors)	.15
j. Finished goods inventory time	.003 years (1 day)
k. Accounts receivable turnover time	.123 years (45 days)
l. Accounts payable turnover time	.082 years (30 days)
m. Paid holidays	8
n. Paid vacation days	13.5
o. Average paid absenteeism days	0
p. 2nd shift wage factor	1.0025
q. 3rd shift wage factor	1.0025
r. Other tax rate	2.1
s. Insurance rate	4.0

(These parameters are based on a Southeastern Michigan site in accordance with the location discussion given in subsections 1.5 and 1.6. The reasons for choosing Southeastern Michigan as the concentrating collector factory site are explained.)

7.7 COMPARATIVE COST ANALYSIS OF FIVE REFLECTOR DESIGNS

Section 6.0 describes the five alternate reflector designs evaluated by CSERC. Final computer-derived cost and selling price estimates for the collectors incorporating these reflector designs are given in Table 7.2 for 1,000 and 100,000 annual volumes. These comparative cost data validate the preliminary manual costing analysis which led to the judgment that the original "Chemically strengthened glass and steel laminate on steel frame panel" design for the collector was not the most cost-effective.

The preliminary costing analysis that the thin annealed glass and the thermally sagged glass (slab) designs were least costly is confirmed by computer. Computer results indicate that the slab glass design is significantly lower in cost than the thin annealed glass design at both low and high volumes. Thermally sagged (slab) glass is a no-iron, water-white glass currently available only from foreign vendors. Thin annealed glass is a low-iron glass readily available from domestic sources. Because of glass availability, the following detailed cost analyses highlight the thin annealed glass design. Comparable data are also presented for the slab glass design, paralleling the approach taken in section 6.0 of discussing the manufacturing process for both designs.

TABLE 7.2: COMPARATIVE COST ANALYSIS OF FIVE ALTERNATIVE REFLECTOR CONCEPTS (1981 Dollars)

	Chemically Strengthened Glass		Thermally Sagged Glass		
Expense Item	Steel Skin	No Skin	Thin Glass Laminate	Slab Glass	Thin Annealed Glass
1,000 ANNUAL VOLUME					
Direct Labor	$ 491	$ 407	$ 266	$ 267	$ 525
Direct Material	5,953	5,651	7,934	5,344	5,091
Direct Utilities	12	9	5	5	13
Indirect Expenses	1,533	1,423	1,432	1,240	1,506
Capital Expenses	846	829	685	642	858
Income Taxes	563	547	520	470	568
Profits	561	545	519	467	565
Selling Price	$9,960	$9,412	$11,361	$8,435	$9,125
100,000 ANNUAL VOLUME					
Direct Labor	$ 107	$ 105	$ 130	$ 176	$ 109
Direct Materials	3,900	3,599	3,587	2,403	3,278
Direct Utilities	7	7	9	44	7
Indirect Expenses	374	349	362	315	335
Capital Expenses	115	109	104	129	121
Income Taxes	99	93	91	97	99
Profits	98	92	91	98	97
Selling Price	$4,698	$4,354	$4,372	$3,262	$4,048

7.8 CAPITAL REQUIREMENT FOR THE MASS PRODUCTION PLANT

Table 7.3 summarizes the capital requirements in 1981 dollars to produce the concentrating collector with the thin annealed glass reflector design at the four stipulated mass production volumes. There are significant economies of scale in both facilities (plant) and in equipment requirements. To increase output from 1,000 to 5,000 collectors annually requires increasing plant and equipment investment only about 32.5 percent because there is considerable unused capacity at the 1,000 level. Another fivefold increase in volume from 5,000 to 25,000, requires tripling the plant investment, but equipment costs increase almost fivefold.

The 100,000 volume plant utilizes essentially the same technology as the 25,000 volume plant. The fourfold increase in volume is accomplished by increasing plant and equipment investment by 69 percent.

Working capital requirements vary more in proportion to volume, except between the 5,000 and 25,000 volumes. Radical changes in processing and make/buy decisions produce significant inventory carrying charge savings at the 25,000 volume and corresponding reductions in working capital requirements.

Land costs, based on average site values in Southeastern Michigan, show relatively insignificant variations, ranging from 0.6 percent of total capital requirements for a small plant to less than 0.3 percent for the largest plant.

TABLE 7.3: CAPITAL REQUIREMENTS - THIN ANNEALED GLASS DESIGN
(Thousands of 1981 Dollars)

Type of Capital	Annual Production Volume			
	1,000	5,000	25,000	100,000
Facilities	$ 2,264	$ 2,999	$ 8,787	$17,516
Equipment	3,141	4,110	19,860	41,037
Working Capital	1,306	5,195	11,638	43,228
Land	44	63	132	238
TOTAL	$ 6,754	$12,367	$40,416	$102,018

TABLE 7.4: CAPITAL REQUIREMENTS - SLAB GLASS DESIGN
(Thousands of 1981 Dollars)

Type of Capital	Annual Production Volume		
	1,000		100,000
Facilities	$ 1,962		$20,695
Equipment	2,344		51,676
Working Capital	1,208		33,653
Land	38		295
TOTAL	$ 5,553		$106,319

Table 7.4 shows the capital requirements for production of the thermally sagged glass (slab) design. The general comments concerning investment requirements for the thin annealed glass design also apply to the requirements for a plant to produce the slab glass design. In terms of absolute dollar amounts, capital requirements for the slab glass design are lower at low volumes and higher at high volumes in comparison with the requirements for the thin annealed glass design.

7.9 MANUFACTURING COST, SELLING PRICE, AND INSTALLATION COST ESTIMATES

The cost analysis for the collector with the thin annealed glass design is given in table 7.5. Material costs account for 90 percent of direct expenses and 56 percent of the final selling price at the 1,000 volume.

The dominance of material costs is greatest at the 100,000 volume, accounting for more than 97 percent of direct expenses and 81 percent of the selling price. Direct labor costs at the 1,000 volume are only 9.3 percent of the selling price. Direct labor costs decrease to 3.2 percent at the 100,000 volume. Clearly these are material/capital intensive, highly automated manufacturing designs.

Profits, defined as amortized one-time costs plus return on equity, were parameterized to yield a 10 percent rate of return on total investment. Profits represent only 6.2 percent of the selling price at the 1,000 volume and 2.4 percent at the 100,000 volume. Installed cost declines from $21.56 at the 1,000 volume to $11.72 per sq. ft. at the 100,000 volume.

Manufacturing cost, selling price, and installed cost estimates for the slab glass design collector are given in Table 7.6 for the 1,000 and 100,000 volumes. The installed cost of the slab glass design is approximately 10 percent less than the cost of the thin annealed glass design at all volumes. Higher material costs for the slab glass design at lower volumes are offset by lower labor and other costs. Production of the slab glass design is even more material intensive than the thin annealed glass design. Material accounts for 90 percent or more of total direct costs at all volumes.

Production and selling price estimates by major subassemblies for the thin annealed glass reflector design appear in Table 7.7. Estimates for the slab glass design appear in Table 7.8. The torque table/reflector assembly accounts for more than half the selling price for both designs at all volumes. The drive mechanism is the next most expensive subassembly and accounts for one-third to one-fourth of the selling price depending on volume and design. The two pylon assemblies are roughly comparable in cost to the receiver for both designs at all volumes.

