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Amorphous Silicon Batch Process Cost Analysis

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a:Si Batch Process Cost Analysis

1. Executive Summary

Given that one of the objectives of the Photovoltaic Manufacturing Technology (PVMaT) project is "...to help US. industry accelerate the scale-up of production resulting in substantial reductions in manufacturing costs...," there is a need for baseline manufacturing cost data to assist PVMaT monitoring teams to assess current and future subcontracts. While the PVMaT project has some similarities to the previous materials R&D projects, the initiative includes emphasis on commercialization and production not previously essential in the materials research projects. A process for the manufacture of a single junction, large area, a-Si module has been modeled using an existing Research Triangle Institute (RTI) computer model. The model estimates a required, or breakeven, price for the module based on its production process and the financial structure of the company operating the process. Sufficient detail on cost drivers are presented that the relationship of the process features and business characteristics can be related to the estimated required price.

While this model has been used in the past by other organizations to project the likely costs and selling price for various photovoltaics modules, all of these previous analyses have relied on extensive extrapolations from existing lab scale activities to full scale production lines. The input data describing the process for this analysis is based on considerable a-Si production experience, and represents the type of plant that will be operational in 1993. Given this experience and the lack of extrapolation in the data, the resulting model of the manufacturing line accurately reflects the current state of a-Si thin film production and, as such, can be used as a baseline to evaluate various proposed process enhancements. It can also be used for comparison with other thin film options if they are modeled in the same manner.

All aspects of a current manufacturing process required to produce 185,874 square meters of photovoltaic modules per annum have been included in this very sophisticated model. Each individual work station with its capital costs, direct materials, labor requirements, yields and reworks have been modeled. All overheads including the indirect labor and management and the factory building, as well as the necessary sales activity, have been included. The financial model is equipped with the debt-to-equity ratio of the specific business, the cost of money, the relevant level of Federal and State taxes, and the required return on investment. A description of the RTI cost model is provided in Appendix B.

Given the focus of the PVMaT project on the production of photovoltaics for the bulk utility power market, an appropriate level of selling effort has been included consistent with servicing a few large US. based customers. The necessary cost of packaging required to facilitate the transportation of 152,356 modules, 155 cm x 78.5 cm in size, to the selected customers has been included; however, no additional distribution costs have been considered. It is recognized that in the near-term any commercial photovoltaics company will find it necessary to supply a variety of products to various types of customer, including a substantial export element; however, the associated cost of this wider product range and customer base has been excluded to facilitate

comparison with previous models. Given the ideal nature of the selected market it has been decided to consider that all of the plant's output is sold each year with no finished goods inventory remaining in stock at the end of each financial year. While this stock situation will be consistent with the selected market, it would not be representative of current manufacturers serving existing markets today.

In all other respects the inputs to the model are consistent with best current practice and all materials costs have been obtained from current volume suppliers. Although forecasts of the likely reduction in purchase price for some key components were obtained as a function of time and quantity, the impact of the forecasts have been reflected in this baseline case in only a limited way. The intent was to establish a realistic base case that accurately reflects the costs, prices and currently achievable yields. In the future this model can be enhanced to include the forecast cost reductions and yield improvements together with time scales for achieving the resultant projected required price reductions.

The a-Si production sequence consists of 22 in-line production stages (discussed in detail in Section 4) as well as additional rework and input stations. The base case considers the preparation of a single junction device on a TCO-coated, glass substrate. The case where the substrate is coated with tin oxide by the PV manufacturer is considered first, and subsequently the results are compared with the costs of purchasing precoated substrates. In all cases the production sets out to produce 185,874 square meters of modules per annum without any appreciation of the efficiency of the a-Si material. Once the minimum required price for the given area of modules is determined, the effective price in $\$/W_p$ can be calculated for various levels of efficiency. While the cost of manufacture is effectively independent of the level of module efficiency, the yields, particularly at the final stages of production, will exhibit a certain performance distribution. It is likely that yield will not be entirely independent of the assumed level of efficiency.

Assuming that the input soda-lime glass costs $2.97 per square meter when purchasing 500,000 square meters per annum, and that two sheets of glass are used to form the module with EVA encapsulant , the latter being included at $4.16 per square meter, the projected minimum required price of the finished module is $97.50 per square meter.

When the TCO deposition equipment is excluded from the calculations, together with the associated labor, materials, and utilities, and the cover glass is assumed to be purchased precoated with tin oxide, at a purchase price of $14.83 per square meter, the resultant minimum required price of the module is reduced to $94.87 per square meter.

Assuming a module efficiency equivalent to 53.76 W/m^2 (5.0 W/ft^2), the required prices above can be expressed as $\$1.81/W_p$ and $\$1.77/W_p$, respectively. At this efficiency level the 185,874 square meters per annum factory will output about 10 MW_p per annum. As the module performance is increased to 107.5 W/m^2 (10.0 W/ft^2), these prices would reduce to $\$0.91/W_p$ and $\$0.88/W_p$, respectively, without including any benefits of improved yields or reduced substrate purchase price.

Table 1-1. Summary of Required Module Price Components

ANNUAL PLANT PRODUCTION (M2 /YR) -	185874.
REQUIRED PRICE ($1993/M2)	97.504
BASE YEAR -	1992
SIMULATION LENGTH (YEARS) -	10
PLANT CAPACITY FACTOR (%) -	100.000
ANNUAL PLANT OPERATING TIME (HRS/YR) -	6016
MAXIMUM NUMBER OF SHIFTS PER WORKING DAY -	3
REQUIRED RETURN ON INVESTMENT (FRACTION) -	.200
DEBT TO EQUITY RATIO (FRACTION) -	.250
COMBINED FED/STATE INCOME TAX RATE (FRACTION) -	.370

PRODUCT PRICE COMPONENTS FIRST FULL YEAR OF PRODUCTION
(END OF YEAR DOLLARS)

COMPONENT	$1993/M2	% OF TOTAL
REQUIRED PRICE	97.504	100.00
ANNUAL MANUFACTURING EXPENSE	65.286	66.96
ANNUAL DIRECT MATERIAL EXPENSE	18.781	19.26
ANNUAL DIRECT LABOR EXPENSE	14.306	14.67
ANNUAL MANUFACTURING OVERHEAD	32.200	33.02
NET ANNUAL WORK-IN-PROCESS	.083	.08
SELLING & ADMINISTRATIVE EXPENSE	4.791	4.91
CORPORATE INCOME TAXES PAYABLE	10.576	10.85
EXCESS REVENUE (INTEREST EARNED)	-1.240	-1.27
ANNUAL NET INCOME	18.008	18.47

INITIAL WORK STATION EQUIPMENT COST ($1992)	15452500
INITIAL FACILITY COST ($1992)	4590605
TOTAL MANUFACTURING AREA (SQ M)	4347
TOTAL NONMANUFACTURING AREA (SQ M)	999
TOTAL FACILITY AREA (SQ M)	5347
TOTAL LAND COST ($1992)	146816
TOTAL DIRECT MANUFACTURING LABOR (# WORKERS)	87
TOTAL INDIRECT MANUFACTURING LABOR (# WORKERS)	18
TOTAL INDIRECT NONMANUFACTURING LABOR (# WORKERS)	22
TOTAL PLANT LABOR (# WORKERS)	127

A breakdown of the major components of cost associated with the estimated required module price (when uncoated glass is purchased) is provided in Table 1-1. The top section of Table 1-1 restates some of the input data and states the resulting required price. The center section provides the component costs in terms of both $\$/m^2$ and percent of the total price. Note that the manufacturing operations contribute 67% of the price and non manufacturing costs are 33%. The latter include costs of sales, management and administration, income taxes and net income (i.e., profit). Direct materials account for just under 20% of the price, while labor is about 15%. The manufacturing overhead includes the depreciation on process equipment and floor space, expenses for R&D, and all fringe benefit costs for manufacturing personnel.

The bottom section of Table 1-1 provides other selected measures of the business, including the cost of the process (work station) equipment, the facilities (i.e., building), the size of the building, and the aggregate employment. Direct manufacturing labor includes people who operate, maintain or service process equipment. Indirect manufacturing labor includes supervision for direct labor, and non manufacturing labor includes all other persons employed in the business.

An important observation regarding the price components in Table 1-1 is that the costs associated with the estimated required price arise from a number of sources. When required price is stated in terms of $\$/m^2$, some of the costs are not amenable to elimination or significant reduction through technological improvements in the manufacturing process or materials technology. For example, the required price is based on annual sales of $18.1 million for a profitable business that must pay income taxes. Those taxes are about 11% of the price, and are not reducible so long as the business remains profitable. Moreover, the capital investment required to establish this business is around $20 million, and a viable business must pay a return to the investors; in this case it over 18% of the price. Whatever the process, the general level of investment specified for the process examined here will be required. Materials incorporated in the modules are over 19% of the price, and while different materials systems may be substituted for the one considered here, the major materials costs (glass and EVA) are common to modules in any materials system. Thus, while changes in process or reductions in cell materials' costs may make modest reductions in the module price in $\$/m^2$, major price reductions are difficult to achieve. When price is stated in $\$/W_p$, however, improvements in the cell and module energy conversion can reduce the required price significantly. Although the area-price does not change, the energy-price can change just through improved efficiency. Thus, increased efficiency for any material system (e.g., a-Si, CdTe, $CuInSe_2$) may contribute more to reduction in the delivered energy price than the choice of material system. Of course, if it turns out that the physical constraints inherent in a given materials system or in the processes available for depositing those materials over large areas do not lend themselves to higher efficiencies, then that material system will be relatively unattractive commercially.

It needs to be recognized that an achievable yield of 67% was assumed for the tin oxide in-house deposition process, based on experience with large area substrate TCO deposition and the experience reported from commercial suppliers. The need for good layer uniformity necessary to achieve acceptable visual and performance specifications for the product has limited the overall yield of this coating process. The impact of improved yields at this stage is indicated in the parametric analysis presented in Section 4.4. No account has been taken of the potential for improving production yields through efficiency improvements obtained with customized TCO layers. The impact of forecasted reductions in the purchase price of precoated substrates in the medium term have been analyzed in Section 5.3. It is conceivable that as the PV markets grow and low "E" glass becomes readily available from numerous suppliers greater supplier flexibility will be possible and PV matching specifications can be met.

Having reached this level of understanding of the accurate economic characteristics of the a-Si production process on a medium scale, the analysis can be developed to consider larger scale production with modest efficiency levels. Various process options can be evaluated, such as

double- and triple-stack devices, as can the comparable economics of other similar thin film processes. In this regard, the CdTe PV production process has many of the same production steps, with the major difference being in the active layer deposition techniques and the speed of deposition.

The RTI costing methodology, when supplied with accurate data representing current state-of-the-art thin film production processes, can be used to evaluate the economic impact of proposed changes and enhancements to the production process. The a-Si single junction production model developed under this contract accurately reflects the total cost and projected minimum required price of modules that will be in production in 1993, subject to the assumptions made regarding process definition, operating schedules, marketing support level and production volume.

2. Product Description

The product being manufactured for this cost analysis is a flat plate photovoltaic module based on single-junction, amorphous silicon cells. The module is constructed using front and back sheets of untempered, soda-lime glass with overall dimensions of 1549 mm by 787 mm. Glass thickness is 3 mm. The cells are deposited on the cover glass sheet and the back sheet of glass is affixed with a sheet of ethylene vinyl acetate (EVA) that serves as an adhesive and for electrical isolation. There are 69 active cells connected in series via the tin oxide top electrode material and the aluminum back electrode material. Cells run the long dimension of the module and the various films are delineated by laser scribing. Electrical connections to the module are provided through two molded rubber boots on the back side. The module is provided with four aluminum mounting channels on the back side, fastened with an adhesive, that accept the head of an M6 bolt used to secure them to the support frame. The module is shipped with a plastic edge-protection channel that is removed prior to mounting. Overall module thickness, including the mounting channels, is 16.5 mm, and total weight is 19.1 kg.

Performance specifications are not germane to the cost of manufacturing the module, but are needed if the price per watt is desired, or if the production volume in terms of megawatts per year are of interest. A set of performance specifications that might be typical of currently produced modules is:

- Nominal maximum power output: 50 W
- Maximum power voltage: 38 Volts
- Maximum power current: 1.32 Amperes
- Open circuit voltage: 55 Volts
- Short circuit current: 1.8 Amperes.

3. Analysis Procedure

3.1. Model Overview

This cost analysis was carried out using a software model called STAMPP (STrategic Analysis of Manufacturing Process and Price) developed by the Research Triangle Institute. STAMPP models the manufacturing operations of a company and its overhead and financial structure to calculate the required, or breakeven, price of the product produced. The product price includes a specified rate of return on equity investment. Among the outputs of the model are a corporate income statement and balance sheet that allow financial analysts and managers to view the financial performance of the projected business over a period of years specified by the modeler. These reports are based on accepted accounting procedures whose input data is developed by a simulation of the product manufacturing operations required. On the manufacturing side, reports are provided that summarize the equipment, labor, materials, floor space, and utilities required in terms of both quantity and cost. Also reported are personnel and associated costs for administrative functions. The result is a complete picture of all aspects of the cost structure underlying the required product price. The STAMPP model provides the capability to define the major price drivers and the sensitivity of price to those drivers. The end result is an understanding of the cost structure of a given product manufacturing process within the context of a complete, profitable business enterprise. Costs can be related to individual process steps and the impact of

changes in those steps can be quantified. More details on the STAMPP model are included in Appendix B.

3.2. Modeling Assumptions

This analysis of a photovoltaic module manufacturing business used Version 4.0 of the STAMPP model, which assumes that the business operates a single plant manufacturing one product, which is the a-Si module previously described. The manufacturing operations are specified in terms of a process flow through a set of work stations defined by their input data. That data includes the throughput rate of product, the process yield, and requirements for labor, materials, floor space, and utilities. The annual production volume of finished product is an input, and based on that input and the performance of the process equipment, the model determines the total number of pieces of equipment at each work station. This result determines the total amounts of labor, materials, facilities and utilities. Costs of those items is then determined from a user-specified cost catalog containing unit costs of those items. The numbers of people employed in supervisory, support and management positions in the business are determined in the model by a set of rules that scale them to either the production volume or to the number of people employed in the processing operations. Facilities and other costs for these people are also calculated by the model.

The STAMPP model assumes that the business includes all of the normal required functions for a business, such as management, sales, human resources, research and development, etc. It also assumes that the business makes a profit and pays taxes commensurate to that profit. Thus, all of these costs of doing business, along with making the product, must be recovered in the sales revenues. The object of the STAMPP model is to determine the required revenue for the entire business supporting the manufacturing operations. This revenue divided by the specified volume becomes the required price calculated by the model. The required price is not a market price, since a market price is determined by market forces and may be either higher or lower than the required price. The value of the required price, if the model input parameters are chosen to produce realistic results, is that it allows the modeler to see the relative contributions to that price of many manufacturing, operational and financial parameters. The modeler should then be able to assess the value of changes and improvements in any aspect of the business, including the manufacturing operations, in attempting to reduce the price at which the product could be sold and make a profit.

3.3. Process Operating Conditions

The operating schedule and other constraints for the process as modeled with STAMPP are controlled by various input parameters. The base case parameter values are given in Table 3-1. The annual production volume for the completed modules is specified in square meters as 185,874. This number is equivalent to 2 million square feet, and also equivalent to 152,356 modules as defined for this analysis. The production equipment was designed to produce the specified volume on a three-shift-per-day, five-day-per-week basis. Shifts were specified as eight hours each, both for plant operation and for working hours of production employees. For these employees, ten days each of vacation, sick leave and holidays annually were specified, and

Table 3-1. Base Case Plant Operating Data

ANNUAL PLANT PRODUCTION (1000 units/yr)	185.874
FINAL PRODUCT UNITS	M2
MAXIMUM NUMBER OF SHIFTS PER WORKING DAY	3.00
PLANT OPERATING HOURS - 1ST SHIFT (hours)	8.00
- 2ND SHIFT (hours)	8.00
- 3RD SHIFT (hours)	8
PLANT OPERATING DAYS PER WEEK (days)	5.00
PLANT OPERATING WEEKS PER YEAR (weeks)	52.14
CLOSED WEEKDAYS PER OPERATING YEAR (days)	10.00
WORKING HOURS PER PERSON - 1ST SHIFT (hours)	8.00
- 2ND SHIFT (hours)	8.00
- 3RD SHIFT (hours)	8.00
WORKING DAYS PER WORKING WEEK (days)	5.00
WORKING WEEKS PER OPERATING YEAR (weeks)	52.14
PAID HOLIDAYS PER OPERATING YEAR (days)	10.00
PAID VACATION DAYS PER OPERATING YEAR (days)	10.00
PAID SICK DAYS PER OPERATING YEAR (days)	10.00
SECOND SHIFT WAGE FACTOR (fraction)	1.10
THIRD SHIFT WAGE FACTOR (fraction)	1.20
PLANT CAPACITY FACTOR (fraction)	1.00
FACILITY SERVICE LIFE (years)	30.00
RAW MATERIAL INVENTORY TIME (months)	1.00
FINISHED GOODS INVENTORY TIME (months)	.00
RESEARCH AND DEVELOPMENT THRESHOLD (output units)	2
MANUFACTURING SPACE MULTIPLIER (fraction)	.00
OFFICE SPACE MULTIPLIER (fraction)	1.00
MISCELLANEOUS SPACE MULTIPLIER (M2 /person)	2.97
EXTERNAL SPACE MULTIPLIER (M2 /person)	15.06
MANUFACTURING LIGHTING MULTIPLIER (W/M2)	100.07
OFFICE LIGHTING MULTIPLIER (W/M2)	100.07
SHIPPING SPACE MULT. (M2 /million output units)	1.00
RECEIVING SPACE MULT (M2 /million output units)	1.00

the model assumes that all days are taken. Additional persons are, in effect, hired to cover these absences. In addition, the plant is assumed closed ten days annually, which could be thought of as coinciding with the vacation periods or the holidays. Also specified are shift payment premiums for the second and third shifts of 10% and 20%, respectively.