TABLE 7.5: MANUFACTURING COST SUMMARY - THIN ANNEALED GLASS DESIGN
(1981 Dollars)

Expense Item	Annual Production Volume			
	1,000	5,000	25,000	100,000
Direct Expenses	$$ 5,628	$ 5,004	$ 3,639	$ 3,394
Direct Labor	525	536	132	109
Direct Materials	5,091	4,454	3,499	3,278
Direct Utilities	13	13	8	7
Indirect Expenses	968	276	116	75
Indirect Labor	798	232	96	64
Indirect Material	37	21	6	5
Indirect Utilities	133	23	14	7
Capital Expenses	1,422	505	351	218
Equipment & Facilities Replacement	456	115	102	52
Amortized one-time Costs	305	97	74	43
Interest on Debt	65	32	18	13
Return on Equity	260	126	73	53
Non-income Taxes	68	37	20	15
Insurance	268	98	64	41
Miscellaneous Expenses	538	403	287	260
Income Taxes	568	224	150	99
SELLING PRICE	9,125	6,412	4,542	4,046
Freight & Installation	2,000	2,000	2,000	2,000
TOTAL INSTALLED COST	$11,125	$8,412	$6,542	$6,046
COST PER SQ. FT. ($516\ ft^2$/Collector)	$ 21.56	$ 16.30	$ 12.68	$ 11.72

TABLE 7.6: MANUFACTURING COST SUMMARY - SLAB GLASS DESIGN
(1981 Dollars)

Expense Item	1,000		100,000
Direct Expenses	$ 5,616		$ 2,623
Direct Labor	267		176
Direct Materials	5,344		2,403
Direct Utilities	5		44
Indirect Expenses	733		108
Indirect Labor	596		93
Indirect Material	25		7
Indirect Utilities	112		8
Capital Expenses	1,109		227
Equipment & Facilities Replacement	309		61
Amortized one-time costs	249		40
Interest on Debt	54		12
Return on Equity	218		50
Non-income Taxes	58		14
Insurance	221		42
Miscellaneous Expenses	508		207
Income Tax	470		97
SELLING PRICE	8,435		3,262
Freight & Installation	2,000		2,000
TOTAL INSTALLED COST	$10,435		$5,262
COST PER SQ. FT. ($516\ ft^2$/Collector)	$ 20.22		$ 10.20

TABLE 7.7: COST ANALYSIS BY MAJOR SUBASSEMBLY - THIN ANNEALED GLASS DESIGN (1981 Dollars)

Subassembly	Annual Production Volume 1,000	5,000	25,000	100,000
Torque/Reflector	$ 5,986	$ 4,058	$ 2,752	$ 2,436
Receiver	611	458	350	312
Single Pylon	575	333	238	208
Double Pylon	279	145	129	108
Drive Mechanism/flex hose	1,681	1,421	1,077	984
SELLING PRICE	$ 9,132	$ 6,415	$ 4,546	$ 4,048

TABLE 7.8: COST ANALYSIS BY MAJOR SUBASSEMBLY - SLAB GLASS DESIGN (1981 Dollars)

Subassembly	Annual Production Volume 1,000		100,000
Torque/Reflector	$ 5,275		$ 1,646
Receiver	613		315
Single Pylon	592		204
Double Pylon	289		107
Drive Mechanism/flex hose	1,672		994
SELLING PRICE	$ 8,440		$ 3,264

7.10 MANPOWER REQUIREMENTS AND COST ESTIMATES

Labor is not a major cost element, but highly specialized skill requirements exist in the mass production of concentrating collectors, and these requirements vary with volume. Table 7.9 lists direct labor requirements for production of 1,000 and 100,000 annual volumes. Although most subassemblies are purchased at the low volume and the major process is final assembly of purchased components, about 21 man-years of direct labor effort are required to produce the 1,000 collectors at a cost of $525 per collector. Material handlers and assemblers account for 67 percent of the direct labor requirements at the 1,000 per year volume.

A hundredfold increase in volume can be achieved with a twentyfold increase in direct labor man-years. When this occurs direct labor costs per collector drop to $108. To fabricate most subassemblies within the plant requires additional skills including maintenance mechanics, operators of grinding machines, punch presses, and broaching machines, machine welders and inspectors.

Total manpower requirements at 1,000 and 100,000 per year volumes are summarized in Table 7.10. At the low volume, direct labor is responsible for 38 percent of total personnel and 40 percent of total manpower costs. At 100,000 per year, scale economies in administration reduce the proportion of indirect and skilled personnel and increase the direct labor percentage to 60 percent of total personnel and 65 percent of total manpower costs per collector.

TABLE 7.9: DIRECT LABOR REQUIREMENTS AND COST ESTIMATES AT THE 1,000 AND 100,000 ANNUAL VOLUMES - THIN ANNEALED GLASS DESIGN (1981 Dollars)

Skill	1,000 Annual Volume		100,000 Annual Volume	
	Number of Person-Years Required	Cost per Collector	Number of Person-Years Required	Cost per Collector
Maintenance Mechanic			115.4	$ 32.24
Material Handler	8.1	$210.20	81.0	20.89
Grinding Machine Operator			41.4	11.64
Machine Welder, Grade B	1.5	37.06	34.9	8.48
Milling Machine Operator, Grade A			25.0	6.48
Assembler, Grade B	0.79	19.18	22.2	5.41
Punch Press Operator, Grade A			14.6	4.33
Drilling Machine Operator, Grade B	0.93	20.54	17.0	3.75
Drilling Machine Operator, Grade A	0.25	6.23	11.8	2.94
Punch Press Operator, Grade B	0.06	1.39	13.4	2.90
Lathe Operator, Grade A	0.27	6.93	7.8	1.99
Machine Welder, Grade A			7.1	1.87
Assembler, Grade A	5.6	145.93	7.1	1.85
Hand Welder	0.91	23.19	6.5	1.66
Machine Tool Operator, Grade C	0.60	14.27	4.4	1.05
Broaching Machine Operator			3.2	0.74
Inspector, Grade A			2.0	0.53
Spray Painter	1.5	37.04		
TOTAL	20.5	$524.75	412.8	$108.22

TABLE 7.10 TOTAL MANPOWER REQUIREMENTS FOR PRODUCTION OF THE THIN ANNEALED GLASS REFLECTOR DESIGN (1981 Dollars)

Type of Personnel	Number of Person-Years Required	Cost per Collector
1,000 ANNUAL VOLUME		
Direct Production	21	$ 525
Indirect Production	16	246
Staff Personnel	17	551
Total Personnel	54	$1,322
100,000 ANNUAL VOLUME		
Direct Production	413	$ 108
Indirect Production	116	27
Staff Personnel	137	33
Total Personnel	666	$ 168

7.11 FACILITY REQUIREMENTS

The principal space requirements for 1,000 and 100,000 annual volumes are summarized in Table 7.11. Consistent with personnel requirements previously discussed, manufacturing space requirements represent a smaller portion of the total plant size at the 1,000 volume than at the 100,000 volume. No scale economies were assumed in the construction cost of manufacturing floor space.

TABLE 7.11 FACILITY REQUIREMENTS FOR PRODUCTION OF THE THIN ANNEALED GLASS REFLECTOR DESIGN (1981 Dollars)*

Type of Space	Square Feet of Space	Investment** (Thousands)	Cost per Square Foot
1,000 ANNUAL VOLUME			
Manufacturing	12,600	$ 690.3	$ 54.79
Support	17,610	1,617.5	91.85
TOTAL	30,210	$ 2,307.8	$ 76.39
100,000 ANNUAL VOLUME			
Manufacturing	139,800	$ 7,654.4	$ 54.75
Support	131,300	10,102.2	76.94
TOTAL	271,100	$17,756.6	$ 65.49

* Facilities are defined as all space requirements including parking, landscaping, heating and air conditioning, as well as material handling equipment (e.g., overhead cranes and forklift trucks).

** Includes land costs.

7.12 DIRECT MATERIAL COST ESTIMATES

Total material costs account for 80 percent of the selling price at the 100,000 annual production volume. Table 7.12 shows that almost two-thirds of the total material costs per collector come from four materials: thin annealed glass, drive mechanism and controls, corten tube (torque tube), and C.R. galvanized aluminum killed sheet steel (reflector frame).

The conclusion is that significant cost reductions in the manufacture of this collector can only be achieved by reducing the cost of these materials or substituting less expensive materials.

TABLE 7.12: DIRECT MATERIAL COST ESTIMATES FOR PRODUCING THE THIN ANNEALED GLASS DESIGN AT THE 100,000 ANNUAL VOLUME LEVEL (1981 Dollars)

Material Material	Cost per Collector	Material	Cost per Collector
Thin Annealed Glass	$ 532.39	Cap Screw (.375 in.-16 x 1.75 in. long)	$ 8.47
Drive Mechanism and Controls	515.98	Expendable Tooling	8.02
Corten Tube (7 in. OD x .157 in. x 20 ft. long)	432.96	Corten Angle - Base Angle	7.32
C.R. Galvanized Aluminum Killed Sheet Steel	409.84	Drive Plate, Corten Steel	7.23
Flex Hose	249.99	Corten Bar Stack	6.45
C.R. Galvanized Sheet Steel-Skin	272.75	Corten Flat Bar - Top Bar	5.05
6000 Series Adhesive	119.07	Flange - Corten Angle	4.64
Pyrex Tube	91.20	Ethanol	4.44
Galvanized Sheet Steel-Rib (.035 in. thick)	82.81	Corten Flat - 5 in. Flat	3.78
Receiver Bearing	63.50	O-Ring (Silicone)	2.07
Chrome Fillings	55.00	Stainless Steel - U-Bracket	1.90
Silvering Chemicals	49.14	Carbon Steel Weld Nut (.375 in.-16 x 1.75 in. long)	1.88
Deburring Media	44.04	Dowel Pin (0.06 in. dia. x 0.5 in. long)	1.64
Corten Jr. Beam	31.16	Dowel Pin (0.006 in. dia. x 0.38 in. long)	1.64
Corten Flat Stock - Flex Plate	30.10	Welding Rod	1.63
Corten S10 Beam	26.24	Dowel	1.50
Black Chrome Plating Material	22.27	ASTM A36 C.R. Coil (1.61 in. x 0.059 in. thick)	1.46
Low Carbon Steel Tube	19.47	Bolt (1/2-13 x 2 in.)	1.00
Stainless Steel Bar (.375 in. dia. x 36.61 in. long)	16.93	Zinc Plating Material	0.89
Primer 6035	16.87	Key	0.80
Hub, Nodular Iron	14.42	L-Shaped Angle	0.74
Grit Blasting Material	14.21	Bolt (12-13 x 2-1/2 in.)	0.60
Brazing Ring	13.36	Stainless Steel Coil Stock (0.62 in. x 0.063 in.)	0.46
Corten Steel - Top Plate	13.16	Stainless Steel Coil Stock (3.5 in. x 0.15 in.)	0.42
Stainless Steel - Receiver Support	11.68	Nut (1/2-13)	0.40
Corten Angle - Cross Angle	11.61	Socket Head Cap Screw (8-32 x 0.5 in. long)	0.38
Receiver Bearing Cap	11.55	Socket Head Cap Screw (10-32 x 0.5 in. long)	0.24
Pillow Block	10.31	Washer (9/16)	0.24
Corten Steel - Bottom Plate	9.87	Socket Head Cap Screw (8-32 x 0.38 in. long)	0.18
Riser Assembly	9.43	Trichloroethylene	0.09
		TOTAL	$3,278.25

7.13 LOW VOLUME PRODUCTION COST ANALYSIS

Market demand must grow before an industry reaches mass production levels, and this market expansion may take years. Thus, during early stages, manufacturers must plan for lower volume productivity. Section 6.6 discusses manufacturing processes for annual production volumes of 100 to 500 modules. Capital requirements for production of thin annealed glass reflector design units are given in Table 7.13 for 100 and 500 modules.

Equipment requirements are identical to produce 100 or 500 modules. The 500 volume requires more space to accommodate the larger number of workers.

Working capital requirements are relatively low at both volumes since final assembly of purchased subassemblies is the only processing that occurs in these plants.

TABLE 7.13: CAPITAL REQUIREMENTS FOR LOW VOLUME PRODUCTION (Thousands of 1981 Dollars)

Type of Capital	Annual Volume	
	100 Modules	500 Modules
Facilities	$1,127.9	$1,190.3
Equipment	1,691.3	1,691.3
Working Capital	171.6	764.5
Land	21.7	24.7
TOTAL	$3,012.5	$3,670.8

Manufacturing cost estimates for these volumes appear in Table 7.14.

Direct labor and material costs are invariant with volume, but economies of scale are present for indirect and capital expense items, as the total selling price falls from $18,902 to $11,809 and the installed cost per square foot drops almost 40 percent from $40.51 to $25.37.

Direct labor requirements at these volumes are given in Table 7.15. Since direct labor requirements are assumed to vary in direct proportion with output, the cost per collector is the same at the two volumes.

TABLE 7.14 LOW VOLUME PRODUCTION
MANUFACTURING COST SUMMARY - THIN ANNEALED GLASS DESIGN
(1981 Dollars)

Expense Item	Annual Volume 100	Annual Volume 500
Direct Expenses	$ 7,731	$ 7,731
Direct Labor	697	697
Direct Materials	7,018	7,018
Direct Utilities	16	16
Indirect Expenses	1,607	589
Indirect Labor	1,308	506
Indirect Materials	55	31
Indirect Utilities	244	53
Capital Expenses	6,345	1,520
Equipment & Facilities Replacement	2,294	462
Amortized One-Time Costs	1,465	329
Interest on Debt	234	72
Return on Equity	938	289
Non-Income Taxes	219	76
Insurance	1,196	292
Miscellaneous Expenses	942	666
Income Taxes	2,290	596
SELLING PRICE	$18,915	$11,102
Freight & Installation	2,000	2,000
TOTAL INSTALLED COST	$20,915	$13,102
COST PER SQ. FT. (516 ft^2/Collector)	$ 40.53	$ 25.39

TABLE 7.15: DIRECT LABOR REQUIREMENTS AND COST ESTIMATES FOR LOW VOLUME PRODUCTION - THIN ANNEALED GLASS DESIGN (1981 Dollars)

Skill	100 Annual Volume: Number of Person-Years Required	100 Annual Volume: Cost per Collector	500 Annual Volume: Number of Person-Years Required	500 Annual Volume: Cost per Collector
Material Handler	0.79	$203.48	3.9	$203.48
Assembler, Grade A	0.70	183.90	3.5	183.90
Spray Painter	0.35	87.96	1.8	87.96
Drilling Machine Operator, Grade B	0.24	52.79	1.2	52.79
Hand Welder	0.17	43.59	0.85	43.59
Machine Tool Operator, Grade C	0.14	34.64	0.72	34.64
Drilling Machine Operator	0.13	31.51	0.63	31.51
Machine Welder, Grade B	0.12	28.59	0.59	28.59
Assembler, Grade B	0.08	19.18	0.39	19.18
Milling Machine Operator	0.02	5.76	0.11	5.76
Lathe Operator, Grade A	0.01	2.12	0.04	2.12
TOTAL	2.8	$693.52	13.7	$693.52

7.14 SENSITIVITY ANALYSIS

Cost estimating requires making many assumptions about various factors such as input prices and rates of return. Sensitivity analysis provides a method for assessing how a given change in one of these factors will affect the final selling price. Both manual manufacturing cost analysis and computerized selling price estimates highlighted the importance of material costs, particularly that of the reflector material, in the total cost of the reflector.

Figures 7.1 and 7.2 show relative and absolute changes in selling price responding to a given percentage change in the cost of thin annealed glass and comparable proportional changes in the rate of return on investment for 1,000 and 100,000 annual production volumes.

At low volumes, overhead and indirect expenses are spread over relatively few units of output and thus represent a larger portion of the selling price. This explains why selling price is more sensitive to changes in rate of return at low volumes than at the 100,000 volume.

Since material prices are a smaller portion of the selling price at low volumes, final selling price is therefore less sensitive to a given percentage change in the cost of the reflector at low volumes than it is at high volumes. For example, a 25 percent reduction in the cost of thin annealed glass reduces the selling price 1.9 percent at the 1,000 volume level, but it reduces the selling price 2.9 percent at the 100,000 volume level.

Utilizing SAMICS methodology in sensitivity analyses is another valuable extension of this tool. The IPEG program discussed in section 7.5 helps users conduct sensitivity analyses at minimal cost.

Material costs are significant factors in establishing the selling prices of concentrating collectors, and sensitivity analyses provide confirmation. Informed decision-making cannot occur without such support consistently and reliably.

Figures 7.1 and 7.2 show how sensitivity analysis data can be plotted for effective guidance in this area.