There are a number of other input parameters that affect various overhead costs for the business. The plant capacity factor, 1.00 in this case, determines the available fraction of the production facility. This factor can be used to account for unscheduled outages of the facility. Facility service life is used to calculate depreciation on the building; equipment life is specified by work station. Materials and finished goods inventory times result in the need for operating capital. Finished goods inventory is zero for this study, implying that product is shipped essentially as fast as it is made. The research and development threshold (expressed as product volume) is set low so that the R&D expense defined in the cost catalog is fully charged as a cost. The manufacturing space multiplier is set at zero in this analysis because the specification of manufacturing floor space in the work station input data includes an allocation of the full amount of plant area to each work station. An alternative is to use the machine footprints as work station space and the multiplier to account for aisles and other necessary plant floor space. The other

space multipliers in Table 3-1 determine area in relation to the number of people involved. The lighting multipliers are used in determining the heating and air conditioning loads in the building.

The STAMPP model calculates the heating and air conditioning loads for the building as part of the utilities costs. There are additional input data (not shown in Table 3-1) that specify the location of the plant (Dallas, TX in this instance) and several location-specific climatic parameters, as well as various heat transfer properties of the building that are required by this calculation.

3.4. Financial Assumptions

In addition to the direct costs of manufacturing, the STAMPP model calculates the overhead costs of manufacturing, such as fringe benefits for employees. It also calculates the cost of capital for the business, as well as taxes paid. The model calculations span a period of years specified by the user, beginning in a specified base year. Unit costs of labor, materials, utilities and equipment are escalated over that span using an inflation table input by the modeler. Values for several financial parameters are input to determine the levels of these costs, and the values for the base case in this study are given in Table 3-2. The analysis time span (simulation length) was set at ten years beginning in 1992. The calculated breakeven price, based on the income statement, reflects the taxes paid and the depreciation for tax purposes for the business. Tax depreciation is based on the federal ACRS rules (the MACRS rules are more current). The balance sheet reflects the book depreciation method, which is straight line for this analysis. Equipment lives were stated in the work station data, and are generally seven to ten years. The cost of capital is essentially set by four parameters. Total capitalization required is determined by the model and divided into two parts by the debt-to-equity ratio of 0.25 in the base case. Debt is set relatively low because photovoltaics is not a well established industry and a standalone photovoltaics business would perhaps require a large part of its capital to be raised as equity investment. An interest rate is input for the borrowed portion of the capital (the bond interest rate) and a required return on equity is also input. Both of these parameters run to the high side for this analysis, again because of the emerging status of the industry. The marketable securities rate shown defines the return on cash invested by the business, which is primarily generated by depreciation. The model does not provide for any retained earnings.

The remaining parameters in Table 3-2 establish costs for employee fringe benefits and social security taxes. The fringe benefit parameter values have been used in previous similar studies and probably should be increased. The social security (FICA) cutoff and rate have recently been changed to a two-tier structure, but the model has not been updated to cover that structure. The error associated with that change is very small for this study. The inflation rate table shown contains values associated with the consumer price index. To be more accurate, separate rates for labor costs, consumable items and equipment costs should be used. The model only provides for a single inflation series, and the one used is a compromise.

Table 3-2. Base Case Financial Data

SIMULATION LENGTH (yrs)	10
BASE YEAR	1992
TAX DEPRECIATION METHOD (ACRS OR STRAIGHT LINE)	ACRS
BOOK DEPR METHOD (STRAIGHT LINE, SYD, OR DDB)	STRAIGHT LINE
REQUIRED RETURN ON EQUITY (fraction)	.200
DEBT TO EQUITY RATIO (fraction)	.250
BOND INTEREST RATE (fraction)	.110
MARKETABLE SECURITIES INTEREST RATE (fraction)	.090
COMBINED FED/STATE INCOME TAX RATE (fraction)	.370
PROPERTY TAX RATE (fraction)	.020
PROPERTY INSURANCE RATE (fraction)	.010
FICA SALARY CUTOFF LEVEL ($/yr)	53400.000
FICA RATE (fraction)	.076
UNEMPLOYMENT INSURANCE ($/person/yr)	245.000
HOSPITALIZATION & MEDICAL BENEFITS ($/person/mo)	150.000
FRINGE BENEFITS (fraction)	.100
PENSIONS (fraction)	.100

INFLATION RATE TABLE 1980-2000

YEAR	RATE
1980	.103
1981	.089
1982	.059
1983	.043
1984	.043
1985	.036
1986	.019
1987	.036
1988	.041
1989	.049
1990	.052
1991	.054
1992	.050
1993	.050
1994	.050
1995	.050
1996	.050
1997	.050
1998	.050
1999	.050
2000	.050

4. Process A: Purchase Plain Glass

4.1. Process Overview

The primary focus of this report is on a process for producing a-Si modules in which the superstrate is purchased as uncoated, untempered, soda-lime, float glass. This process is designated Process A to distinguish it from Process B, discussed in Section 5, in which the superstrate is purchased as the same glass with the addition of a TCO coating applied by the glass manufacturer. The process steps to coat glass are removed in Process B. The objective in examining this process variation is to illustrate the impact of a make-or-buy decision for a major component in the cost structure of producing the module.

Amorphous silicon modules are in routine production in at least 10 different locations in the world. Initially the material was used exclusively in portable consumer products such as calculators and therefore the starting substrate size tended to be relatively modest (less than 400 square centimeters) and the process was relatively expensive since the typical effective selling price of the calculator a-Si chip was effectively over $ 20 per watt. Once terrestrial applications were seen as a market for a-Si modules the need for larger area substrates and lower cost production became apparent. Many thin film production lines were established based on a substrate dimension of 30 x 90 cm. with soda lime float glass chosen as the low cost transparent substrate. These lines with a potential annual production capacity of 1 MW used a batch process to deposit the front and back electrodes as well as the semiconductor layers. The p, i and n layers were generally deposited in sequence in the same chamber using a box carrier to achieve efficient deposition of the a-Si onto the glass substrate by plasma enhanced chemical vapor deposition.

While this batch process was relatively easy to control and was capable of producing 40 watts per square meter modules on a high yield basis, the high capital cost relative to the throughput, the high labor content per module both in terms of direct operators and maintenance technicians, and the higher than acceptable direct materials costs for a complete encapsulated and framed module rendered this approach unsuitable for the lower-priced, utility power applications. Scaling up many of the individual process steps could improve the step economics, and the addition of automatic substrate handling was seen as a way of reducing the direct labor content per module. Modifications to the module design, such as abandoning the frame and changing the selected encapsulation technique, provided a viable process for the design and construction of a 10 MW per annum production plant.

The computerized economic model developed at RTI was supplied with data representing a current state of the art a-Si production process. Based on 22 in-line production stages, two additional rework stages, and two backing glass processing stages, the process-descriptive data have been developed from considerable thin film PV production experience, as well as specific supplier cost inputs and existing published material. Every effort has been made to avoid extrapolation to arrive at an accurate, current model of the a-Si production process to be used as the baseline from which process modifications and advancements can be evaluated.

The 22 in-line production work stations are as follows:

1. Unload Glass
2. Wash
3. TCO Deposit
4. Buffer
5. Wash
6. TCO Laser Scribe
7. Load Carrier
8. Preheat
9. a-Si Deposit
10. Unload
11. a-Si Laser Scribe
12. Al Sputter

13. Buffer
14. Al Laser Scribe
15. Isolate
16. Contact
17. Test
18. Anneal/Cool
19. Encapsulate
20. Frame and Connect
21. Test
22. Sort/Pack.

In addition to these in-line stations (called trunk stations in the STAMPP terminology), there are two branch stations (numbered 23 and 24 in some STAMPP output reports):

23. Unload Glass
24. Wash Glass,

and two rework stations (numbered 25 and 26 in some STAMPP output reports) that allow repairs where possible after each of the testing stations:

25. Rework First Test
26. Rework Final Test.

The data items that define a work station are as follows.

Process Data
- Work Station Name
- Work Station Description
- Process yield (fraction)
- Nominal production rate(product units/min)
- Machine availability (fraction)
- Product residence time (minutes) for WIP value
- Number production shifts per day
- Rework stream yield (fraction)
- Sample stream yield (fraction)
- Output product units (i.e. kg)
- Number of incoming branches
- Branch conversion factor (each branch)
- Input product units (i.e. kg)

Equipment data
- Purchase price ($1000s)
- Price year (i.e. 1992)
- Useful service life (years)
- Installation/replacement cost ($1000s)

Factory floor (area per machine)

Direct labor data

- Process operator (no. persons per/machine/shift)
- Mechanical/Electrical maintenance (no. persons per/machine/shift)
- Material handler (no. persons per/machine/shift)

Direct Materials (for each material)
- Material name
- Units of measure
- Price
- Quantity required (per unit product or time)
- Utilization factor

Utilities (for each utility)
- Utility name
- Units of measure
- Price
- Quantity required (per unit product or time)

Detailed model outputs are provided in Appendix A, including summaries of input data, process characterization data, and financial data.

The process yield, as the name implies, is a measure of the fraction of the product that enters the work station that proceeds to the next process step. In most cases for the in-line work stations this yield is in excess of 0.97 except for the TCO deposition, and the first and the final tests where the figure drops to 0.67, 0.92 and 0.95, respectively.

The nominal production rate in units per minute determines the necessary number of machines at a given work station to process the required throughput of product. The model works backwards from the stated annual product output at the final station via the yield fraction and the throughput rate to determine the effective throughput at every subsequent stage of the process. In the event that a single machine at a given station is unable to process the requested volume, the model will add an additional machine to achieve the stated volume. It is possible to run the program in another mode where the machine capacity is fixed and the output volume is maximized for that given capacity. In most of the stages of the process for the fixed output case selected here, namely 185,874 square meters of finished modules per annum (2 million square feet per annum) the capacity is handled by one machine operating at a rate of 1.22 square meters per minute. In some specific cases, namely the a-Si deposition and the encapsulation stages, the process rate is significantly lower at 0.80 and 0.81 square meters per minute, respectively. In the case of work station 9, the a-Si deposition, the process requires two machines to achieve the throughput.

The machine availability fraction takes into account down time and maintenance requirements. Typically this fraction is over 0.95 per work station. The program uses this average availability factor and production rate for each machine to calculate the total machine requirement. No account is taken of situations where the breakdown of one machine over a prolonged period of time might shut down other related machines due to lack of input components at the later stages of the process. This is a realistic concern in plants designed with only one machine at a given work station, which is largely the case for this analysis. Similarly the failure of two machines at the same time is not specifically considered. In the event that this type of stoppage hindered production one would set out to increase planned maintenance and provide buffer stocks of

materials as required. The product residence time is used to calculate the work in process at the end of each accounting period so as to calculate the carrying costs.

The plant is assumed to operate on a 5-day, 3-shift basis, and with the other operating parameters this results in the plant operating for 6016 hours per year. Maintenance is assumed to be completed during this normal work week. In the event that additional production is required from the given set of production equipment then the plant could be run on a 7-day, 4-shift basis. The rework stream yield takes account of the fraction of product that having failed the initial test is subsequently passed as good after rework. The sample stream yield in the above list of work station data defines the fraction of acceptable output at a given work station that is removed from the main process for analysis. The process analyzed here did not use this feature of the model.

In this analysis, the input and output product unit for a given work station is a unit of area (square meters). The output substrate from one stage proceeds to the next stage for further processing and so on. The output of the total plant has been defined in terms of a total area of finished modules per annum (185,874 square meters).

The capital cost of the individual work station in 1992 dollars and the useful service life and installation and replacement costs are used to calculate the depreciation charges on the business as well as the initial needs for financial resources. Typically a machine in this process is expected to last 7 years. Machine costs are reported in Appendix A.

The floor area requirement is used to determine the total area requirement and hence the total cost of the factory by using relatively standard rates. The extent to which the total required floor area is greater than the addition of individual machine footprints is determined by allowing sufficient additional room around a machine to enable the maintenance and production process to occur efficiently. Account is also taken of the need to be able to move stillages (i.e., movable racks) of glass around the plant by fork-lift truck from time to time. Sufficient area has also been allowed for offices, workshops and labs for this production plant to operate on a self sufficient basis.

The total labor requirement per shift for the process is calculated from the individual needs of the various work stations. Three categories of labor have been identified and suitable wage rates and shift premiums supplied to the model.

The direct materials and utilities required by each work station in the process are also provided to the model as usage rates based on operating time or per unit product. The only utility specified in this analysis is electricity. Specific direct materials are provided to the model in terms of the rate at which that material is consumed. For example, the TCO deposition station requires tin tetrachloride, oxygen and liquid nitrogen at specified rates. The annual consumption is determined by the model, and the total cost determined using unit prices in the requisite quantities obtained from the suppliers and entered into the cost catalogue.

Although the program accounts for over twenty different materials' costs, the major annual cost, as might be expected, is in three materials; namely, the front and back glass and the EVA encapsulant.

The key characteristics of each individual work station and the process through which the product is manufactured are now considered in sequence.

4.2. Detailed Process Description

Work Station 1: Unload Glass

The glass is assumed to be supplied precut to the required dimensions namely 155 cm x 78.5 cm with a thickness of 3 mm. Given the quantity of glass purchased for such a production unit it is possible to obtain the glass edge treated, thus avoiding the need for subsequent seaming on the line. The glass, being supplied in convenient stillages, is transported to the first work station by fork lift truck. Once positioned, the stillage is unloaded sheet by sheet using a custom built, electromechanical, automated process. Light sensors are used to enable the machine to locate the sheet of glass and four air driven suction cups are clamped onto the sheet to facilitate lifting. The automatic unloader can run at a rate of over one substrate per minute and achieve a high stage yield with little need for maintenance or material handling labor. The introduction of machine handling particularly with large area substrates has been found to reduce the occurrence of edge chips and subsequent substrate losses.

Work Station: 2 Wash

The as-unloaded substrate is cleaned using a standard automatic glass washer of the type supplied by Bilco. The detergent and water wash followed by air drying can be accomplished at a rate of better than one substrate per minute. The cleaned glass sheets are carried by motorized rollers to the next stage of the process.

Station 3 TCO: Deposition

This is one of the more critical steps of the production process. The electrically conductive, transparent tin oxide electrode is deposited using chemical vapor deposition on top of a coating of silicon dioxide used to limit the impact of any contaminants remaining in the as-supplied glass. Using relatively inexpensive tin tetrachloride as the source material at a rate of 0.031 kg. per minute, the tin oxide layer is designed to achieve the required conductivity, transparency and granularity to enable the subsequent layers of a-Si to absorb as much of the incident radiation as possible. A sheet resistance of 10 ohms/square and an optical transmission in the visible spectrum of greater than 85% has been found to give the best results. While increased surface roughness of the layer improves the device response, there is an upper limit set by the need of the thin semiconductor p-layer to completely cover the rough TCO layer. A white light haze of around 5% has been found to be satisfactory.

The other major inputs to this work station are nitrogen and oxygen at rates of 70 standard liters and 50 standard liters per minute, respectively. Based on a standard annealing furnace, the series of rollers, heaters, removable oil cooled injectors and forced air cooling enable the two layers to be coated onto the moving glass substrate at approximately the melting point temperature

(600 °C). The furnace and associated rollers and injectors are capable of processing glass 1.5 meters in width.

Work Station: 4 Buffer

Recognizing that the TCO coating equipment will require regular maintenance, including the removal of the injector assemblies for cleaning, it is convenient to have a buffer station between the coater and the first laser scribing station. The facility can exist to allow the substrates to bypass this station as and when the rate of TCO coating matches the input requirement to the next section of the line. Based on optical sensors, suction cups and a hydraulic arm that picks substrates from the line, this equipment is designed to remove plates from the line and stack them onto storage frames. The arm mechanism can also load glass from storage frames onto the next section of the line to maintain the product flow as and when the coating section is out of service. A suitable quantity of coated glass will be stored on theses frames and brought into service to keep the line flowing at the required rate. If it were valuable to mix purchased TCO coated glass with the in-house product, it could be conveniently introduced at this point. This machine would need to be of a custom design with many features in common with the unloader station at the start of the line.