FIGURE 7.1: SENSITIVITY ANALYSIS OF SELLING PRICE TO CHANGES IN RETURN ON EQUITY AND THE PRICE OF THIN ANNEALED GLASS (1,000 ANNUAL VOLUME)

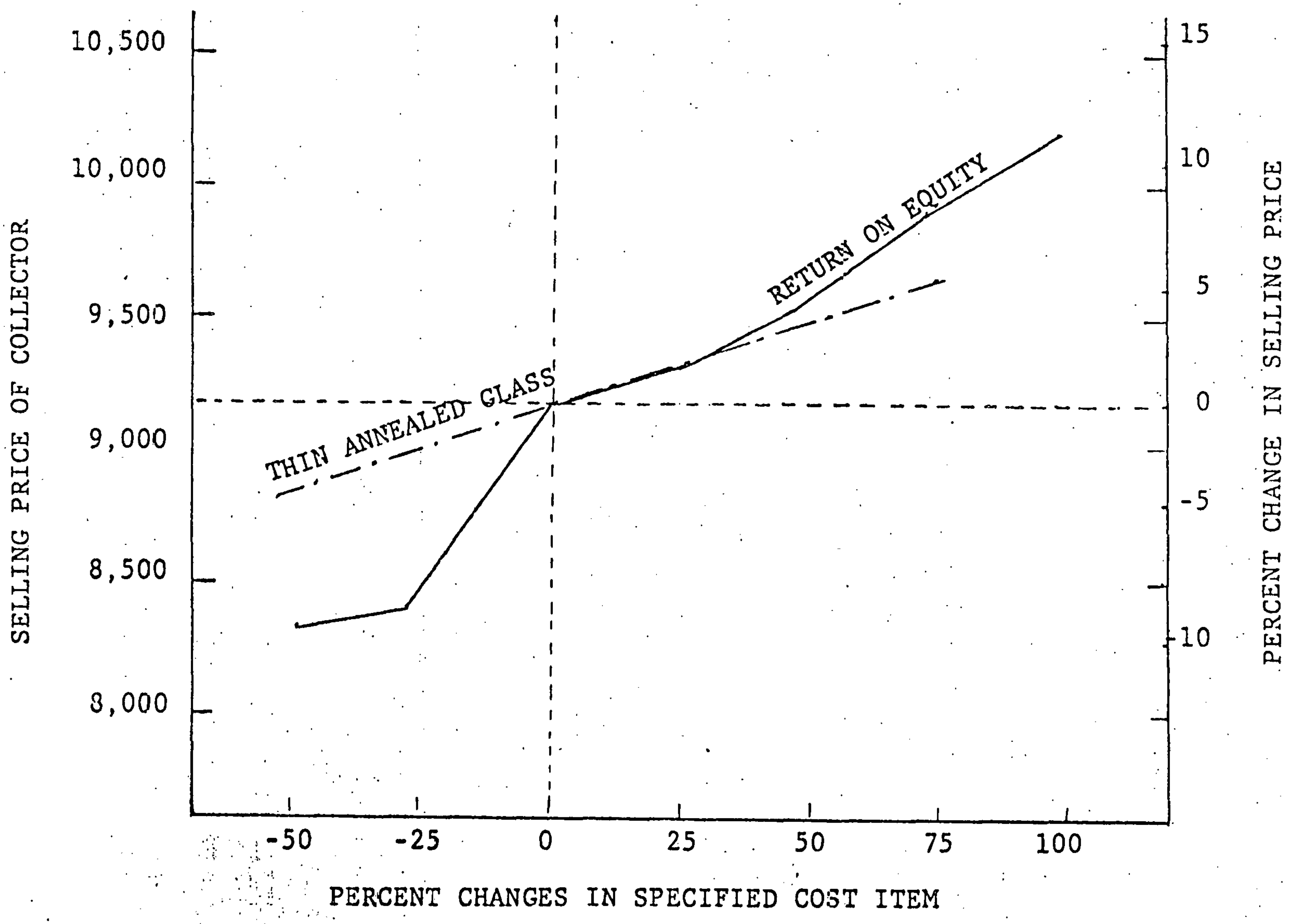
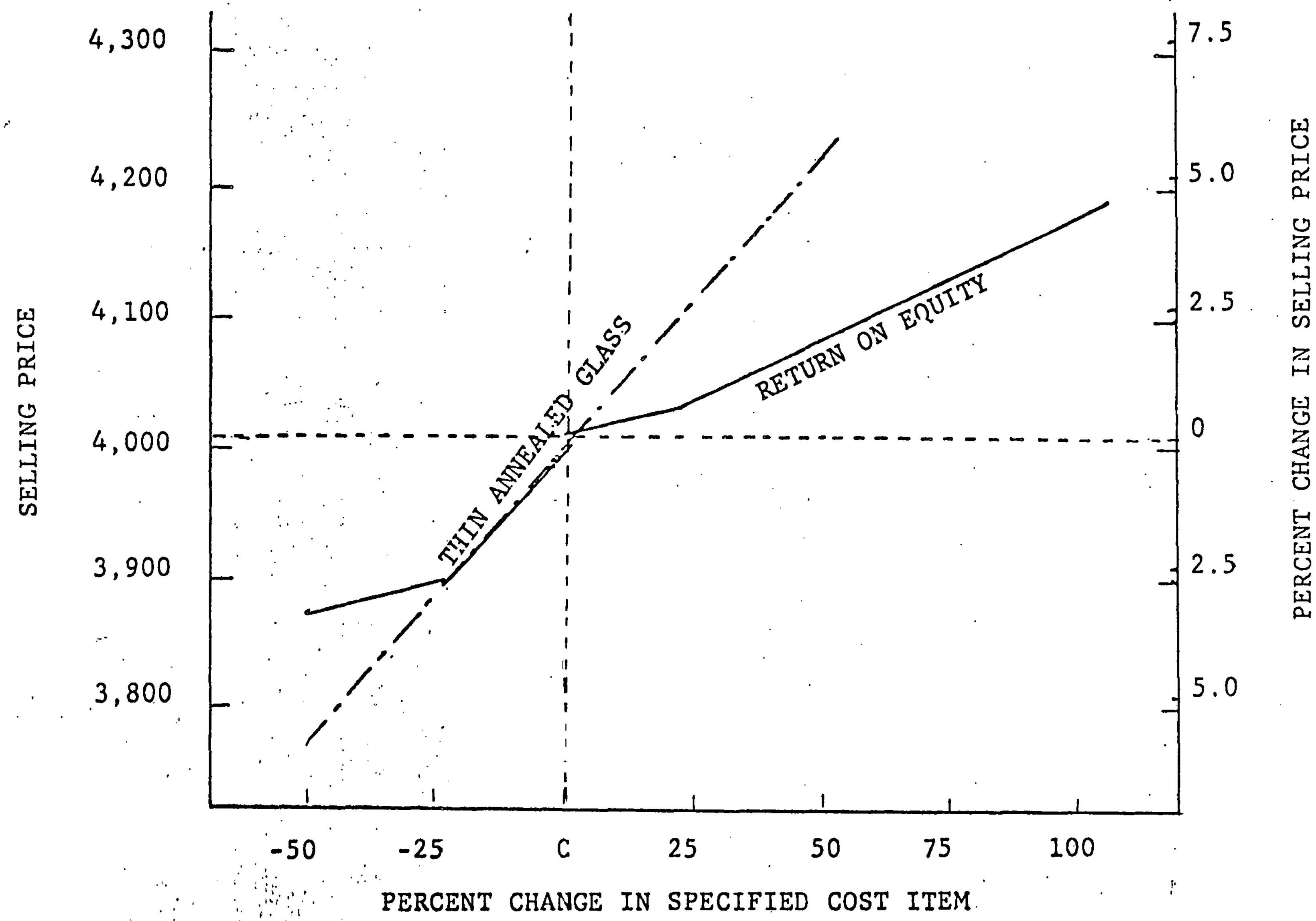


FIGURE 7.2: SENSITIVITY ANALYSIS OF SELLING PRICE TO CHANGES IN RETURN ON EQUITY AND THE PRICE OF THIN ANNEALED GLASS (100,000 ANNUAL VOLUME)



7.15 MASS PRODUCTION REDUCES COSTS

The major finding of the computerized manufacturing cost analysis is that mass production can bring significant cost reductions. Figure 7.3 shows the reduction in normative selling price from a production volume of 100 to 100,000 collectors per year. The benefits of mass production are evident.

From an installed cost of almost $21,000 ($40.51 per sq. ft.) at the 100 collectors per year level the installed cost decreases to less than $6,000 ($11.58 per sq. ft.) at the 100,000 annual volume level.

Tables 7.16 and 7.17 give normative price figures, with CSERC design changes and lowest cost alternatives applied, per square foot of aperture for 1,000 and 100,000 modules per year. Figures are supplied for both the thin annealed glass and slab glass designs.

TABLE 7.16: PPT CONCENTRATING COLLECTOR - NORMATIVE PRICE (LOWEST COST ALTERNATIVES) (INCORPORATING CSERC-RECOMMENDED DESIGN CHANGES) [$/Square Foot of Aperture, 1,000 Modules/Year]

Item	Thin Annealed Glass	Slab Glass
Reflector Assembly	$11.57	$10.21
Receiver	1.18	1.18
Pylons	1.65	1.65
Driving Mechanism	3.26	3.26
Freight & Installation	3.88	3.88
TOTAL	$21.55	$20.18

TABLE 7.17: PPT CONCENTRATING COLLECTOR - NORMATIVE PRICE (LOWEST COST ALTERNATIVES) (INCORPORATING CSERC-RECOMMENDED DESIGN CHANGES) [$/Square Foot of Aperture, 100,000 Modules/Year]

Item	Thin Annealed Glass	Slab Glass
Reflector Assembly	$ 4.58	$ 3.27
Receiver	.60	.60
Pylons	.61	.61
Driving Mechanism	1.90	1.90
Freight & Installation	3.88	3.88
TOTAL	$11.58	$10.26

As noted in section 7.7, the slab glass design proved less costly than the thin annealed glass design at both low and high volumes. For each the special significance of these results is the reduced cost and the correspondingly reduced price achieved through mass production economies.

Mass production costs make the concentrating collector economically viable at alternative energy prices prevailing in the 1980s. The trend of energy pricing anticipated during the remainder of the 20th century indicates

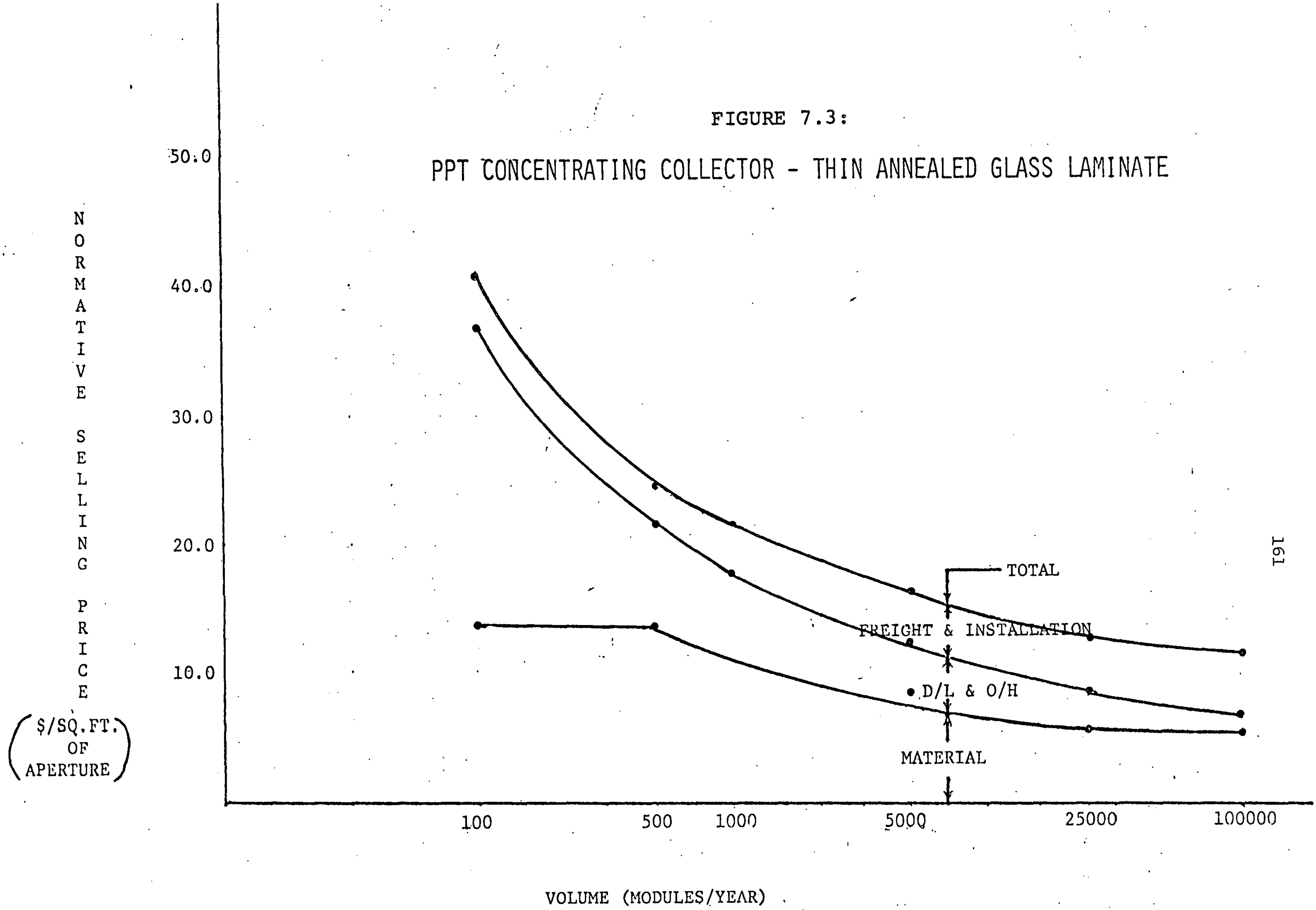


FIGURE 7.3:

PPT CONCENTRATING COLLECTOR - THIN ANNEALED GLASS LAMINATE a pattern of steadily improving competitiveness for mass-produced concentrating collectors.

7.16 COST ANALYSIS FINDINGS OF SPECIAL NOTE

As shown in Figure 7.3 and other data in the CSERC report, the major portion of cost reductions through large-scale manufacturing of the concentrating collector is realized at the relatively low 5,000 annual volume level.

Material costs dominate at all volumes. This means further significant cost reductions can be achieved only by reducing material costs. The CSERC project achieved successes in this direction and highlighted future possibilities for further reductions.

CSERC evaluated five designs and selected the two that led in cost-effectiveness. The two chosen designs were hundreds of dollars lower in material costs than the three alternative designs.

SAMICS methodology provided a versatile analytical resource for many phases of the CSERC study. In addition to cost analyses for selected designs and manufacturing processes, SAMICS was valuable for evaluating the costs of other designs and for appraising subassembly alternatives.

SAMICS was also used effectively to perform make/buy analyses for various components in border line cases.

Sensitivity analyses affirmed the importance of material cost variations in determining the final selling prices of concentrating collectors.

Costing and price estimating utilizing CSERC data and SAMICS furnished essential information for effective establishment and operation of concentrating collector mass production facilities.

8.0 RECOMMENDATIONS FOR COST REDUCTION AND RELIABILITY IMPROVEMENT

8.1 MASS PRODUCTION AND VALUE ENGINEERING REDUCE COSTS

A logical extension of the CSERC mass production feasibility assessment made on the PPT Concentrating Collector was a concerted effort to identify cost saving opportunities in connection with production, materials, and design. A broad-based and multifaceted study of the type undertaken could not be responsibly carried out without facts being discovered and judgments reached that affect costs. Also inevitable in such a probing look at a process is the detection of ways and the development of ideas to enhance producibility.

It is virtually an axiom that effective utilization of mass production techniques and value engineering requires simplifying designs, eliminating unnecessary steps, streamlining operations, minimizing the number of components, and reducing the cost of materials. The goal of such activities is no less axiomatic: Through successful use of mass production methods, lowest costs are achieved to enhance marketability and greatly widen use.