Station 5: Wash

Allowing for the possibility that the TCO coated glass may have collected dust during the period of storage or during the coating process, this washer station is included to ensure that the plates entering the semi-clean environment of the laser station are clean and free of particulate. This station has the same characteristics as station number 2.

Work Station 6: TCO Laser Scribe

The laser scribe station makes use of Nd:YAG lasers, beam splitters and a moving XY table to cut 70 cells, each 1.11 cm wide and 150 cm long in the TCO layer. The length of the cells is restricted by two laser isolation lines cut across the short ends of the panel 2.5 cm in from the ends. Subsequent laser scribing stations are of the same basic design; however, the laser wavelength is halved to 0.53 microns to cut the a-Si and metal layers. The combination of the three laser cuts results in an active area loss of some 5.4%, with the width of the interconnect region being 600 microns.

Using a combination of roller tables and hydraulically driven arms, the substrate enters the laser station moving perpendicularly to the 155 cm dimension. The substrate is then automatically loaded onto the XY table that moves the product rapidly under the multiple laser beam pattern. Several passes of the plate are required to achieve the full 70 cells. The total laser scribing process can be completed within 75 seconds. This equipment uses standard laser components and specially built glass handling equipment. Care is taken to remove the laser generated debris to avoid particulate damage either at subsequent stations or to following plates at the laser station.

Station 7: Load Carrier

The a-Si deposition process is the only batch process in this production line. To ensure good uniform a-Si layers, and to avoid the need for extensive cleaning of the deposition chambers between runs, the substrates are assembled into a box carrier that can accommodate 48

substrates. The loader consists of a system for raising each substrate into a vertical orientation and a sensitive arm that locates the substrate, clamps onto it and inserts it into guides in the box carrier. This equipment is designed to load 48 plates within 48 minutes. Once a box is loaded the sequence commences again with another box. The substrates will remain in the box through preheat, a-Si deposition and cool down prior to unloading onto the a-Si laser station by a similar loader arm.

Work Station: 8 Preheat

Given the sophistication of the deposition chambers and the time the plates will occupy that chamber, it is more cost effective to preheat the considerable thermal mass of the box and the 48 plates to the required deposition temperature within a preheat chamber. The box is therefore automatically inserted into a heating chamber of the same physical dimensions as a deposition camber but without the associated RF, vacuum and gas flow equipment. The box remains in this heater chamber, once heated to the appropriate level, until a deposition chamber is available.

Station 9: a-Si Deposition

The plasma assisted a-Si deposition of the p, i and n layers occur in the same vacuum chamber. Once the box is inserted in the cylindrical chamber and the door closed the entire deposition process for the 48 plates takes 2.40 hr. By using two deposition chambers running in parallel an effective processing rate of 0.81 square meters per minute can be achieved. The design of this chamber minimizes the exposure of non substrate surface area to the plasma. A ratio of non substrate area to substrate area exposed to the plasma as low as 1.2% is achievable. This design results in extremely low levels of cross contamination, resulting in large fill factors for the finished modules. Fill factors in excess of 68% have been reported for this type of deposition.

Unlike the various continuous deposition processes, such as multi-chamber or roll-to-roll, the chamber used in this process is evacuated, flushed and filled with the required dopant gases in sequence to achieve the p, i and n layers. While the p and n layers use diborane and phosphene mixed with silane to achieve these relatively thin layers (less than 500 Angstroms), the economics of this deposition stage are dictated by the deposition rate and gas flow for the thick i layer (approximately 3000 Angstroms). A flow rate of 4 standard liters per minute is assumed for the silane for most of the deposition process, resulting in a consumption rate of 5.2 gm per minute.

The other major consumable required by this station is liquid nitrogen used to cool the pump traps and supply a nitrogen gas stream. The total liquid nitrogen consumption rate is assumed to be 1000 liters per day, equivalent to 0.694 liters per minute. The liquid nitrogen is specified to be purchased and stored in a leased storage tank. During the entire deposition process the substrates are maintained at the required temperature for optimum deposition. The entire sequence of this process is controlled by a dedicated computer system.

Work Station 10: Unload

This station is equivalent to the loader at work station 7. The arm is programmed to run the reverse sequence, loading the substrates onto the input roller table of the a-Si laser station. In addition to unloading the plates, sufficient time must be allocated at this station to allow the box and plates to cool. Provided that a sufficient quantity of box carriers and a large enough space is

available, the plates can be allowed to cool naturally. In the event that faster cooling would be required, cooling blowers can be modeled. This was not done in this study. This unload sequence can be carried out at a rate of 1.22 square meters per minute.

Station 11: a-Si Laser Scribe

This station is identical to station number 6 except that the laser wavelength has been shifted to 0.53 microns to ensure better absorption in the a-Si layer and therefore more effective cutting. The cutting sequence is assumed to be achieved at 0.97 square meters per minute (one substrate every 75 seconds).

Work Station 12: Al Sputter

While most of the other processes in this production line are scaled up versions of the techniques used in the small batch processes, the back contact layer that is used to form the series cell interconnection is a new approach in this large scale operation. Typically the final aluminum contact layer has been prepared using thermal evaporation, but in this full scale process sputtering has been selected as the preferred method. This continuous coating station consists of a series of load locks through which the substrate passes. The substrate moves horizontally perpendicular to the 78.5 cm. dimension beneath a cylindrical aluminum cathode that coats a 0.3 micron, continuous aluminum layer over the entire surface of the substrate. The coater can process the substrates at a rate of 0.97 square meters per minute. The consumption rate of the cylindrical aluminum target is assumed to be 4.32 gm per minute. The liquid nitrogen used to supply the cold traps is consumed at a rate of 0.174 liters per minute. This is a custom built sputtering system with approximately a 70 square meter footprint. It is assumed that the sputtered aluminum forms a better electrical contact than the thermally evaporated material. The coated substrates pass through the exit load lock via a roller table to a buffer station.

Station 13: Buffer

This buffer station is similar to station number 4 previously described. In this case the aluminum coated product is either passed directly to the laser scribe station or loaded onto storage frames for subsequent use, allowing for maintenance of the sputtering equipment. This buffer also will take up any mismatch between the relative processing rates of the stations following the buffer and the continuous flow of product from the a-Si laser station.

Work Station 14: Al Laser Scribe

The aluminum laser scriber uses the frequency doubled Nd:YAG lasers to achieve effective cutting of the aluminum layer. The remainder of the laser station is identical to the previously described systems. The substrate then moves on roller tables to the isolation station.

Station 15: Isolate

To avoid electrochemical corrosion of the final encapsulated product the various thin film layers are removed from the perimeter of the substrate, forming an isolation border of approximately 2 cm. in width. There are a number of different ways of removing these films including etching and abrasion. In this process the layers are removed using abrasive bead blasting. Four spray heads accomplish this removal without causing additional damage to the active layers. Appropriate orientation and positioning of the spray jets can accomplish this task. This operation

can be completed in a period of less than 1.22 minutes per substrate. The substrate then moves to the contact station.

Work Station 16: Contact

This station is designed to apply two strips of aluminum foil buss bar, one to each of the long edges of the substrate. The 1.6 cm wide foil strips are attached using ultrasonic bonding to the sputtered aluminum contacts at the extremities of the substrate inboard of the clear region of substrate resulting from the abrasion of the thin films. The bonding is achieved by two ultrasonic heads that are applied to the foil as the substrate is moved automatically, perpendicular to the short side, through this station. The foil contact strips serve to carry the high current of the entire panel and to form the connection to the lead-throughs to the outside of the encapsulation. The aluminum foil is consumed at a rate of 0.0595 square meters per square meter of module. Once the ultrasonic bonding is complete, additional lengths of foil are allowed to facilitate the connection to the external contacts. These contacts can be made either by taking the foil into sealed rubber boots at the edge of the substrate or by arranging to a have holes in the backing glass and contacting via boots set into the backing glass. For this model the contacts are assumed to be made at the extremity of the substrate. No major impact on cost is anticipated if one decides to bring the contacts out via the backing glass. Holes can readily be made in the glass by the supplier at a nominal cost given the volume of glass being purchased or the holes can be made within the plant using relatively inexpensive equipment. The product then moves from the contact station to the tester.

Station 17: Test

The I-V characteristic of the full size a-Si panel is measured at this point. The flash test is designed to simulate the AM1 spectrum at 1000 W/m^2 over the entire area of the panel and to achieve this illumination level within a period of 20 seconds once the panel is in position. A combination of xenon flash lamps arranged in a matrix and a computerized electronic load permit the I-V characteristics to be captured rapidly, allowing one tester to process all of the plant's throughput. The panel is automatically indexed in front of the light source and momentarily clamped in position while the analysis occurs. A combination of in-house standard test cells and periodic calibration with national standards ensures that this flash test accurately reflects the response achieved under static test conditions. Typically the panel with 69 active cells (one cell is lost to contacting) will exhibit an I-V curve with the I_{sc} between 1.5 and 2.0 amps and the V_{oc} between 50 and 60 volts. The fill factor of the panel is expected to be between 60 and 70%. It is assumed that a percentage of the panels at this first test will exhibit shunts that may well be the result of pin holes in the semiconductor layers that occurred during deposition. The model assumes that 8% of the product fails the first test and is subsequently passed via a rework work station for shunt treatment prior to being passed through the tester once again. The shunt treatment involves passing current through the shunts by applying voltage to the individual cells. The rework station is a work station in the same sense as the in-line work stations and has the same categories of input data. It is assumed that 80% of the reworked product is retested at the test work station 17 and 20% is discarded.

Work Station 18: Anneal/Cool

It has been found that a period of heat treatment enhances the contact stability of the PV panels. The product passes automatically through an oven at 100 °C and is subsequently cooled prior to passing to lamination. While the product is assumed to remain in this station for 90 minutes, the

production rate in terms of panels leaving the station is assumed to be 1.22 square meters per minute. This custom built work station is based on a modified, commercially available oven with access provided to allow the panels to be moved continuously into and through the heating zone. From this station the panels move to encapsulation.

Station 19: Encapsulation

Ethylene vinyl acetate (EVA) film has been in use as a PV encapsulant, meeting the necessary environmental tests routinely, for over 10 years, and as such provides a reliable, proven approach. Commercial laminators exist to perform this function. The backing glass that has been unloaded and washed using equipment identical to work stations 1 and 2, receives the layer of EVA, which is automatically fed from rollers to cover the entire area of the glass. The backing glass is identical to the initial substrate in terms of area and thickness and edge treatment. The EVA film is assumed to be 0.46 mm thick (0.018 in.), and is purchased at a price of $ 3.76 per square meter. The backing glass together with the EVA film in place are flipped over automatically onto the PV panel such that the PV panel comes into contact with the EVA and the two glass panels are aligned. The stream of laminates are then passed into two lamination presses to achieve the required throughput. Each lamination chamber can laminate two modules at a time. The laminate passes into the chamber where it is heated to approximately 100 °C and subjected to an even pressure from a rubber diaphragm, the bottom compartment having been evacuated and the top compartment containing the diaphragm having been vented to atmosphere. The modules can be processed at a nominal production rate equivalent to 0.82 square meters per minute. The work station is defined to include two lamination presses having a cycle time of 6 minutes. Once laminated the modules converge onto a single conveyor to enter the next station.

Work Station 20: Frame and Connect

At this station the four back-mounted support struts are bonded to the laminate and the sealed electrical connections are made. The module has been designed to meet environmental test standards without the addition of an expensive metal edge mounted frame. The absence of an electrically conductive frame at the perimeter of the module not only reduces cost but improves the ability of the product to pass the high-pot test. The length of any electrical breakdown path is considerably increased by placing the mounting struts at the rear of the module. In addition to bonding these struts and forming the contacts, this station also attaches a temporary polycarbonate edge-protection sleeve to facilitate handling prior to installation without chipping the edges of the glass. Once the product has been installed within an array the protective sleeve is removed.

The four 30-cm-long, anodized, extruded aluminum support channels are automatically bonded to the rear of the module in pre-set positions using a bonding adhesive. The aluminum contacts can be connected to the external electrodes via either a premolded insulating boot or an insulator that is molded in situ. This process used the premolded boots. The finished product then passes automatically to the final test station.

Station 21: Test

The finished module is I-V tested using a test station identical to that described in Work Station 17. The measured characteristics recorded on the first test are compared with the second test

readings with any significant variations being subject to further examination. This station automatically produces a measured performance label that is subsequently attached to the product. All performance data for modules are stored for future reference. The finished product then passes to sorting and packing. The product that fails the final test the first time (5% of the product flow) is passed to a rework station to allow any possible repairs. It is assumed that 80% of the product passing through the rework station is resubmitted to the test station and the remainder is discarded.

Station 22: Sort and Pack

It is assumed that the distribution in output product performance is segregated into several different performance bands at this point by referring to the measured data from station 21. Product of the same performance band is selected and packed in containers and suitably marked. It is assumed that 50 modules are packed in a single carton container and that each box, together with the polystyrene dividers, costs $125. No additional transportation or packaging costs have been included in this analysis. In the event that a wide range of different customers in different markets were to be supplied it is likely that the cost of transportation to the port of exportation would be born by the manufacturer. In addition higher selling and distribution costs are likely to be incurred.

4.3. Cost Drivers

4.3.1. Aggregate Measures

The breakeven price computed for the a-Si module is $97.50/m^2 in 1993 dollars. This price is equivalent to $118.98 per module. At a module conversion efficiency of 5%, the price is $1.95/$W_p$, and $0.98/$W_p$ at 10% efficiency. The various unit costs for such items as labor, material and equipment were input in beginning-of-year 1992 dollars, and these were escalated to end-of-year 1993 using an inflation table input to the STAMPP model. The version of the model used in this study employs a convention of defining the first year of operation of the business as a "start-up year" in which the plant is assumed to begin operation on January 1st (of 1992, in this instance). In the start-up year, the plant operates with a full complement of people and equipment, but it produces only one-half of the specified number of products. Materials costs are therefore halved. The above prices are for the second year of operation, 1993, in which the full volume is produced.

A breakdown of the price is shown in Figure 4-1, which gives the product price components in both dollars and in percent of the total. The price shown in the figure is determined from annual sales divided by the annual product volume. Figure 4-1 shows that the costs directly associated with manufacturing account for 66.96% of the cost , leaving 33.04% for nonmanufacturing costs. In the STAMPP model, the direct material expense (19.26%) includes only the materials actually used to construct the modules. Direct labor (14.67%) covers only people directly assigned to operate or maintain process equipment and to handle materials on the process floor. The cost of supervisors for these people in manufacturing are included in the annual manufacturing overhead item (33.02%). Also included in this manufacturing overhead are expenses for the fringe benefits for all manufacturing people, the R&D labor, utilities for the manufacturing operation and the depreciation on process equipment and facilities. A further breakdown of labor, materials and overhead costs is provided later.

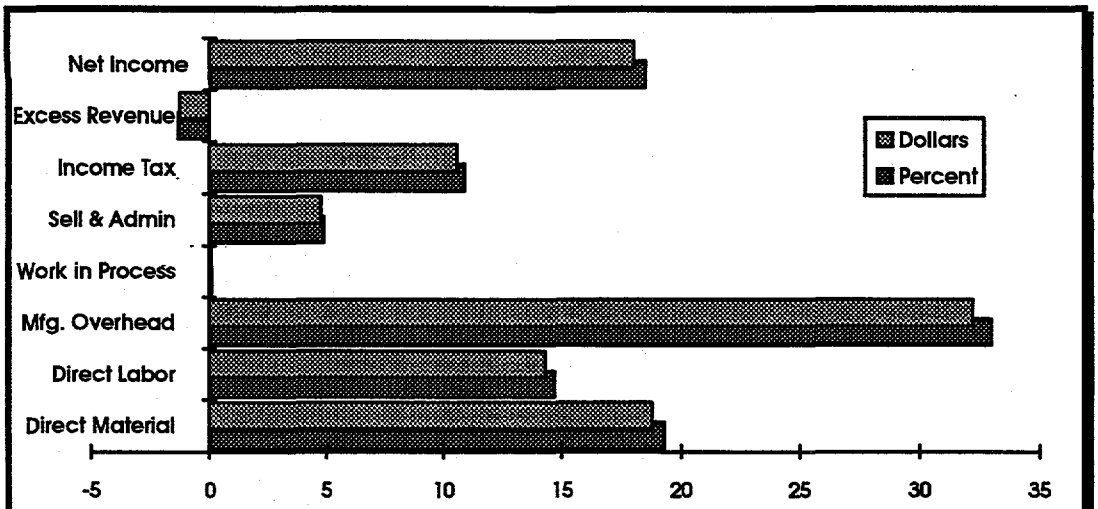

Figure 4-1. Required Price Components, Dollars and Percent of Total (Total = $97.50 in 1993 end-of-year dollars)

The selling and administrative expense shown in Figure 4-1 (4.91%) covers all of the expenses of the people who are not employed directly in manufacturing, including their salaries, fringe benefits, supplies, depreciation on their facilities, and utilities for those facilities. These people include top management, sales, and administrative functions.