The CSERC study of the PPT Concentrating Collector confirms the cost benefits of mass production. Through the specification of sophisticated processing such as transfer lines, automation, and robotics when they are justified at higher volume production levels, CSERC has provided a clear-cut road map for high volume manufacturing with costs held to a minimum. Further cost reductions have been recommended based on value engineering techniques.

Each fundamental technique--simplifying designs, minimizing components, reducing material costs, eliminating process--is illustrated in the changes CSERC recommended and saw adopted during this project. Consider one example: The original design for the baseline alternate (Chemically Strengthened Glass and Steel Laminate on a Steel Frame Panel) specified a 5 part receiver bearing which was reduced to 2 parts. This produced savings. There are many other examples of savings achieved in like fashion.

Examples of reduced material costs are numerous. One was the recommendation to eliminate the need for a special absorber tube because of stringent ovality requirements. An in-plant operation was added that permitted the use of standard Pyrex tube simply by grinding the inside diameter of the tube at each end.

8.2 RECOMMENDED DESIGN CHANGES

Following are details on the leading changes effected in the course of the CSERC study.

8.2.1 Substitution of a Welded Rolled Section for a Seamless Section on the Torque Tube

The baseline design (Chemically Strengthened Glass and Steel Laminate on a Steel Frame Panel) specified a seamless torque tube. The fixture CSERC designed for welding reflector supports to the torque tube (using tooling holes in the torque tube flanges to establish focal length) permitted accepting the looser tolerance of welded tube at no sacrifice in efficiency.

8.2.2 Substitution of Galvalume and Galvanized Sheet Steel for Cold Roller Painted Steel in the Skin Panel and Frame Panel Respectively

The baseline design stipulated paint for corrosion-protection of components. The long-term reliability of paint protection was a strong question. Also the paint, plant facility, and floor area requirement costs were enormous. Adopting Galvalume, an aluminum-zinc alloy coated steel, for the skin panel and galvanized steel for the frame panel offers superior corrosion protection at substantial savings.

8.2.3 Substitution of a Spherical Wooden for a Spherical Bearing Pillow Block

Since the spherical bearing or pillow block is not subjected to high rotational requirements, a less expensive wooden bearing was proven adequate. This switch illustrates a classic method of reducing cost: evaluating performance goals and utilizing the most economical materials to achieve the goals without harming quality or jeopardizing performance.

8.2.4 Substitution of a Readily Oxidizable Carbon Steel for Hot Rolled Galvanized Steel on the Pylons, Torque Tube and Flexural Plates

Since a readily oxidizable material such as Corten is less expensive than galvanized material, using Corten is indicated at higher production volumes (i.e., 25,000-100,000 modules per year). The savings possible with Corten are peculiar to high volumes, because vendors are unwilling to supply all different sections at low volumes.

8.2.5 Substitution of a Welded Rolled Section for a Seamless Section on the Receiver Tube

When it was confirmed that welded and drawn tubes meet pressure and temperature requirements, they replaced seamless sections on receiver tubes. Seamless tubes are two to three times costlier.

8.2.6 Substitution of a Two-Piece Investment Casting for a Five-Piece Machined Receiver Tube Bearing

The baseline design specified a five-piece machined steel casting. Since bearing dimensions are critical to the establishment of the focal length, the five-piece casting was considered advisable to achieve the precision required. However, analysis showed that the bearing surface is subject only to the motion caused by the expansion of the tube along its longitudinal axis. Determining as well that it is unnecessary to open the bearing in field installation, instituting the use of a cored casting broached in-house permits extensive savings. The investment casting process should be investigated further, because it eliminates the need for machining.

8.2.7 Substitution of a One-Piece Stamping for the Channel, Tube and Angle Weldment Reflector Support

At higher production volumes where the tooling could be absorbed, adoption of a one-piece stamping proved cost-effective. At lower volumes, the weldment remains the more economical design.

8.2.8 Substitution of a Polyurethane Adhesive

The original design indicated the use of an adhesive which created a significant floor space penalty, although the adhesive was competitive in its material and application labor cost. The floor space penalty was a result of the required 24-hour curing time. This long curing time requirement also imposed unwieldy operating demands. Extensive consultation with and research by adhesive vendors led to the recommended adoption of a polyurethane material whose short curing time and suitability for bonding glass to steel eliminated the need for excessive storage.

8.2.9 Substitution of Standard Absorber Tube for Special Absorber Tube

A tight seal between the "O" ring and the absorber tube is critical to the durability of the receiver tube plating and hence to the efficiency of the collector. This fact as well as state-of-the-art capabilities of tube vendors in regard to ovality brought about the original specification for swaging the ends of the absorber tube. This placed a premium cost on the tube. Working with an equipment vendor, CSERC learned that grinding the inside diameter of the standard tube can meet ovality specifications cost-effectively with an in-house operation. Thus a standard component replaced a more expensive special component.

8.2.10 Substitution of Tube Fittings for Specific Design

In-house processing could not be considered, because the specific design is patented by the manufacturer. Consequently, more economical alternatives were sought. An alternate, cost-effective design was found and specified.

8.2.11 Substitution of Low Iron Glass

Specialty glass was considered for the thin glass and chemically strengthened glass designs. An equivalent, less expensive low iron glass was recommended as an effective substitute.

8.2.12 Substitution of Slab Glass

As an alternative to thermally sagged glass and thin glass laminate (space frame), CSERC recommended slab glass. Sandia National Laboratories agreed to make slab glass one of the alternatives.

8.2.13 Driving Mechanism

To facilitate production and achieve the lowest possible costs, every component and assembly in a manufactured item must be exhaustively analyzed. One phase of this effort in connection with the concentrating collector led to evaluation of driving mechanism requirements. CSERC located a source for a cost-effective driving mechanism that meets operational goals.

8.3 CHANGES TO IMPROVE PROCESSES

Cost reduction is not the only objective of design recommendations. Some important changes are put forward to facilitate manufacturing processes and increase their reliability, even when substantial cost savings are not directly apparent. All improvements, of course, ultimately contribute to better cost-effectiveness or better products, and sometimes both.

Among the submissions made by CSERC to bring about improvements during processing were the following:

- Suggested revised design for the driveshaft which eliminates two-sided welding and provides a better mechanical coupling.
- Tack welds on the receiver support.
- Introduction of dowels to achieve positive, all-time alignment.
- Puddle welds rather than fillet welds to restrict distortion during the welding of the torque tube.
- Introduction of an "L" shaped bracket to ensure reliable assembly.
- Providing for the linear motion of the receiver rather than curvilinear motion.
- Locating points, lines, and surfaces for components, assemblies, and subassemblies.

These and a multitude of further process recommendations were determined in the course of the CSERC study and were collectively aimed at achieving precise production guidelines and ensuring cost-effective as well as efficient manufacturing.

The attempt by all concerned--design engineers, manufacturing engineers, computer analysts, draftsmen, and many others--to define problems and solve them, to identify an appropriate regimen for concentrating collector mass production, and to confirm economic feasibility of such production, naturally resulted in a multitude of design and process-oriented needs. Turning those needs into practical adjustments and changes effectively reduced cost and improved reliability. That has long been an objective in solar energy manufacturing.

9.0 MANUFACTURING RESEARCH PROGRAM PROPOSALS

9.1 BACKGROUND ON RESEARCH PROPOSALS

During CSERC producibility analyses of concentrating collectors, extensive knowledge was gained about existing practices and current designs. This knowledge ranged from solar device functioning and construction criteria to intricate design features and process details that could eventually deliver mass quantities at minimum price. As work progressed, design proposals were made by CSERC that were self-evident in the light of manufacturing practice, clearly cost-effective, and readily acceptable for incorporation without extensive testing. Several more complex proposals also developed in the course of the project, and these necessarily require detailed analyses before adoption.

This section discusses such proposals in terms of need, objectives, costs, priorities, and time phasing. This information may be helpful in programming, arranging for engineering and financial support, and synchronizing important research efforts. The proposals examined in this report are divided into three categories: Assembly, Components, Materials.

Basic principles that guide mass production industries in devising cost-effective, reliable processes include:

- Maximum use of low cost materials.
- Simplified assembly.
- Minimum use of secondary operations (through high precision use of casting, molding, cold and hot forming, and available modern technology.)

The CSERC proposals are derived from these principles as well as from the insights gained by experienced engineers working closely with the needs and problems of solar device manufacturers. The proposals are summarized in Table 9.1, which also includes a "confidence level" judgment. Manufacturing engineers select processes on the basis of their experience or experience from the manufacturing community. Such choices normally are supported by a high confidence level that a particular process will not develop problems that cannot be efficiently solved to avoid jeopardizing production schedules. One rule of thumb is that the manufacturing engineer have a confidence level of at least .92 to consider using a given process. When the confidence level is below this figure, research efforts, as with some of the current proposals, may eventually improve the confidence level.

These research proposals are intended to apply new technology to the manufacturing of solar energy devices. Their implementation could lead to further advances in solar technology. The same as spreading ripples from a pebble dropped in water, research progress in a developing field tends to stimulate additional progress, as the ripples broaden.

TABLE 9.1: SUMMARY OF RESEARCH PROGRAM PROPOSALS

Category	Research Program Title	Objective
Assembly	Precision Factory-Focused Reflector	Verify assembly processing to minimize field assembly costs.
	Pedestal Mounted Reflector	Use of 20-ft. modules with simplified drive, plumbing, and structural support.
Component	Frame Panel Stamping from Thinner Material	Cost Reduction
	Receiver Hardware	
	Low Cost High Temperature Fluid Fittings	Cost Reduction
	I.D. Grinding of Absorber Tube	Cost Reduction
	Hexagonal Lateral Receiver Bearing	Improve Performance
	Pylon Design	Cost Reduction
	Drive Alternates	Cost Reduction
Material	Production of No-Iron Glass by the Float Process	Cost Reduction
	Wood for Structural Members	Cost Reduction
	Composites for Structural Members	Cost Reduction

9.2 RESEARCH PROGRAM PRIORITIES

The proposed programs have been assigned priorities based on a subjective evaluation of cost saving potential, potential quality and performance improvement, development costs, and timing. Such priorities provide guidance for engineers, but their subjectivity and general imprecision make them more a basis for considered evaluation than for sequential adoption.

In setting priorities for manufacturing research, the following rationale is useful:

a. Top priority should be given concepts with a high confidence level and corresponding probability of success.

b. High priority should be assigned concepts with modest development effort required and with good prospects of providing early answers.

c. Priority should be given concepts with the greatest cost saving potential.

d. Priority should be given concepts with high quality improvement potential.

e. Priority should take into account facility conditions and timing factors.

f. Priority should consider the availability of engineering and research talent to conduct the proposed programs.

g. Priority and confidence level are not synonymous. High priority may be given a program with a low confidence level because of cost or quality imperatives that must be served.

Table 9.2 lists research program proposals in priority order with confidence levels and rationale statements.

TABLE 9.2: MANUFACTURING RESEARCH PROGRAM PROPOSALS IN PRIORITY SEQUENCE

Research Program Title	Confidence Level	Rationale
Precision Factory-Focused Reflector	.92	Successful completion of a Phase I study will provide an assembly technique immediately applicable to all focusing systems.
I.D. Grinding of Absorber Tube	.9	Cost and quality improvements will be incorporated into current designs.
Hexagonal Lateral Receiver Bearing	.9	
Low Cost High Temperature Fluid Fittings	.8	
Pylon Design	.8	Cost reductions are possible. Research efforts together with appropriate engineering and testing studies could benefit concentrating collector development. Design studies are advisable to assess the cost reduction potential.
Frame Panel Stamping from Thinner Material	.8	
Drive Alternates	.6	
Production of No-Iron Glass by the Float Process	.6	
Pedestal Mounted Reflector	.6	
Wood for Structural Members	.5	Although confidence levels are conservatively low, potential cost savings from the use of low density materials are so significant that preliminary design work for costing purposes is recommended.
Composites for Structural Members	.5	

9.3 RESEARCH PROPOSAL DESCRIPTIONS

The Appendices (Volume II) contain "Program Planning Detail" forms with particulars on each research proposal. The following descriptions identify leading features of various proposals.

9.3.1 Precision Factory-Focused Reflector

An assembly process is needed to facilitate focusing the parabolic trough upon the line receiver/absorber assembly located along the foci of the reflector. CSERC engineers envisioned a system in which a parabolic surface on an assembly fixture and the locator for the receiver are in theoretical geometrical relationship with each other. A measurement system is proposed that would provide assurance that the total system is in theoretical focus.

The recommended system is based on feasible equipment, but the application has not been tested. When implemented, a hardwood model of the proposed mandrel would be constructed. This model would be used to approximate the exact mode of operation required from the metal mandrel. The over-all research program would verify and modify as required the various manufacturing steps involved.

When successful, the proposal will supply tools and instruments to assist in assembling and measuring 20-ft. sections of the PPT Reflector/Torque/Tube/Receiver Assembly. This will minimize field assembly costs and usefully verify assembly processing for the PPT Concentrating Collector.

Time Phasing: 12 months
Labor Cost: $180,000
Material/Equipment Costs: $92,000

9.3.2 Pedestal Mounted Reflector

The proposal is a major departure from the concentrating collector evaluated in the CSERC study. The concept involves modularizing the collector so that two identical modules would perform the same task as one 80-ft. collector.

Such a design would reduce the number of different pylons. It would move total production requirements closer to the volumes that support mass production efficiencies through the use of specialized equipment.

To determine potential manufacturing economies and other cost reduction simplifications such a design might support, a study group is proposed with the task of assessing the concept.

9.3.3 Frame Panel Stamping from Thinner Material

Using thinner gauge material for frame panel stamping provides an avenue for cost reduction through material savings. Section 4.6.2 discusses the frame materials considered for the mirror support of the concentrating collector. Among materials evaluated are various types of steel (e.g., aluminized, galvanized, Galvalume, plain carbon steels). The material used must resist corrosion caused by environmental factors 15-20 years.

Galvanized steel and Galvalume steel are the choices for the concentrating collector. Steel 0.030 inches thick has been used for the mirror support, but thinner steels (0.025 or 0.020 inches) are recommended to reduce costs.

Thus, a logical future development project for the concentrating collector is to devise methods of stamping frame panels from thinner materials. The necessary research and engineering can follow the guidelines of existing technology.

9.3.4 Receiver Hardware Developments

To simplify the receiver system, reduce costs, and improve performance, three proposals grew out of the CSERC producibility analysis:

a. Low cost high temperature fluid fittings.
b. I.D. grinding of the absorber tube.
c. Hexagonal lateral receiver bearing.

The first concept would replace a proprietary fluid fitting with a new design specific to the fluid flow requirements of the PPT Concentrating Collector. One advantage would be reduction in the number of mating parts between two adjacent receiver modules.

The second concept proposes grinding the inside diameter of the absorber tube as a way to eliminate a special, costly swaging operation on absorber tube. Preliminary tests demonstrated engineering feasibility. The proposal includes developing a glass grinding machine with appropriate material handling equipment to minimize costs.

The third concept derived from the finding that the flexible anchor for the receiver bearing support might cause the receiver to deflect as a result of thermal expansion. Using a hexagonal lateral receiver bearing system is proposed as a potential way to solve the linear expansion problem cost-effectively.

The projected research programs associated with these developments primarily involve the completion of engineering programs initiated during the CSERC study.

9.3.5 Pylon Design

The existing design requires the welded assembly of various sizes and shapes to produce three different pylon designs. To reduce cost this proposal concerns a design study to reduce the number of components to a minimum.

Alternates to consider include stamped 1- or 2-piece designs, nodular iron castings, and reinforced plastic composites. The proposed study would examine manufacturing-oriented approaches as it seeks ways to simplify and to reduce costs through modularity and the use of alternate materials.

9.3.6 Drive Alternates

The CSERC study did not deviate from design specifications for an electric motor and a speed-reducing gear box; but from the viewpoint of energy conservation, possible drive alternates should be considered as a means of saving energy and reducing cost.

Efforts to use thermal energy directly in the tracking system in combination with hydraulic cylinders or rotary actuators should continue. The possibility should also be investigated that an air flotation system in conjunction with an air jet motor could be adapted as a drive alternate for some configuration of a concentrating collector.