Net income (18.47%) is a required return on equity investment (hence the term "required price"). It is calculated as a fraction of the equity investment in the business, the fraction (0.20) being input data to the model. The model first determines total capital required by determining the amount of process equipment needed and the associated floor space. Also determined by the model is the amount of floor space required for all of the supervisory and administrative personnel. Costs for all of the equipment and facilities constitute the total investment, which is separated into two parts, debt and equity, based on an input debt-to-equity ratio. The total capital required for the business is $20,920,089, of which $15,452,500 is for process equipment. Also included in the total is $3.77M for process floor space and $500k for an R&D lab.

Given the net income, the corporate income tax payable (10.85%) can be determined using the input tax rate. The tax rate for the model is a combined federal and state rate. In this particular case the state rate is zero.

The item "excess revenue" accounts for the balance between two items: 1., the interest paid on the debt portion of the total capital required, and 2., the interest earned on the investment of the cash generated, principally from the depreciation charges. In this analysis, there is a net income from these two items, shown as -1.27%.

The remaining item in Figure 4-1, net annual work-in-progress, is quite small in this analysis (0.08%). The cost of work in progress is calculated by specifying to the model the amount of in-

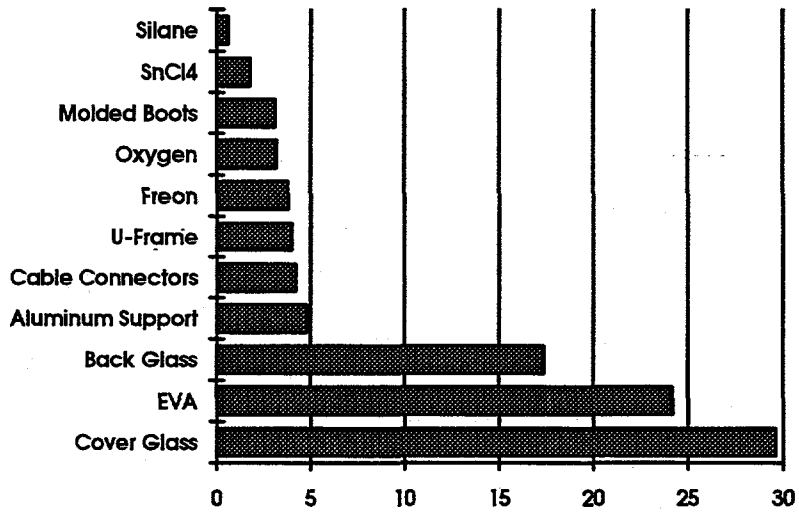

Figure 4-2. Percent of Total Materials Cost (1993 end-of-year dollars)

process product at each work station. The model calculates the cost associated with this product based on a value of one-half the cost of completed product. This is admittedly a simplistic approximation, but the result is very small relative to other costs, indicating it is probably good enough.

4.3.2. Materials Costs

The materials used to construct the modules are a significant factor in the breakeven price. Figure 4-2 lists the 11 highest total cost materials that were accounted for in the analysis. The cover glass is the most expensive item in the materials list, accounting for about 30% of the total materials cost. When combined with the back glass, the total contribution of glass to the materials cost is 47%. In terms of the total module price, glass contributes just over 9%. A 3 mm thick (0.118 inch), untempered glass was specified for both parts. The unit price for both glass parts was the same, but due to yield attrition in the process the quantity of the cover glass, which is processed first, is considerably higher than that of the back glass. EVA is the second most expensive material, accounting for about 24% of the materials total, and contributing almost 5% of the module price.

The contribution of the individual materials to module price drops substantially after the back glass, none of the remaining ones contributing more than 1% to the module price.

4.3.3. Labor Costs

The numbers of people employed by the modeled business are detailed in Table 3-3 for both the manufacturing and non manufacturing operations. Direct manufacturing labor requirements for the process were specified in the three categories indicated in Table 3-3; namely, process operator, mechanical/electrical maintenance, and material handler. These requirements are specified to the STAMPP model for each work station in terms of whole or fractional numbers of persons per machine per shift. The process is operated three shifts per day for five days per week. The model determines how many machines are required and thus how many persons in each category are required for each shift. Even though fractional numbers of persons may be specified as required, only whole numbers are allowed for each job title for each shift. The result is that a total of 87 people are employed in these jobs, contributing about 15% of the total module price.

Table 3-3. Employment Summary

(1993 End-of-Year Dollars)

MANUFACTURING DIRECT LABOR

LABOR CATEGORY	NO. OF PERSONS*	HRS/YR	SALARY	$/YR**
1 PROCESS OPERATOR	45	80280	16.5 $/HR	1510819
16 M/E MAINT	9	8091	14.3 $/HR	261875
21 MATL. HANDLER	33	53037	13.2 $/HR	886347
TOTAL DIRECT LABOR	87	141408		2659042

MANUFACTURING INDIRECT LABOR

LABOR CATEGORY	NO. OF PERSONS	SALARY	TOTAL
SHIFT EMPLOYEES			
1 Material Handlers	3	19042	62839
2 Production Supervisors	3	50178	165587
3 Clerks, Production Supervisors	3	22258	73452
6 Plant Production Foremen	3	38984	128648
10 Machine Shop Workers	3	33837	111665
TOTAL INDIRECT MANF SHIFT LABOR	15	N/A	542193
NON-SHIFT EMPLOYEES			
1 Vice President Manufacturing	1	78740	78740
2 Director of R&D	1	59699	59699
8 Manufacturing Sec II	1	21057	21057
R&D EXPENSE/YEAR	N/A	N/A	1102502
TOTAL INDIRECT MANF NON-SHIFT LABOR	3	N/A	1261999
TOTAL MANUFACTURING INDIRECT LABOR	18	N/A	1804193

NON-MANUFACTURING LABOR

LABOR CATEGORY	NO. OF PERSONS	SALARY	TOTAL
NON-SHIFT EMPLOYEES			
1 President	1	88199	88199
2 Vice President Finance	1	48620	48620
4 Payroll Accountant	1	29266	29266
6 Manager of Data Processing	1	29877	29877
8 Vice President Facility Administrat	1	46966	46966
10 Clerks, Personnel	1	18191	18191
11 Director of General Facility Operat	1	31862	31862
14 Receptionist	1	13781	13781
15 Vice President Sales	1	67472	67472
20 Administrative Sec II	4	21057	84230
SHIFT EMPLOYEES			
21 Security Personnel	3	16316	48950
22 General Facility Maintenance Worker	6	16647	99886
TOTAL NON-MANUFACTURING LABOR COST	22	N/A	607307

The model also determines a number of employees in certain supervisory and support activities in manufacturing listed as indirect manufacturing labor in Table 3-3. The materials handlers in this category are not the same as the ones directly involved with process equipment (direct labor). The item "R&D Expense/Yr" is listed in the indirect labor category because an R&D expenditure has been specified on a per-unit-product basis, and it is assumed that most of it will be spent on R&D personnel. No number of people is specified in this activity, however.

All of the non manufacturing employment shown in Table 3-3, except for security, maintenance, clerks and secretaries, is fixed in the model. These are considered a minimum complement of administration. The variable positions are determined by the model in proportion to the total employment of the business. The model generally provides for several other job titles, but given the relatively small size of the business modeled, these were either not required by the size or were artificially zeroed out to reduce overhead costs.

In the specification of the process for this analysis, the work stations were assigned to three cost centers, which provides some disaggregation of costs by cost center. The STAMPP model also restricts direct labor personnel to the cost center to which their work stations are assigned; that is, direct labor personnel cannot cross cost center boundaries. The result is that the utilization of people in the direct labor positions, defined as the number of hours available among the people hired divided by the hours actually required, may be less than 100%. Figure 4-3 shows the labor utilization for each cost center and for the process overall. Utilization overall is high for all but the maintenance personnel. No attempt was made in this analysis to optimize the use of personnel, and the cost of labor could perhaps be reduced if further consideration were given to this issue.

4.3.4. Manufacturing Overhead Costs

In Figure 4-1, manufacturing overhead is shown to account for about 33% of the module required price. The components of manufacturing overhead as defined in the STAMPP model are shown in Figure 4-4. The largest component is the depreciation on process equipment and facilities, of which most is depreciation on equipment since it represents about 80% of the capital cost and has a shorter depreciation life. Two categories of labor are included in the overhead: R&D labor and supervisory labor. R&D labor is modeled as a dollar amount per unit product and assumed to be primarily labor. The supervisory labor is composed of specific job titles wherein the number of people is determined by the direct labor employment required. For example, for each increment of 25 people in the process operator category one foreman is required.

All of the costs of fringe benefits for all manufacturing personnel, including direct labor personnel, are included in the manufacturing overhead cost. Property taxes and insurance on all of the manufacturing equipment and facilities are likewise included.

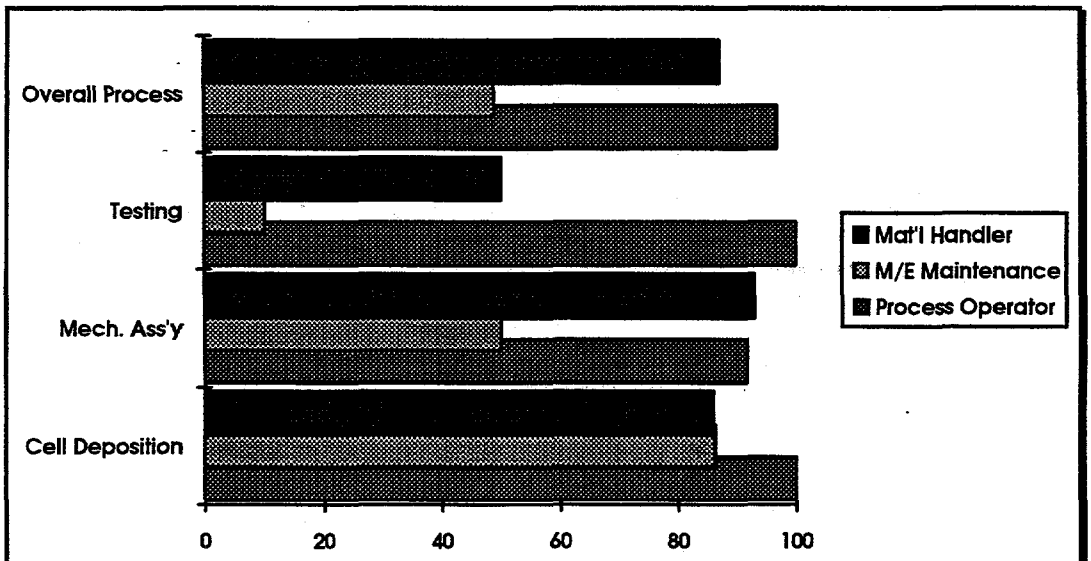

Figure 4-3. Labor Utilization (%)

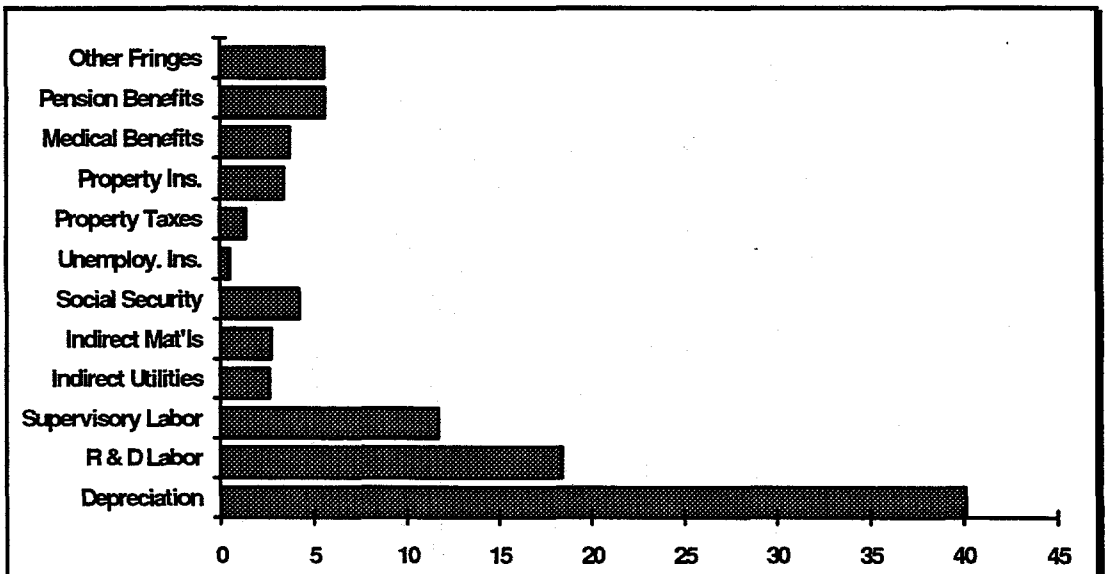

Figure 4-4. Manufacturing Overhead Components (%)

4.4. Parametric Analysis

In the foregoing subsections, the cost components of the module required price for the base case when purchasing plain glass as a sub- and superstrate have been compared to one another. Some of these components of price are clearly large contributors, and some are quite small. There is always uncertainty in the statement of the underlying data for these components. For example, labor rates tend to vary from place to place and materials costs fluctuate with their markets. It is useful to consider what are the impacts on required price relative to some of its larger contributors. Figure 4-5 illustrates the sensitivity of price to eight parameters selected to cover several types of data inputs. The parameters are:

- Process yield of the TCO deposit work station
- Price of the TCO work station machine (CVD reactor)
- Process yield at the first, or unencapsulated cell, test work station
- R&D expense expressed as dollars per unit product
- Unit cost of plain glass sheet, dollars per square meter
- Unit cost of manufacturing floor space, dollars per square meter
- Unit cost of all three direct labor positions, dollars per hour
- Return on investment expressed as a fraction of equity investment.

The variation in price is plotted for each parameter as a function of the base case value of the parameter (= 100%). This causes all of the parametric curves to pass through the base case point and means that the slopes of the curves represent the sensitivity of price to the parameter. Sensitivities can then be compared for the various parameters.

The TCO deposition unit process is a very important one because its yield is specified as being low (67%) relative to the other unit processes, and because a single reactor for this unit process is the most costly single piece of equipment. Also, the product rejected at this point includes one piece of glass, which is the most expensive single materials component in the module. Although the points related to the two yield parameters are connected by lines in Figure 4-5, the sensitivity relationships are not necessarily smooth curves because changes in yield can result in discrete changes in the number of machines and people who operate them, and this discrete change would result in a discontinuity in the curve. The lines in the case of yield parameters suggest a trend rather than a continuous function.

All of the sensitivity relationships for the unit prices of components, including the one for return on equity, which is the unit price of equity capital, are straight lines with a positive slope. The lines for glass price, manufacturing floor price and TCO equipment price are nearly coincident.

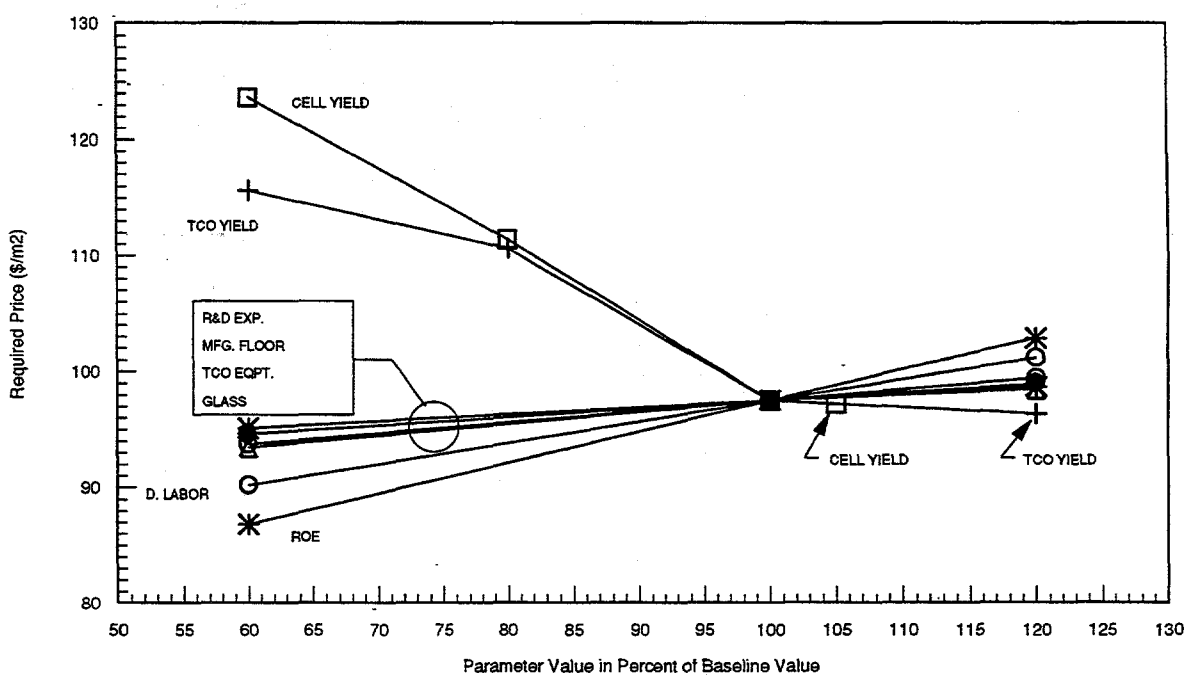

Figure 4-5. Sensitivity of Required Price to Selected Parameters

4.5. Annual Production Volume Effect on Required Price

The process described above for making a-Si modules has been designed to produce nominally 186,000 m^2/yr while running three shifts per day, five days per week. The work station throughput rates for the base case were specified such that one machine per work station satisfied the production volume, except in the case of the p-i-n deposition, which requires two batch reactors. In a number of the work stations the throughput rates are such that machine utilization is near 50%, meaning that substantial additional production could be achieved with the same equipment. Given the base case work station definitions, it is of interest to determine the effect on module cost of running more or less volume with this equipment. Since annual product volume is an input to the STAMPP model, and the model calculates the required number of machines at each work station, taking into account the number of shifts and number of days operated, one can determine the product price for any volume and the commensurate amount of process equipment.