To implement this program, an industry task force, with manufacturers of hydraulic systems and solar energy systems participating, is recommended to study hydraulics in depth with the goal of developing a program. Other options should also be explored as they appear.

9.3.7 Production of No-Iron Glass by the Float Process

Using the float process to produce no-iron glass should have practical advantages including reduced cost. As indicated in section 4.7 on glass manufacturing, the expectation is that the float process can be adapted to produce sodalime no-iron glass when the volume demand is sufficient. Sodalime no-iron glass is not yet produced by this process in part since solar applications for the glass are not large enough. To prepare for the anticipated rapid expansion in production of solar devices, development work in this field is recommended as a CSERC research proposal offering good prospects of success.

Currently low-iron sodalime glass is typically produced using the drawing process, which is considerably slower than the float process. Application of the float process to produce the large quantities of no-iron glass that will be required in future manufacturing is a highly promising step.

9.3.8 Wood for Structural Members

An examination of low cost structural materials shows steel and wood close to the lowest in cost, with wood on a volume basis costing roughly 10 percent the cost of steel. This price-density leverage makes it advantageous to design for the use of wood in structures requiring mid-range physical properties.

Recent work on wood reconstituted with chemical resins illustrates one opportunity. Successful research on the production of high quality wood by mixing low quality wood fibers with resin and compressively molding it shows promise of supplying an economical and reliable product. Other work with reconstituted wood encourages steps to develop low-cost, low-weight wood structural members for solar devices.

This research proposal is for a design study conducted by developers of manufacturing process systems and experts in wood technology to choose a component in the concentrating collector and to evaluate it in terms of design and cost reduction potential with the use of wood. A by-product of using molded wood technology successfully would be new employment opportunities in parts of the country currently afflicted with unemployment and related economic problems.

The current state of reconstituted wood research and resin technology suggests that the use of wood for structural parts in concentrating collectors may prove to be economical with the combined benefits of low cost and low density.

9.3.9 Composites for Structural Members

In addition to reconstituted wood, fiber-reinforced composites may also provide suitable material for structural members in concentrating collectors as an alternate means of reducing cost. This proposal recommends initiating a design-manufacturing study to identify uses for composites in existing and new solar energy systems.

An intriguing option with composites is the possibility of building special properties into them since a wide range of molding materials and practices are available to form composites. The engineering uses of composites are limited only by the ingenuity of the investigators, and the proposed study would consider their uses in a variety of concentrating collector applications.

10.0 CONCLUSIONS

10.1 ENERGY COST ANALYSIS

The use of parabolic trough concentrators in the conversion of solar energy for industrial process applications depends primarily on the economic factors and costs. Durability, reliability, and upkeep of materials, components, and systems are also important to those considering adoption of this technology. Industries can be expected to utilize solar energy systems only when they deliver useful energy at costs below the costs for competing energy sources. Switching from coal, oil, gas, or purchased electricity to solar installations without the incentive of lower costs is an unlikely move by industries while current energy economic conditions prevail. The decline in conventional energy resources coupled with corresponding price rises for those fuels may be one of the factors that makes solar energy systems a practical future answer to industrial energy needs.

Economic parameters affecting the expansion of solar energy use for industrial process heat applications include tax incentives, tax credits, cost of competing fuels, cost of capital, cost of ownership (taxes), rate of inflation, rate of fuel cost escalation, type of capital borrowing, borrowing time periods, discount rate on capital, maintenance costs, total installed costs of concentrating collectors, cost of auxiliary equipment such as heat exchangers, conversion efficiencies, and the geographic location.

Each parameter inevitably raises one or more questions that need specific answers before solar energy systems can achieve the popularity and widespread use that are considered critical parts of the U.S. national energy program.

Many answers were acquired by CSERC in the course of the PPT concentrating collector studies. They are spelled out in this report and in the Appendices (Volume II). More answers are needed and will be learned as further work is done following completion of the CSERC mass production feasibility analysis.

A realistic energy cost analysis was conducted by John A. Clark, a CSERC consultant at the University of Michigan. Dr. Clark used technical performance characteristics of the collector based on work by Sandia National Laboratories, and calculated results for three representative U.S. locations: Albuquerque, New Mexico, Fresno, California, and Caribou, Maine. This information provides authoritative support with regard to the investment opportunities of industrial solar energy system utilization. Both life-cycle economic analysis and annual cash flow analysis are considered, with results for the total dollar return (or loss) based on investment periods up to 15 years as well as present break-even costs in terms of conventional fuel costs at the meter.

These results indicate lowest break-even costs for Albuquerque, New Mexico, followed by Fresno, California (approximately 25% higher) and Caribou, Maine (approximately 200% higher). For total installed costs of the collector field (e.g., $14.17 per square foot of collector consisting of $11.37 for the concentrator and $2.80 for auxiliary equipment), present break-even metered fuel costs are less than $6 per million Btu at all locations and for periods of investment greater than 10 years. With a 5-year investment period, the costs are about $14.50 per million Btu (Caribou, Maine), $7.50 per million Btu (Fresno, California), and $6.25 per million Btu (Albuquerque, New Mexico).

The long-term benefits of solar energy utilization on the part of American industries highlight a special point that became clear during the CSERC concentrating collector assessment project: That a valuable opportunity awaits manufacturers who enter solar system production in a substantial way and introduce the cost savings available through mass production.

This report confirms that readily adaptable technology is available now to produce concentrating collectors in large quantities. Paralleling the production of collectors will be the need for hard-driving marketing efforts. It is naive to expect that potential users of solar energy systems will in many cases take the initiative. Potential users must be located and sold.

That users can be sold is increasingly evident because of many factors: declining supplies of traditional fuels, government policies, higher energy prices, solar energy systems that perform as promised, and the admitted cost-effective use of solar energy systems in various parts of the United States.

American automobile manufacturers did not put the world on wheels simply by perfecting manufacturing processes and making them work. They perfected the processes; then they vigorously sold the low-priced vehicles that resulted.

CSERC benefitted in this mass production feasibility study from the information, ideas, guidance, and expertise of American automobile makers. Potential manufacturers of concentrating collectors using the data assembled in this report could effectively adopt another lesson from the car people--the lesson of salesmanship as a proven way to build a market and help it grow.

With solar energy ripe for expansion, those who invest the time and capital needed to deliver solar energy systems will be in the best position to profit. The first to enter this field with mass production efficiencies will have a chance to develop a substantial lead. Early manufacturers should emphasize marketing, but marketing concentrating collector systems does not consist simply of arguments about the need for alternate energies. Provide the facts and figures, and potential customers can accurately interpret contemporary energy trends. Projected to the end of this century, available figures suggest a steady growth pattern in the use and cost-effectiveness of solar energy systems compared with traditional fuels.

10.2 CSERC DETERMINATIONS AND THEIR SIGNIFICANCE

CSERC evaluated five collector designs. Designs C (Thin Annealed Glass and Steel Laminate on Steel Frame Panel) and E (Thermally Sagged Glass [Slab]) were carried well beyond the evaluation stage with manufacturing processes worked out for production of large volumes (100,000 modules per year). For Design C, a process analysis is also given to cover low volume production (100-500 modules per year).

The five evaluated designs were originated at Sandia National Laboratories in the course of a research and development program. The PPT Concentrating Collector was designed to show what a high performance line focus system could accomplish. The components of the system emerged from the Sandia research and development effort.

The manufacturing processes recommended by CSERC give manufacturers a foundation for profitable production of concentrating collectors. The work done takes manufacturers well beyond the starting point. If this work had to be performed by a manufacturer, the time and expense required would burden the project with prohibitive research and development weights.

The CSERC findings are unambiguous. Mass production feasibility is amply demonstrated and supported for the concentrating collector designs selected and studied. The possibility for large-scale production of the systems has been confirmed, and indications are strong that such production is potentially economical, as fuel costs rise and the switch to solar energy grows in acceptance. This report identifies a number of ways future production can be made more efficient and cost-effective.

With the completion of the report, Volumes I and II, CSERC has done what it can to assist potential manufacturers of solar systems in starting effectively. The opportunity is real and immediate.

11.0 REFERENCES

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