Figure 4-6 shows the results of a number of model runs for varying product volume, plotted as a percentage of the base case value of 185,874 m^2/yr (= 100% volume). Three combinations of shifts/day and days/week were examined over a range ofvolumes to find the points where

changing the operating schedule resulted in lower product cost. The base case process was 3 shifts/day, 5 days/week at 100% volume, and the lowest price at that volume is obviously for that schedule.

That same schedule also produces the lowest price among the three schedules so long as the volume is from about 50% to 135%. The shape of the 3-shift, 5-day curve is explained by the fact that the model cannot reduce equipment as the volume is reduced below 100% because there is only one machine at all but one work station, and so the equipment depreciation, as well as the building depreciation, is carried by fewer and fewer units of product. There are other fixed overheads as well that cannot be reduced. Moreover, because the number of direct labor employees is tied to the number of production machines, direct labor cannot be reduced either. The result is a fairly sharp increase in module price as the volume decreases.

If volume is increased on the same production schedule, then these costs are spread over more product and the price goes down. Other fixed costs are also spread over more volume. As the volume increases, it is possible for the model to add process equipment, floor space and people as needed. These are added in discrete increments, which means that the price-volume curve is not smooth as shown, but will have discontinuities. Not enough points were generated to illustrate this effect, and the "curve" is actually shown as straight-line segments. These additions can increase the price over a narrow range of volume, but the trend is down. In every instance, the direct materials are consumed in direct proportion to the product volume, so they do not contribute to the product unit price variation shown.

A smooth line drawn through the price-volume relationship would approach an asymptote because the nature of the model is such that it begins to add components of cost (equipment, floor space, people) in proportion to the volume, so long as the operating schedule remains the same. Changing the schedule, as illustrated in Figure 4-6, at appropriate volumes will result in lower product prices. For example, if the schedule is changed to one shift per day, five days per week when the volume is below about 50%, then a lower product price will result. In the process analyzed here, the equipment still cannot be reduced, but the labor utilization will be increased because the second and third shifts will not be hired. All production occurs on one shift rather than being spread over three shifts.

If the production volume is increased above about 135%, then Figure 4-6 shows that it is more cost effective to change the schedule to 3 shifts per day and 7 days per week. This in effect adds a fourth shift of people and gets better utilization of the process equipment. It also spreads some fixed costs, such as management and administrative support costs, over more product. The reduction in cost over the base case schedule is modest, however. Practically speaking, the reason for the modest cost reduction is that the process again begins to be replicated by the model as volume increases and the price-volume relationship becomes asymptotic. In a realistic situation, additional cost reductions would likely be gained by redesigning the process equipment to get economies of scale in the equipment design. It may be intuitively argued, however, that so long as the same physical processes are employed in the work stations, the price reductions available from this redesign are not without limit; there is an asymptote somewhere that can only be overcome with different physical processes.

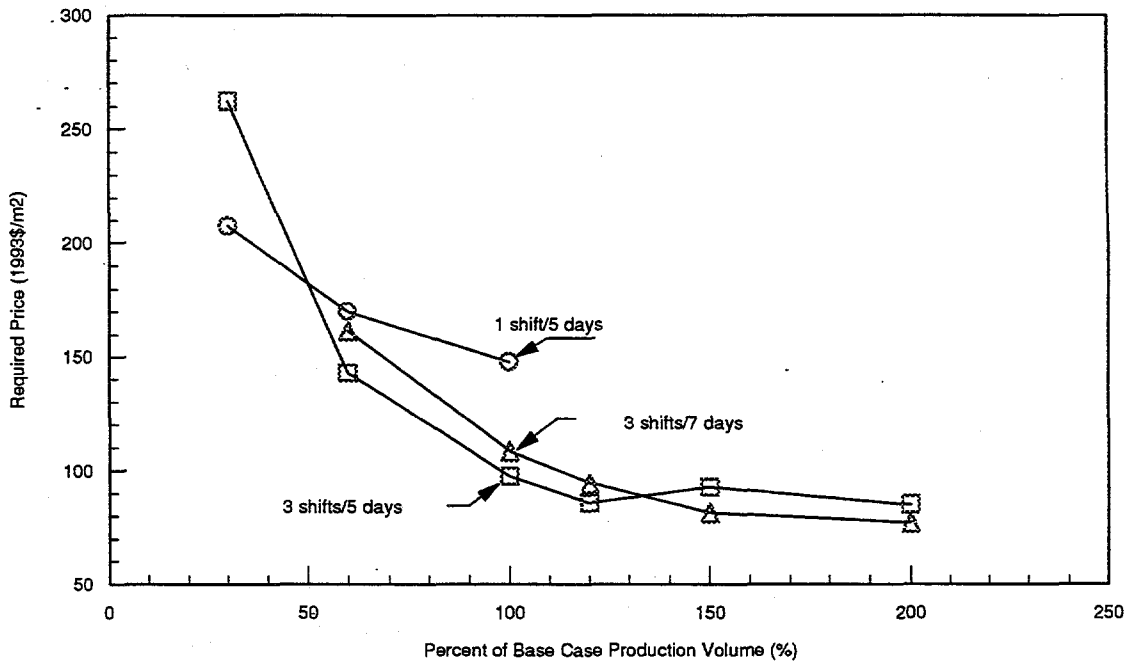

Figure 4-6. Effect of Production Volume on Required Price

5. Process B: Purchase TCO-Coated Glass

5.1. Process Overview

The work station with the highest capital cost in Process A described in Section 4, in terms of equipment cost, is the TCO deposition. The most costly single material was shown to be the glass used as the cover glass. Since glass manufacturers routinely coat glass with various thin films for the purpose of aesthetics or solar heat gain control, the question arises at to whether it might be cheaper to buy the cover glass with the tin oxide coating already on it - a classical make-or-buy question.

To analyze this question, a separate Process B was defined in which the specification and unit cost of the purchased cover glass were changed to reflect the increased cost from the manufacturer and the TCO coating operations were removed from Process A. Specifically, the price of the glass was increased from $\$2.69/m^2$ to $\$13.45/m^2$, a factor of five. Parametric variations of the price were also examined. Three work stations were omitted from Process B: the TCO deposition work station; the buffer work station following the deposition; and the washing work station prior to scribing the TCO. The cover glass in this process is unloaded as before, cleaned and immediately scribed. These changes reduce the capital cost for equipment

by $4,885,000, or almost 32%. The cost of cover glass increases to 333% of the Process A cost, from $972,034 to $3,240,069. The reason that the total glass cost does not increase in proportion to the glass unit price is that the TCO deposition step was specified to have a process yield of 67%. When the glass is coated by the glass maker, this step is removed and the glass quantity drops from 327,756m^2 to 218,501 m^2 per annum. Other less obvious changes occur in the components of the estimated price of the module, and the significant changes are discussed in the following section in terms of a comparison between the two processes.

5.2. Cost Comparison: Make or Buy TCO Coating

The cost components from Figure 4-1, relating to Process A for making TCO in the PV module plant, are reproduced in Table 5-1 along with the values for the same components for Process B, buying TCO-coated glass. The total reduction in estimated module price is only about $2.63/m^2 when buying TCO-coated glass, or less than 3%, despite having eliminated a relatively expensive processing step. The reasons for this modest change can be seen by considering the cost components in Table 5-1, starting with the cost of materials. Materials costs are approximately $10/m^2 more when the coated glass is purchased at the prices given in the previous section. The materials cost as a percent of the total module price is also about ten percentage points higher when purchasing coated glass. A comparison of the contribution of the various materials to the total materials costs for the two processes is shown in Figure 5-1. Glass is the largest cost for either process, but the coated glass is a much higher fraction (61.7%) for the buy-TCO process. Freon, oxygen and silane are not used in the buy-TCO process, but they are small contributors to the make-TCO case. It is possible that the coated glass can be purchased at a lower cost that the base case value for Process B, and this effect is examined in the next section.

The reduced cost of process equipment reflects itself in three major cost components: manufacturing overhead, net income and corporate income tax. Figure 5-2 shows the relative contributions of the work station equipment to total process equipment cost. Note that in the make-TCO case the TCO deposition equipment cost is 29.3% of the total, and is the largest single cost. Without this process step, the aluminum sputtering equipment is the largest in the buy-TCO case at 23.9% of the total. But, as noted above, the total is nearly $5M less. This reduction in total capital requirement is responsible for the fact that net income is down in the buy-TCO case by almost $5/m^2, and income tax is down about $2.50/m^2. Net income is determined in the model as proportional to equity capital investment. Taxes are reduced because they are in direct relation to net income. With regard to this aspect of the make-buy issue, there can be additional benefits to buying the coated glass, depending on one's business priorities. Buying TCO reduces the capital required to get into the business, and it puts the risk associated with producing good quality coatings in large quantities on a supplier. It also puts the process in the hands of the glass makers who have more experience at this time in such coatings. However, it does put a key operation outside of the PV manufacturer's control and puts his production at risk if the supplier does not meet his requirements or production schedule. This is not seen as a serious risk given that there are several potential suppliers.

The manufacturing overhead reduction for the buy-TCO process of almost $5/m^2 shown in Table 5-1 is also due to the reduced cost of process equipment, which reduces the depreciation

Table 5-1. Comparison of Major Price Components for Make/Buy TCO

ANNUAL COMPONENT	MAKE TCO		BUY TCO	
	1993$/M2	% OF TOTAL	1993$/M2	% OF TOTAL
SALES	97.504	100.00	94.871	100.00
MANUF.EXPENSE	65.286	66.96	69.706	73.47
DIRECT MAT.	18.781	19.26	28.972	30.54
DIRECT LABOR	14.306	14.67	13.330	14.05
MANUF. O/H.	32.200	33.02	27.403	28.88
NET WIP	0.083	0.08	0.045	0.05
SELLING AND ADMIN	4.791	4.91	4.791	5.05
CORP. INCOME TAX	10.576	10.85	7.798	8.22
EXCESS REVENUE	- 1.240	-1.27	-0.745	-0.79
NET INCOME	18.008	18.47	13.277	14.00

charges. Figure 5-3 shows the relative contribution of the various manufacturing overhead components. Depreciation is the largest contributor for make- or buy-TCO, but is smaller in the latter process. R&D labor and indirect labor are the same in absolute terms for both processes, but are relatively larger in the buy-TCO process because depreciation is so much smaller in absolute terms.

In Table 5-1, direct labor cost is slightly reduced in the buy-TCO case because direct labor is specified in terms of persons/machine at the work stations and fewer pieces of process equipment are used. The reduction in labor cost is nominally $1.00/m^2.

It is apparent, therefore, that the elimination of a process step whose equipment is relatively costly and whose yield is relatively low (TCO deposition) could significantly reduce the price of the module. This is offset in this analysis by the increased cost of the a material (purchased glass), and it happens that the net reduction turns out to be rather modest. If the price of the coated glass were less than estimated for this case, then a larger net saving would accrue. In the following sections, some more detailed examination is made of the size of additional cost components, and a parametric analysis is given to illustrate the impact of variations in those costs.

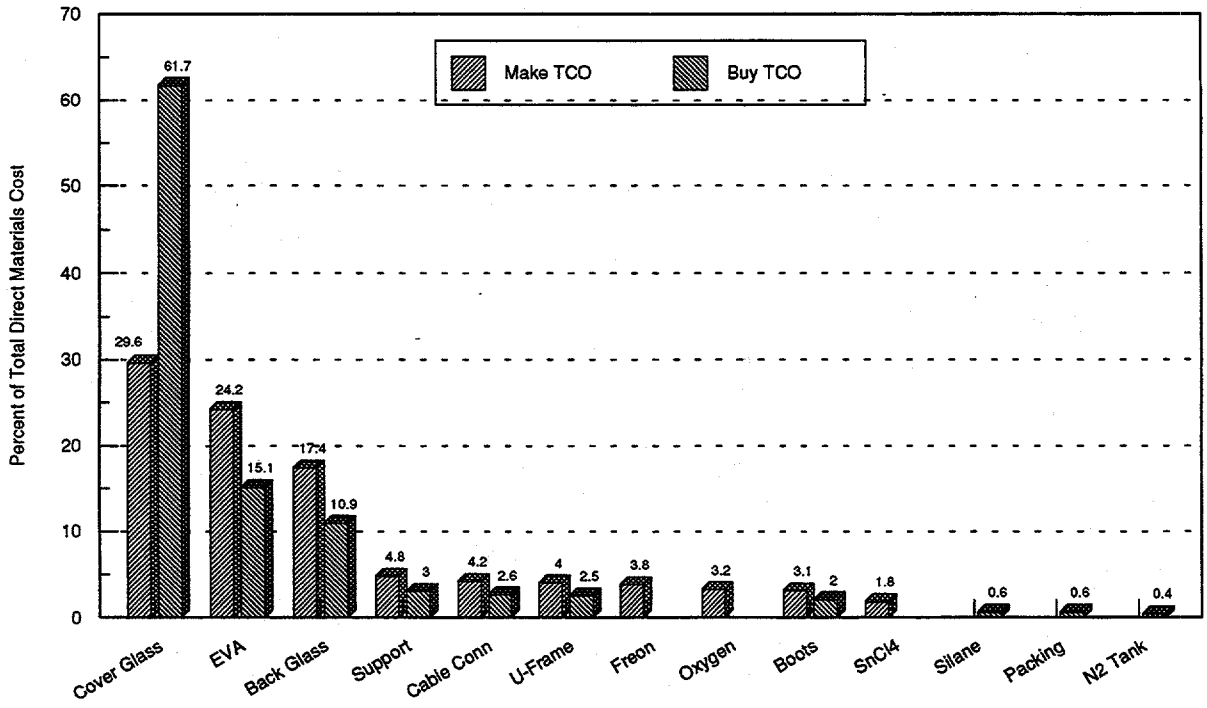

Figure 5-1. Relative Cost of Direct Materials

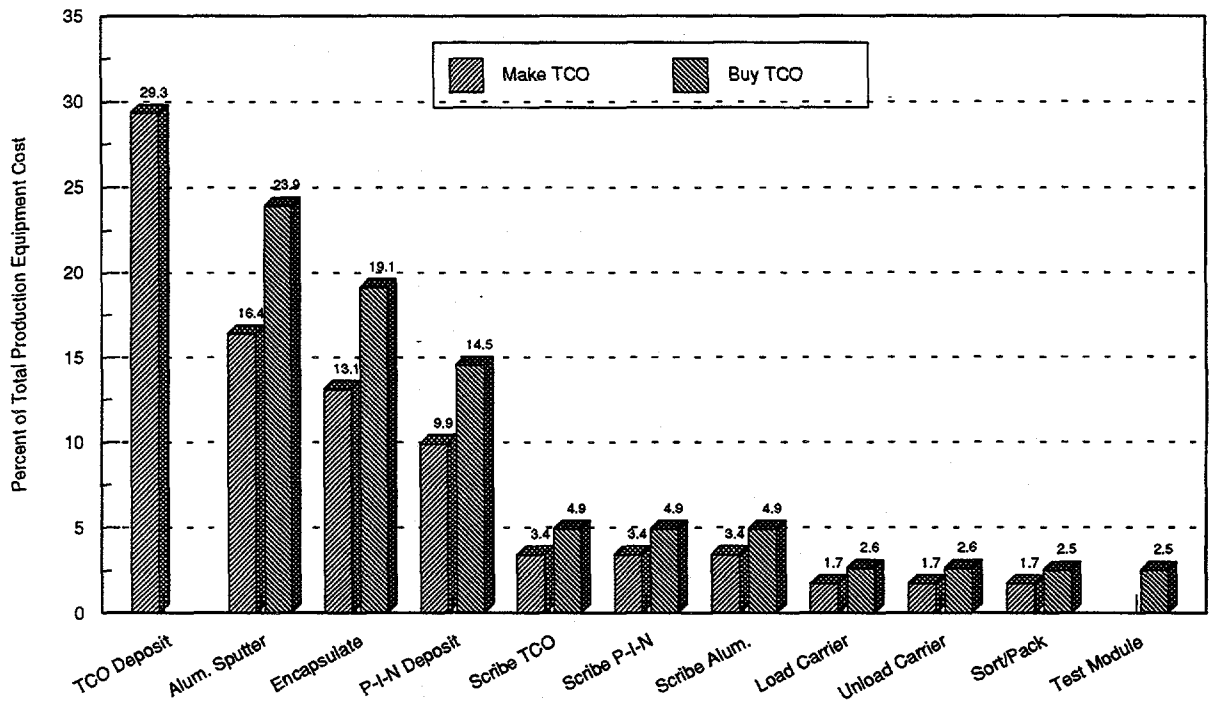

Figure 5-2. Relative Cost of Work Station Equipment

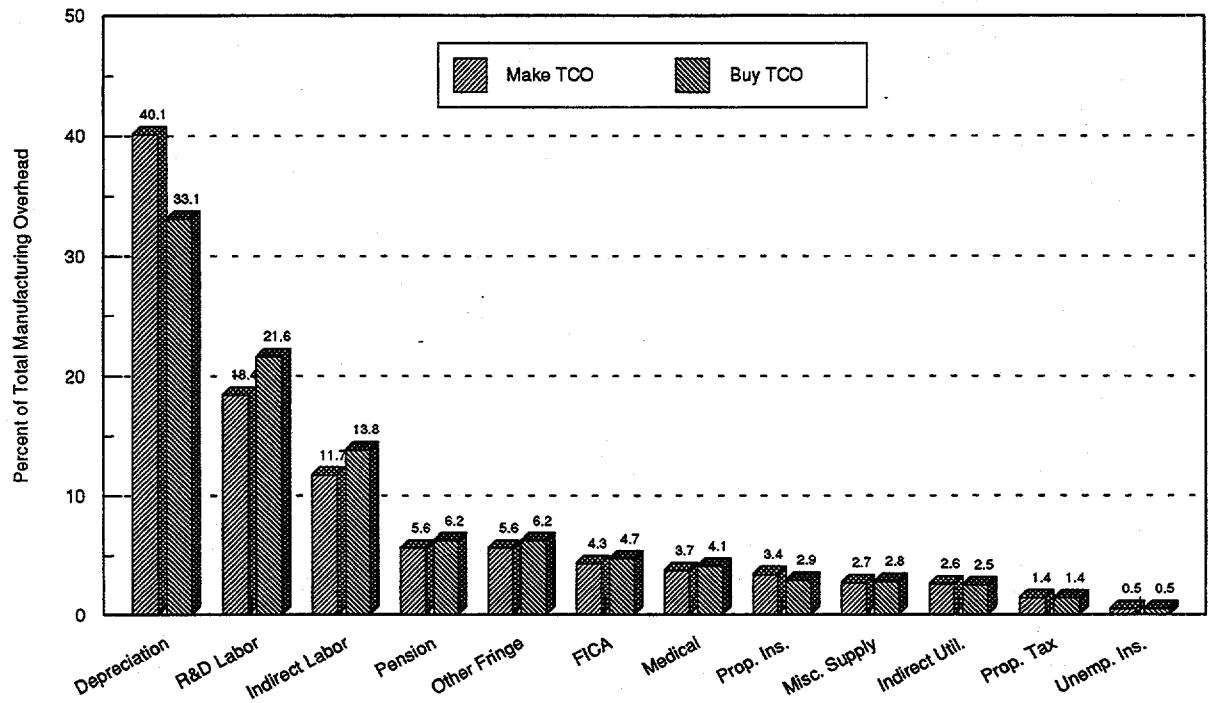

Figure 5-3. Relative Cost of Manufacturing Overhead Components

5.3. Parametric Analysis

A parametric analysis showing the sensitivity of the required price for Process B, the buy-TCO case, shows relationships of price to major cost drivers similar to those of Process A, the make-TCO process, in Section 4.4. The drivers chosen for Process B are:

- Process yield at the first, or unencapsulated cell, test work station
- Process yield at the final, or encapsulated module, test work station
- Sputtering equipment capital cost, dollars
- R & D expense expressed as dollars per unit product
- Unit cost of manufacturing floor space, dollars per square meter
- Unit cost of all three direct labor positions, dollars per hour
- Unit cost of coated glass, dollars per square meter
- Return on investment expressed as a fraction of equity investment.

These cost drivers were selected for examination as price parameters because they are the parameters that are most responsible for the magnitude of major cost components in the process. The overall process yield is a major determinant of the required price, and the two yields examined are the lowest individual work station yields in the process. In addition, both yields are for process steps that are near the end of the process, which magnifies their impact because product volume at all work stations prior to these test steps is influenced by the test yields. The unit cost parameters chosen represent the largest single cost in the other major cost components of the price. For example, glass is the largest single cost in the direct materials component of the price.

The module and cell yields generate the highest sensitivities at values well below their base case values, but the sensitivities are less at values near to or above the base case values, as seen in Figure 5-4. The six unit cost parameters shown fall into two groups of three whose sensitivities are almost indistinguishable. The highest sensitivity group includes direct labor rates, unit cost of coated glass and return-on-equity fraction. The individual curves (actually straight lines) for these three parameters are identified in the list in Figure 5-4 in the same order as the curves appear from upper to lower; that is, labor has the lowest sensitivity in the group and glass the highest. The group including the aluminum sputtering equipment cost, R & D cost per product, and manufacturing floor unit price are identified similarly. The sensitivities associated with these parameters are numerically almost the same.

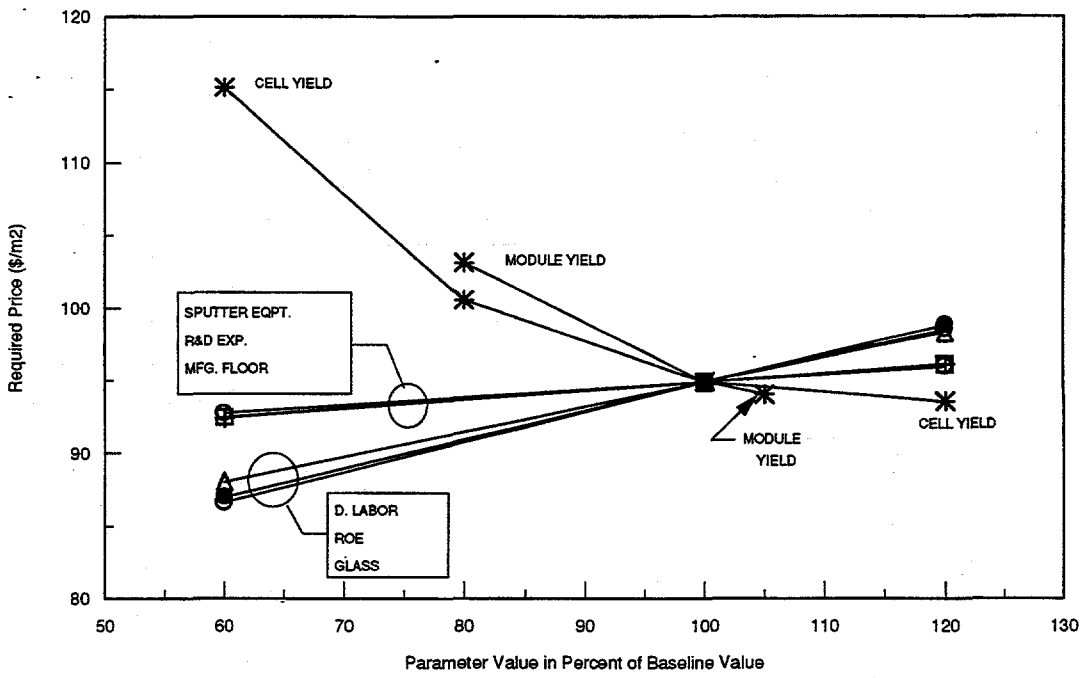

Figure 5-4. Sensitivity of Required Price to Selected Parameters

5.4. Trade-off of Coated Glass Price and TCO Coating Yield

The two processes defined previously, Process A and Process B, to consider the make-or-buy question for the TCO coating for the cover glass showed a modest difference in favor of buying the TCO coating. It was noted previously that the process step eliminated when purchasing the coated glass has a rather low yield. The question arises as to what the trade-off is between the yield of the coating step and the unit cost of the purchased coated glass. Another way to state the question is: what glass price would be justified by higher yield in the coating operation? Or, what coated glass price and yield in the coating operation result in the same module price? This question can be answered by examining the parametric variation of module price with coating yield in Process A and the parametric variation of module price with glass price in Process B. The solution can be done graphically by plotting both relationships, selecting arbitrary values of module price and reading the corresponding glass price and coating yield from the plots. In making these graphs, an unexpected result was found; namely, when the yield of the coating step was raised to 98% the module price was still higher than the base case module price in Process B. This result means that the coated glass price can be increased from the base case value of $\$13.45/m^2$ to give module prices equivalent to those in the Process A range corresponding to

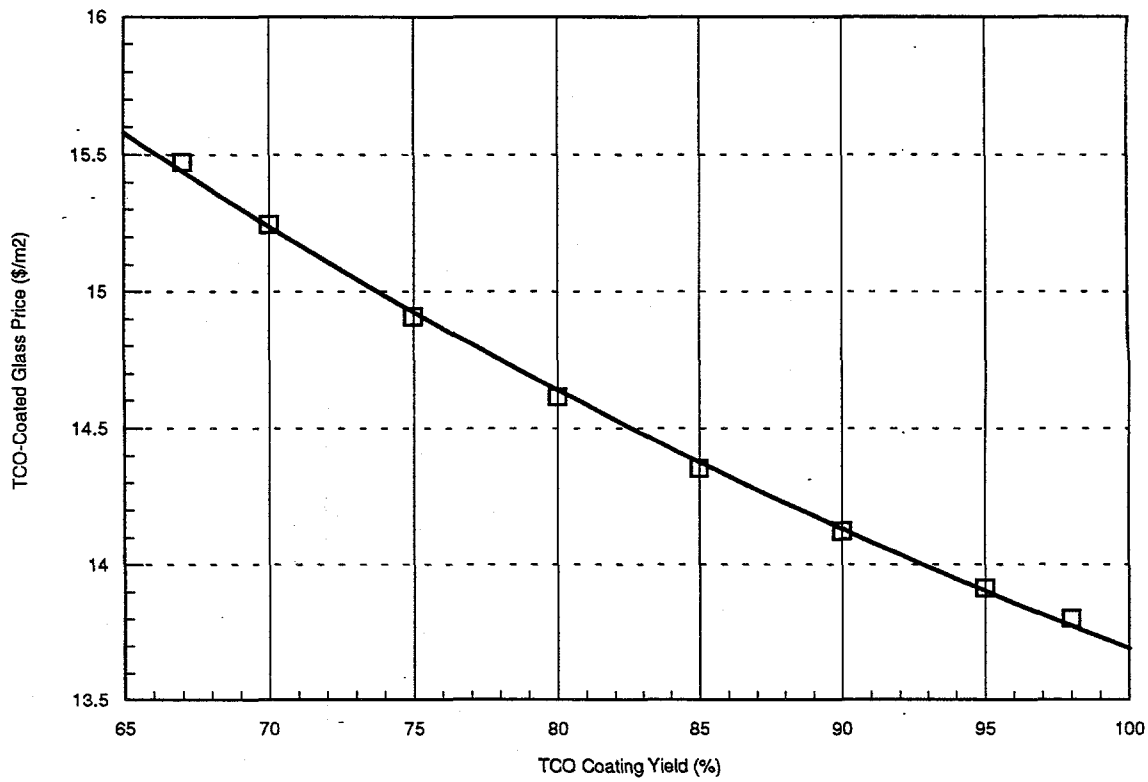

Figure 5-5. Equivalent Coated Glass Price and TCO Coating Yield

coating yields in the range 67% to 98%. The relationship of coating yield and coated glass price that results in the same module price is shown in Figure 5-5.

Part of the reason for the result in Figure 5-5 is that the major effect of increasing the coating yield is simply to reduce the amount of glass required in Process A. Since this step comes almost at the beginning of the process, most of the process is unaffected in terms of throughput, as are the costs of the rest of the process. Therefore, the price of the module only drops from $\$97.50/m^2$ at 67% yield to $\$95.33/m^2$ at 98% yield.

5.5. Annual Production Volume Effect on Required Price

In Section 4.5 the effects of production volume and different operating schedules on Process A, make-TCO, were discussed in some detail. The same analysis was performed for Process B, in which the glass is purchased with the TCO coating already applied. The general nature of the relationship between module price and the volume and schedule is the same for both processes. The results of the Process B analysis are shown in Figure 5-6, and the discussion of Section 4-5 applies to it as well.

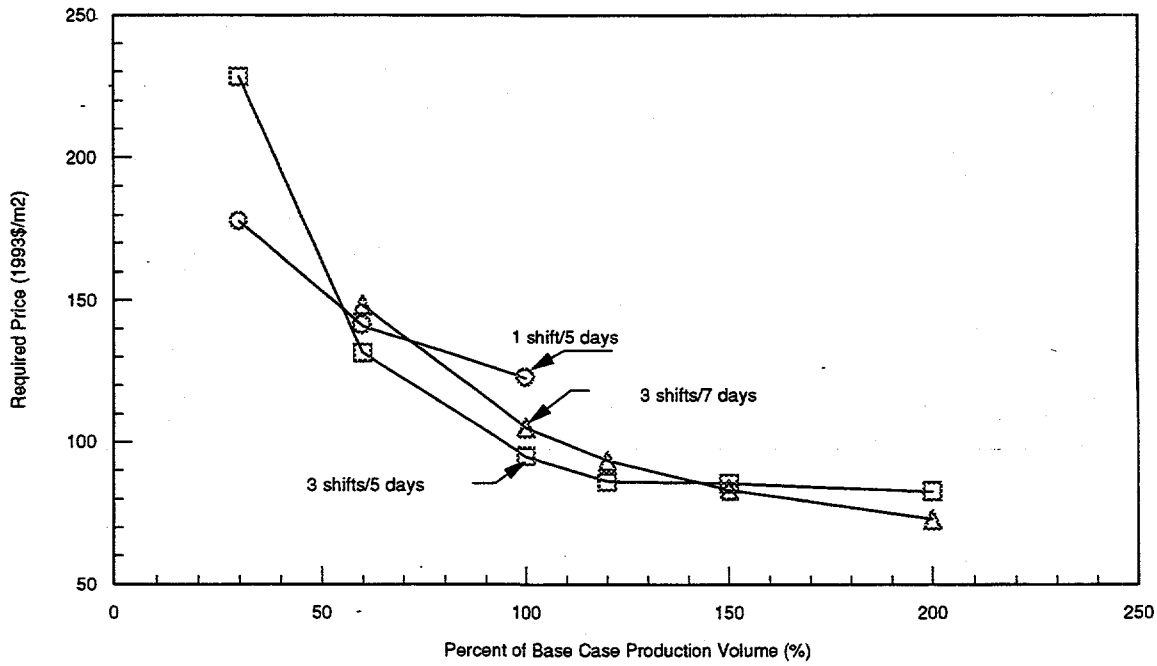

Figure 5-6. Effect of Production Volume on Required Price

Appendix A:

STAMPP Model Detailed Output Reports and Input Data

The following pages contain process reports for Process A: Make TCO-coated glass.

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PRODUCTION COST EXECUTIVE SUMMARY

MANUFACTURING PROCESS NAME: ASIBATC2
A-SI BATCH PROCESS, 2ND VERSION, 10/6/92
CASE: PURCHASE PLAIN GLASS

ANALYSIS MODE: MINIMUM PLANT

ANNUAL PLANT PRODUCTION (M2 /YR) -	185874.
UNIT PRICE ($1993/M2) -	97.504
BASE YEAR -	1992
SIMULATION LENGTH (YEARS) -	10
PLANT CAPACITY FACTOR (%) -	100.000
ANNUAL PLANT OPERATING TIME (HRS/YR) -	6016
MAXIMUM NUMBER OF SHIFTS PER WORKING DAY -	3
REQUIRED RETURN ON INVESTMENT (FRACTION) -	.200
DEBT TO EQUITY RATIO (FRACTION) -	.250
COMBINED FED/STATE INCOME TAX RATE (FRACTION) -	.370

PRODUCT PRICE COMPONENTS FIRST FULL YEAR OF PRODUCTION
(END OF YEAR DOLLARS)

COMPONENT	$1993/M2	% OF TOTAL
ANNUAL SALES	97.504	100.00
ANNUAL MANUFACTURING EXPENSE	65.286	66.96
ANNUAL DIRECT MATERIAL EXPENSE	18.781	19.26
ANNUAL DIRECT LABOR EXPENSE	14.306	14.67
ANNUAL MANUFACTURING OVERHEAD	32.200	33.02
NET ANNUAL WORK-IN-PROCESS	.083	.08
NET FINISHED GOODS INVENTORY	.000	.00
SELLING & ADMINISTRATIVE EXPENSE	4.791	4.91
CORPORATE INCOME TAXES PAYABLE	10.576	10.85
EXCESS REVENUE (INTEREST EARNED)	-1.240	-1.27
ANNUAL NET INCOME	18.008	18.47

INITIAL WORK STATION EQUIPMENT COST ($1992)	15452500
INITIAL FACILITY COST ($1992)	4590605
TOTAL MANUFACTURING AREA (SQ M)	4347
TOTAL NONMANUFACTURING AREA (SQ M)	999
TOTAL FACILITY AREA (SQ M)	5347
TOTAL LAND COST ($1992)	146816
TOTAL DIRECT MANUFACTURING LABOR (# WORKERS)	87
TOTAL INDIRECT MANUFACTURING LABOR (# WORKERS)	18
TOTAL INDIRECT NONMANUFACTURING LABOR (# WORKERS)	22
TOTAL PLANT LABOR (# WORKERS)	127

13:02:07
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CAPITAL EQUIPMENT COST SUMMARY
(JANUARY $1992)

MANUFACTURING PROCESS NAME: ASIBATC2
A-SI BATCH PROCESS, 2ND VERSION, 10/6/92
CASE: PURCHASE PLAIN GLASS

WORK STATION	INITIAL MACH COST, $/mach	NUMBER OF MACH	TOTAL INITIAL MACH. COST, $
1 UNLDCOVR - UNLDCOVR: A-SI UNLOAD COVR GLS	80000	1	80000
2 CLNCOVR - CLNCOVR: A-SI CLEAN COVER GLAS	155000	1	155000
3 TCODEP - TCODEP: DEPOSIT TCO	4525000	1	4525000
4 BUFFER1 - BUFFER1: A-SI BUFFER AT TCO	205000	1	205000
5 WASHTCO - WASHTCO: A-SI WASH AFTER TCO	155000	1	155000
6 SCRIBTCO - SCRIBTCO: A-SI SCRIBE TCO	520000	1	520000
7 LOADCAR - LOADCAR: A-SI LOAD BATCH CARRY	270000	1	270000
8 PHEATCAR - PHEATCAR: A-SI PREHEAT BATCH	157500	1	157500
9 ASIDEP - ASIDEP: A-SI P-I-N BATCH DEPOS	765000	2	1530000
10 UNLDCAR - UNLDCAR: A-SI UNLOAD BATCH CAR	270000	1	270000
11 SCRIBASI - SCRIBASI: A-SI SCRIBE P-I-N	520000	1	520000
12 SPUTRAL - SPUTRAL: A-SI SPUTTER ALUMINUM	2530000	1	2530000
13 BUFFER2 - BUFFER2: A-SI BUFFER ALUMINUM	205000	1	205000
14 SCRIBAL - SCRIBAL: A-SI SCRIBE ALUMINUM	520000	1	520000
15 ISOLATE - ISOLATE: A-SI ISOLATE	210000	1	210000
16 CONTACT - CONTACT: A-SI CONTACT	210000	1	210000
17 TESTCELL - TESTCELL: A-SI TEST UNENCAPSUL	250000	1	250000
18 ANELCOOL - ANELCOOL: A-SI ANNEAL & COOL	160000	1	160000
19 ENCAPSUL - ENCAPSUL: A-SI ENCAPSULATION	2020000	1	2020000
20 FRAMCONN - FRAMCONN: A-SI ADD FRAME/CONN	110000	1	110000
21 TESTMODL - TESTMODL: A-SI TEST FINAL PROD	260000	1	260000
22 SORTPACK - SORTPACK: A-SI SORT MODUL/PACK	265000	1	265000
23 RWKCELL - RWKCELL: A-SI REWORK UNENCAPSL	50000	1	50000
24 RWKMODL - RWKMODL: A-SI REWORK FINAL PRD	40000	1	40000
25 UNLDBACK - UNLDBACK:A-SI UNLOAD BACK GLAS	80000	1	80000
26 CLNBACK - CLNBACK: A-SI CLEAN BACK GLASS	155000	1	155000
TOTAL MANUFACTURING EQUIPMENT COST			15452500

OTHER EQUIPMENT	NUMBER OF MACHINES	TOTAL INITIAL MACH. COST, $
TOTAL MANUFACTURING EQUIPMENT COST		15452500
PROCESS COMP		100000
BUSINESS COMP		50000
R&D LAB		500000
MANFACTURING OFFICE FURNITURE		23714
TOTAL MANFUFACTURING EQUIP & FURNITURE		16126214
TOTAL NON-MANFUFACTURING EQUIP & FURNITURE		56453
TOTAL CAPITAL EQUIPMENT COST		16182668

13:01:50
01/06/93

COST AND YIELD SUMMARY - WORK STATION LEVEL
($1993 END OF YEAR DOLLARS)

MANUFACTURING PROCESS NAME: ASIBATC2
A-SI BATCH PROCESS, 2ND VERSION, 10/6/92
CASE: PURCHASE PLAIN GLASS

WORK STATION	NET YIELD	HRS/ PART	UNIT COST ($/M2) LABOR	MATL	OVHD	TOTAL
19 ENCAPSUL: A-SI ENCAPSULATION	99.00	.12	2.15	4.35	5.23	11.73
3 TCODEP: DEPOSIT TCO	67.00	.04	.76	1.96	4.97	7.69
1 UNLDCOVR: A-SI UNLOAD COVR GLS	99.50	.01	.14	5.23	.46	5.83
20 FRAMCONN: A-SI ADD FRAME/CONN	99.50	.05	.79	2.85	1.47	5.11
22 SORTPACK: A-SI SORT MODUL/PACK	99.80	.09	1.56	.18	3.04	4.78
12 SPUTRAL: A-SI SPUTTER ALUMINUM	99.70	.04	.77	.06	3.52	4.35
9 ASIDEP: A-SI P-I-N BATCH DEPOS	97.00	.04	.77	.42	2.69	3.88
25 UNLDBACK:A-SI UNLOAD BACK GLAS	99.50	.01	.14	3.08	.46	3.68
14 SCRIBAL: A-SI SCRIBE ALUMINUM	99.50	.03	.64	.11	1.44	2.20
11 SCRIBASI: A-SI SCRIBE P-I-N	99.50	.03	.64	.11	1.44	2.19
6 SCRIBTCO: A-SI SCRIBE TCO	99.50	.03	.64	.10	1.44	2.18
21 TESTMODL: A-SI TEST FINAL PROD	95.00	.04	.73	.01	1.38	2.12
17 TESTCELL: A-SI TEST UNENCAPSUL	92.00	.04	.73	.01	1.32	2.06
24 RWKMODL: A-SI REWORK FINAL PRD	80.00	.04	.73	.02	1.16	1.91
23 RWKCELL: A-SI REWORK UNENCAPSL	80.00	.04	.73	.01	1.17	1.91
10 UNLDCAR: A-SI UNLOAD BATCH CAR	98.00	.03	.48	.00	1.08	1.56
7 LOADCAR: A-SI LOAD BATCH CARRY	98.00	.03	.48	.00	1.08	1.56
4 BUFFER1: A-SI BUFFER AT TCO	99.80	.01	.18	.01	.65	.84
13 BUFFER2: A-SI BUFFER ALUMINUM	99.80	.01	.18	.01	.65	.84
15 ISOLATE: A-SI ISOLATE	99.70	.01	.14	.01	.52	.67
16 CONTACT: A-SI CONTACT	99.70	.01	.14	.02	.50	.67
18 ANELCOOL: A-SI ANNEAL & COOL	99.80	.01	.14	.07	.42	.63
8 PHEATCAR: A-SI PREHEAT BATCH	99.00	.00	.05	.07	.29	.41
2 CLNCOVR: A-SI CLEAN COVER GLAS	99.70	.00	.03	.04	.20	.26
5 WASHTCO: A-SI WASH AFTER TCO	99.70	.00	.03	.03	.20	.25
26 CLNBACK: A-SI CLEAN BACK GLASS	99.70	.00	.03	.03	.20	.25
	56.71	.76	13.80	18.78	36.99	69.57

* - Multi-Pass Work Station
OVHD = Manuf. Ovhd. + Selling & Admin. Expense

PRODUCT COST CENTER	NET YIELD	HRS/ PART	UNIT COST ($/M2)
1 CELL DEPOSITION	59.78	.31	34.05
2 MECHANICAL ASSEMBLY	97.53	.37	31.34
3 TESTING	97.27	.08	4.18
TOTAL MANUFACTURING COST	56.71	.76	69.57

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01/06/93

PROCESS TOTALS & LABOR REQUIREMENTS

MANUFACTURING PROCESS NAME: ASIBATC2
A-SI BATCH PROCESS, 2ND VERSION, 10/6/92
CASE: PURCHASE PLAIN GLASS

DIRECT MANUFACTURING LABOR
(1993 END OF YEAR DOLLARS)

OVERALL PROCESS TOTAL

	LABOR CATEGORY	NO. OF PERSONS*	HRS/YR	SALARY	$/YR**
1	PROCESS OPERATOR	45	80280	16.5 $/HR	1510819
16	M/E MAINT	9	8091	14.3 $/HR	261875
21	MATL. HANDLER	33	53037	13.2 $/HR	886347
	TOTAL DIRECT LABOR	87	141408		2659042

* - INCLUDES LABOR SHIFT MULTIPLIER ** - INCLUDES WAGE SHIFT PREMIUMS

MANUFACTURING INDIRECT LABOR

	LABOR CATEGORY	NO. OF PERSONS	SALARY	TOTAL
	SHIFT EMPLOYEES			
1	Material Handlers	3	19042	62839
2	Production Supervisors	3	50178	165587
3	Clerks, Production Supervisors	3	22258	73452
4	Area Supervisors	0	42201	0
5	Clerks, Area Supervisors	0	17497	0
6	Plant Production Foremen	3	38984	128648
7	Mech/Elec Maint. Forman	0	38984	0
8	Material Handling Foremen	0	38984	0
9	Machine Shop Foremen	0	38984	0
10	Machine Shop Workers	3	33837	111665
11	Q/C Foremen	0	38984	0
	TOTAL INDIRECT MANF SHIFT LABOR	15	N/A	542193

* - INCLUDES LABOR SHIFT MULTIPLIER ** - INCLUDES WAGE SHIFT PREMIUMS

	NON-SHIFT EMPLOYEES			
1	Vice President Manufacturing	1	78740	78740
2	Director of R&D	1	59699	59699
3	Director of Manufacturing Engineeri	1	0	0
4	Engineers, Manufacturing Engineerin	1	0	0
5	Draftsmen, Manufacturing Engineerin	1	0	0
6	Director of Q/C	1	0	0
7	Manufacturing Sec I	2	0	0
8	Manufacturing Sec II	1	21057	21057
	R&D EXPENSE/YEAR	N/A	N/A	1102502
	TOTAL INDIRECT MANF NON-SHIFT LABOR	9	N/A	1261999
	TOTAL MANUFACTURING INDIRECT LABOR	24	N/A	1804193

DIRECT MANUFACTURING FACILITIES
(JANUARY $1992)

OVERALL PROCESS TOTAL

FACILITY CATEGORY	AREA (SQ M)	$/SQ M	$
2 FACTORY FLOOR	3020	1248.00	3769509
TOTAL DIRECT FACILITIES	3020	N/A	3769509

OTHER MANUFACTURING FACILITIES
(JANUARY $1992)

FACILITY CATEGORY	AREA (SQ M)	$/SQ M	$
MACHINE SHOP FLOOR SPACE	55	724.79	40414
SHIPPING FLOOR SPACE	185	724.79	134719
RECEIVING FLOOR SPACE	185	724.79	134719
MANUFACTURING OFFICE FLOOR SPACE	124	724.79	90250
MISC. MANUFACTURING FLOOR SPACE	127	790.86	101136
MANUFACTURING EXTERIOR SPACE	647	10.76	6966
INDIRECT MANUFACTURING FACILITIES	1327	N/A	508207
TOTAL MANUFACTURING FACILITIES	4347	N/A	4277716

DIRECT MANUFACTURING UTILITIES
($1993 END OF YEAR DOLLARS)

OVERALL PROCESS TOTAL

UTILITY CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
1 ELECTRICITY	KW	4784033.	.04	210976.
TOTAL DIRECT UTILITIES		N/A	N/A	210975

INDIRECT MANUFACTURING UTILITIES
($1993 END OF YEAR DOLLARS)

MATERIAL CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
MANUFACTURING SPACE LIGHTING	kwh	2076013	.04410	91552
MANUFACTURING OFFICE LIGHTING	kwh	151971	.04410	6701
NATURAL GAS	ft3	0	.07828	0
COOLING ELECTRICITY	kwh	1353825	.04410	59703
TOTAL MANUFACTURING UTITLIIES		N/A	N/A	157957

DIRECT MANUFACTURING MATERIALS
($1993 END OF YEAR DOLLARS)

OVERALL PROCESS TOTAL

MATERIAL CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
1 SILANE	GM	182932.	.19	34286.
2 LIQUID NITROGEN	LITER	19052100.	.00	3014.
3 TIN TETRACHLORIDE	KG	8262.	7.28	60117.
4 DEMINERALIZED WATER	M3	29515.	.52	15457.
5 COVER GLASS	M2	327756.	2.97	972034.
6 BACK GLASS	M2	192600.	2.97	571198.
7 OXYGEN	LITER	13325410.	.01	104675.
8 FREON	LITER	533016.	.23	123407.
10 AL. SPUTTER SOURCE	GM	876031.	.00	1795.

11 ARC LAMP	EA	62.	192.94	11930.
12 EVA	M2	191062.	4.16	794135.
13 AIR FILTER & PARTS	EA	4.	220.50	840.
14 ALUMINUM FOIL	M2	11624.	.30	3447.
15 MOLDED RUBBER BOOTS	2EA	154915.	.66	102477.
16 CABLE CONN. & ADHESV	UNIT	154915.	.88	136635.
17 POLYCARB. U-FRAME	M	724263.	.18	130954.
18 PACKING MATL	EA	152535.	.21	31952.
19 ALUM SUPP STRUTS	GM	48052170.	.00	158933.
20 SILICONE RESIN	GM	40188.	.06	2570.
21 LIQ. N2 TANK LEASE	MIN	520517.	.04	20085.
TOTAL DIRECT MATERIALS		N/A	N/A	3279930

DIRECT MANUFACTURING MATERIALS BYPRODUCTS
($1993 END OF YEAR DOLLARS)

OVERALL PROCESS TOTAL

MATERIAL CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
10 AL. SPUTTER SOURCE	GM	438015.	.00	0.
TOTAL DIRECT MATERIAL BYPRODUCTS		N/A	N/A	0

MISCELLANEOUS MANUFACTURING ITEMS
($1993 END OF YEAR DOLLARS)

CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
MANF. OFFICE SUPPLIES		24	275.625	6614
FACILITY REPAIR		N/A	N/A	157206
TOTAL MISCELLANEOUS MANF COST		N/A	N/A	163821
MANF. OFFICE FURNITURE	($1992)		190.450	23714

NON-MANUFACTURING TOTALS AND REQUIREMENTS

NON-MANUFACTURING LABOR
($1993 END OF YEAR DOLLARS)

LABOR CATEGORY	NO. OF PERSONS	SALARY	TOTAL
NON-SHIFT EMPLOYEES			
1 President	1	88199	88199
2 Vice President Finance	1	48620	48620
3 Cost Accountant	1	0	0
4 Payroll Accountant	1	29266	29266
5 Manager of Credits and Collection	1	0	0
6 Manager of Data Processing	1	29877	29877
7 Clerks, Finance	4	0	0
8 Vice President Facility Administrat	1	46966	46966
9 Director of Recruitment	1	0	0
10 Clerks, Personnel	1	18191	18191
11 Director of General Facility Operat	1	31862	31862
14 Receptionist	1	13781	13781
15 Vice President Sales	1	67472	67472
16 Salesmen	0	44099	0
19 Administrative Sec I	10	0	0
20 Administrative Sec II	4	21057	84230

SHIFT EMPLOYEES

21 Security Personnel	3	16316	48950
22 General Facility Maintenance Worker	6	16647	99886
TOTAL NON-MANUFACTURING LABOR COST	39	N/A	607307

NON-MANUFACTURING FACILITIES
(JANUARY $1992)

FACILITY CATEGORY	AREA (SQ M)	$/SQ M	$
ADMINISTRATIVE OFFICE SPACE	296	724.79	214842
MISC. ADMINISTRATIVE SPACE	115	790.86	91728
NON-MANUFACTURING EXTERIOR SPACE	587	10.76	6318
TOTAL NON-MANUFACTURING FACILITIES	999	N/A	312889

NON-MANUFACTURING INDIRECT UTILITIES
($1993 END OF YEAR DOLLARS)

UTILITY CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
ADMINISTRATIVE SPACE LIGHTING	kwh	82770	.04410	3650
NATURAL GAS	ft3	0	.07828	0
COOLING ELECTRICITY	kwh	35767	.04410	1577
TOTAL NON-MANUFACTURING UTITLIIES		N/A	N/A	5227

MISCELLANEOUS NON-MANUFACTURING ITEMS
($1993 END OF YEAR DOLLARS)

MATERIAL CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
ADMIN. OFFICE SUPPLIES		39	275.625	10749
FACILITY REPAIR		N/A	N/A	8127
TOTAL MISCELLANEOUS ADMIN COST		N/A	N/A	18877
ADMIN. OFFICE FURNITURE ($1992)			190.450	56453
LAND ($1992)	M2	5882	24.960	146816

The following pages contain financial reports for Process A: Make TCO-coated glass.

13:02:38
01/06/93

ANNUAL CORPORATE FINANCIAL REPORTS
INCOME STATEMENT

MANUFACTURING PROCESS NAME: ASIBATC2
A-SI BATCH PROCESS, 2ND VERSION, 10/6/92
CASE: PURCHASE PLAIN GLASS

(END OF YEAR DOLLARS)

YEAR	1992	1993	1994
SALES	14057440.	18123390.	18348790.
COST OF GOODS SOLD			
BEGINNING FINISHED GOODS	0.	0.	0.
MANF GOODS ADDED TO FINISHED GOODS	8651503.	12150410.	12601860.
GOODS AVAILABLE FOR SALE	8651503.	12150410.	12601860.
ENDING FINISHED GOODS	0.	0.	0.
COST OF GOODS SOLD	8651503.	12150410.	12601860.
GROSS PROFIT	5405937.	5972982.	5746934.
SELLING AND ADMINISTRATIVE EXPENSES	849765.	890459.	933188.
INCOME FROM OPERATIONS	4556172.	5082523.	4813746.
OTHER REVENUE AND EXPENSES			
INTEREST EARNED	1217109.	690757.	959536.
INTEREST EXPENSE	460242.	460242.	460242.
EXCESS	756867.	230515.	499294.
INCOME BEFORE TAXES	5313039.	5313039.	5313039.
CORPORATE INCOME TAX EXPENSE	1965825.	1965825.	1965825.
INCOME TAXES PAYABLE	1631493.	916462.	1660715.
DEFERRED INCOME TAXES	334332.	1049363.	305109.
NET INCOME	3347215.	3347215.	3347215.

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ANNUAL CORPORATE FINANCIAL REPORTS
BALANCE SHEET (TAX BASIS)

MANUFACTURING PROCESS NAME: ASIBATC2
A-SI BATCH PROCESS, 2ND VERSION, 10/6/92
CASE: PURCHASE PLAIN GLASS

(END OF YEAR DOLLARS)

YEAR	1992	1993	1994
ASSETS			
CURRENT ASSETS			
CASH	137034.	195021.	204772.
MARKETABLE SECURITIES	6126777.	9223386.	12099630.
ACCOUNTS RECEIVABLE	0.	0.	0.
INVENTORIES			
MATERIALS	130156.	273328.	286995.
WORK IN PROCESS	107252.	91888.	95202.
FINISHED GOODS	0.	0.	0.
TOTAL INVENTORIES	237408.	365217.	382197.
TOTAL CURRENT ASSETS	6501219.	9783624.	12686600.
PROPERTY PLANT & EQUIPMENT			
LAND	146817.	146817.	146817.
BUILDINGS	4590606.	4590606.	4590606.
ACCUMULATED DEPRECIATION (BUILDINGS)	153020.	306040.	459061.
NET BOOK VALUE (BUILDINGS)	4437586.	4284565.	4131545.
EQUIPMENT AND FURNITURE	16182670.	16182670.	16182670.
ACCUMULATED DEPRECIATION (EQUIP/FURN)	2258780.	4517559.	6776339.
NET BOOK VALUE (EQUP/FURN)	13923890.	11665110.	9406330.
TOTAL PROPERTY PLANT AND EQUIPMENT	18508290.	16096490.	13684690.
TOTAL ASSETS	25009510.	25880120.	26371290.
LIABILITIES			
TAXES PAYABLE	407873.	229115.	415179.
DEFERRED INCOME TAXES	334332.	1383695.	1688804.
DIVIDENDS PAYABLE	3347215.	3347215.	3347215.
BONDS PAYABLE	4184018.	4184018.	4184018.
TOTAL LIABILITIES	8273438.	9144043.	9635215.
STOCKHOLDERS EQUITY			
COMMON STOCK	16736070.	16736070.	16736070.
RETAINED EARNINGS	0.	0.	0.
TOTAL STOCKHOLDERS EQUITY	16736070.	16736070.	16736070.
TOT LIABILITIES AND STOCKHOLDERS EQUITY	25009510.	25880120.	26371290.

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ANNUAL CORPORATE FINANCIAL REPORTS
MANUFACTURING & NON-MANUFACTURING OVERHEAD

MANUFACTURING PROCESS NAME: ASIBATC2
A-SI BATCH PROCESS, 2ND VERSION, 10/6/92
CASE: PURCHASE PLAIN GLASS

(END OF YEAR DOLLARS)

YEAR	1992	1993	1994
MANUFACTURING OVERHEAD			
DEPRECIATION	2399488.	2399488.	2399488.
MISCELLANEOUS OVERHEAD			
INDIRECT LABOR	1718280.	1804194.	1894404.
INDIRECT UTILITIES	150436.	157958.	165856.
MATERIALS & SUPPLIES	156020.	163821.	172012.
TOTAL MISCELLANEOUS OVERHEAD	2024736.	2125973.	2232272.
SOCIAL SECURITY	243271.	254622.	266540.
UNEMPLOYMENT INSURANCE	27195.	27195.	27195.
PROPERTY TAXES	85554.	85554.	85554.
PROPERTY INSURANCE	204039.	204039.	204039.
FRINGE BENEFITS			
HOSPITALIZATION & MEDICAL BENEFITS	209790.	220280.	231293.
PENSION (EMPLOYER CONTRIBUTION)	318064.	333968.	350666.
OTHER FRINGE BENEFITS	318064.	333968.	350666.
TOTAL FRINGE BENEFITS	845919.	888215.	932626.
TOTAL MANUFACTURING OVERHEAD	5830203.	5985087.	6147715.
NON-MANUFACTURING OVERHEAD			
DEPRECIATION	12311.	12311.	12311.
MISCELLANEOUS OVERHEAD			
INDIRECT LABOR	578388.	607308.	637673.
INDIRECT UTILITIES	4979.	5228.	5489.
MATERIALS & SUPPLIES	17978.	18877.	19821.
TOTAL MISCELLANEOUS OVERHEAD	601345.	631412.	662983.
SOCIAL SECURITY	42328.	44242.	46250.
UNEMPLOYMENT INSURANCE	9555.	9555.	9555.
PROPERTY TAXES	6258.	6258.	6258.
PROPERTY INSURANCE	3693.	3693.	3693.
FRINGE BENEFITS			
HOSPITALIZATION & MEDICAL BENEFITS	73710.	77396.	81265.
PENSION (EMPLOYER CONTRIBUTION)	50282.	52796.	55436.
OTHER FRINGE BENEFITS	50282.	52796.	55436.
TOTAL FRINGE BENEFITS	174274.	182988.	192137.
TOTAL NON-MANUFACTURING OVERHEAD	849765.	890459.	933188.
TOTAL ANNUAL OVERHEAD EXPENSE	6679968.	6875546.	7080903.

The following pages contain input data summaries for Process A: Make TCO-coated glass.

13:03:12
01/06/93

COST CATALOG

MANUFACTURING PROCESS NAME: ASIBATC2
A-SI BATCH PROCESS, 2ND VERSION, 10/6/92
CASE: PURCHASE PLAIN GLASS

DIRECT MANUFACTURING FACILITIES COST YEAR: 1992

CATEGORY		UNITS	COST UNITS	COST
1	CLEAN ROOM FLOOR	M2	$/M2	2152.00
2	FACTORY FLOOR	M2	$/M2	1248.00

DIRECT LABOR - PRODUCTION WORKERS COST YEAR: 1992

CATEGORY		UNITS	COST UNITS	SALARY
1	PROCESS OPERATOR	PER/MACH/SHIFT	$/HR	15.00

DIRECT LABOR - MECH/ELEC MAINT WORKERS COST YEAR: 1992

CATEGORY		UNITS	COST UNITS	SALARY
16	M/E MAINT	PER/MACH/SHIFT	$/HR	13.00

DIRECT LABOR - MATERIAL HANDLERS COST YEAR: 1992

CATEGORY		UNITS	COST UNITS	SALARY
21	MATL. HANDLER	PER/MACH/SHIFT	$/HR	12.00

DIRECT LABOR - QUALITY CONTROL HANDLERS COST YEAR: 1992

CATEGORY		UNITS	COST UNITS	SALARY

DIRECT MANUFACTURING UTILITIES COST YEAR: 1992

CATEGORY		UNITS	COST UNITS	COST
1	ELECTRICITY	KW	$/KWH	.0400
2	NATURAL GAS	M3/MIN	$/M3	.0710
3	FUEL OIL	LITER/MIN	$/LITER	.0000

DIRECT MANUFACTURING MATERIALS COST YEAR: 1992

CATEGORY		UNITS	COST UNITS	PRICE	DISPOSAL COST
1	SILANE	GM	$/GM	.1700	.0000
2	LIQUID NITROGEN	LITER	$/LITER	.0001	.0000
3	TIN TETRACHLORIDE	KG	$/KG	6.6000	.0000
4	DEMINERALIZED WATER	M3	$/M3	.4750	.0000
5	COVER GLASS	M2	$/M2	2.6900	.0000
6	BACK GLASS	M2	$/M2	2.6900	.0000
7	OXYGEN	LITER	$/LITER	.0071	.0000
8	FREON	LITER	$/LITER	.2100	.0000
9	HELIUM	LITER	$/LITER	.0000	.0000
10	AL. SPUTTER SOURCE	GM	$/GM	.0019	.0000
11	ARC LAMP	EA	$/EA	175.0000	.0000
12	EVA	M2	$/M2	3.7700	.0000
13	AIR FILTER & PARTS	EA	$/EA	200.0000	.0000

14	ALUMINUM FOIL	M2	$/M2	.2690	.0000
15	MOLDED RUBBER BOOTS	2EA	$/2EA	.6000	.0000
16	CABLE CONN. & ADHESV	UNIT	$/UNIT	.8000	.0000
17	POLYCARB. U-FRAME	M	$/M	.1640	.0000
18	PACKING MATL	EA	$/EA	.1900	.0000
19	ALUM SUPP STRUTS	GM	$/GM	.0030	.0000
20	SILICONE RESIN	GM	$/GM	.0580	.0000
21	LIQ. N2 TANK LEASE	MIN	$/MIN	.0350	.0000

INDIRECT MANUFACTURING LABOR COST YEAR: 1992

	CATEGORY	COST UNITS	SALARY	FLOOR SPACE (FT2)
1	Material Handlers	($/yr)	17272.00	.00
2	Production Supervisors	($/yr)	45513.00	11.15
3	Clerks, Production Supervisors	($/yr)	20189.00	6.97
4	Area Supervisors	($/yr)	38278.00	11.15
5	Clerks, Area Supervisors	($/yr)	15871.00	6.97
6	Plant Production Foremen	($/yr)	35360.00	6.97
7	Mech/Elec Maint. Forman	($/yr)	35360.00	6.97
8	Material Handling Foremen	($/yr)	35360.00	6.97
9	Machine Shop Foremen	($/yr)	35360.00	46.47
10	Machine Shop Workers	($/yr)	30692.00	9.29
11	Q/C Foremen	($/yr)	35360.00	6.97
12	Vice President Manufacturing	($/yr)	71420.00	13.94
13	Director of R&D	($/yr)	54149.00	13.94
14	Director of Manufacturing Engineering	($/yr)	.00	.00
15	Engineers, Manufacturing Engineering	($/yr)	.00	.00
16	Draftsmen, Manufacturing Engineering	($/yr)	.00	.00
17	Director of Q/C	($/yr)	.00	.00

INDIRECT NON-MANUFACTURING LABOR COST YEAR: 1992

	CATEGORY	COST UNITS	SALARY	FLOOR SPACE (FT2)
1	President	($/yr)	80000.00	13.94
2	Vice President Finance	($/yr)	44100.00	13.94
3	Cost Accountant	($/yr)	.00	.00
4	Payroll Accountant	($/yr)	26546.00	13.94
5	Manager of Credits and Collection	($/yr)	.00	.00
6	Manager of Data Processing	($/yr)	27100.00	11.15
7	Clerks, Finance	($/yr)	.00	.00
8	Vice President Facility Administration	($/yr)	42600.00	13.94
9	Director of Recruitment	($/yr)	.00	.00
10	Clerks, Personnel	($/yr)	16500.00	9.29
11	Director of General Facility Operations	($/yr)	28900.00	13.94
12	Security Personnel	($/yr)	14800.00	.00
13	General Facility Maintenance Workers	($/yr)	15100.00	.00
14	Receptionist	($/yr)	12500.00	6.97
15	Vice President Sales	($/yr)	61200.00	13.94
16	Salesmen	($/yr)	40000.00	11.15
17	Manufacturing Sec I	($/yr)	.00	.00
18	Manufacturing Sec II	($/yr)	19100.00	9.29
19	Administrative Sec I	($/yr)	.00	.00
20	Administrative Sec II	($/yr)	19100.00	9.29

MISCELLANEOUS ITEMS COST YEAR: 1992

	ITEM	COST UNITS	COST
1	Shipping Floor SpaceCost	$/M2	724.79
2	Receiving Floor Space Cost	$/M2	724.79
3	Machine Shop Floor Space	$/M2	724.79
4	Manufacturing OfficeFloor Space Cost	$/M2	724.79
5	Non-Manufacturing Office Space Cost	$/M2	724.79
6	Manufacturing Misc. Space Cost	$/M2	790.86

7	Non-Manufacturing Misc. Space Cost	$/M2	790.86
8	Manufacturing Exterior Space Cost	$/M2	10.76
9	Non-Manuf. Exterior Space Cost	$/M2	10.76
10	Land	$/M2	24.96
11	Manuf. Office Furniture cost	$/M2	190.45
12	Non-Manuf. Office Funiture Cost	$/M2	190.45
13	Research and Development Cost	$/OUTPUT UNIT	5.38
14	Manufacturing Office Supply Cost	$/PERSON	250.00
15	Non-Manufacturing Office Supply Cost	$/PERSON	250.00

MISCELLANEOUS EQUIPMENT COST YEAR: 1992

	ITEM	COST
1	PROCESS COMP	100000.00
2	BUSINESS COMP	50000.00
3	R&D LAB	500000.00

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FINANCIAL MODEL INPUT DATA

MANUFACTURING PROCESS NAME: ASIBATC2
A-SI BATCH PROCESS, 2ND VERSION, 10/6/92
CASE: PURCHASE PLAIN GLASS

SIMULATION LENGTH (yrs)	10
BASE YEAR	1992
TAX DEPRECIATION METHOD (ACRS OR STRAIGHT LINE)	ACRS
BOOK DEPR METHOD (STRAIGHT LINE, SYD, OR DDB)	STRAIGHT LINE
REQUIRED RETURN ON EQUITY (fraction)	.200
DEBT TO EQUITY RATIO (fraction)	.250
BOND INTEREST RATE (fraction)	.110
MARKETABLE SECURITIES INTEREST RATE (fraction)	.090
COMBINED FED/STATE INCOME TAX RATE (fraction)	.370
PROPERTY TAX RATE (fraction)	.020
PROPERTY INSURANCE RATE (fraction)	.010
FICA SALARY CUTOFF LEVEL ($/yr)	53400.000
FICA RATE (fraction)	.076
UNEMPLOYMENT INSURANCE ($/person/yr)	245.000
HOSPITALIZATION & MEDICAL BENEFITS ($/person/mo)	150.000
FRINGE BENEFITS (fraction)	.100
PENSIONS (fraction)	.100

INFLATION RATE TABLE 1980-2000

YEAR	RATE
1980	.103
1981	.089
1982	.059
1983	.043
1984	.043
1985	.036
1986	.019
1987	.036
1988	.041
1989	.049
1990	.052
1991	.054
1992	.050
1993	.050
1994	.050
1995	.050
1996	.050
1997	.050
1998	.050
1999	.050
2000	.050

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PROCESS INPUT PARAMETERS AND WORK STATION SEQUENCE

MANUFACTURING PROCESS NAME: ASIBATC2
A-SI BATCH PROCESS, 2ND VERSION, 10/6/92
CASE: PURCHASE PLAIN GLASS

ANNUAL PLANT PRODUCTION (1000 units/yr)	185.87
FINAL PRODUCT UNITS	M2

LABOR UTILIZATION

MAXIMUM NUMBER OF SHIFTS PER WORKING DAY	3.00
PLANT OPERATING HOURS - 1ST SHIFT (hours)	8.00
- 2ND SHIFT (hours)	8.00
- 3RD SHIFT (hours)	8
PLANT OPERATING DAYS PER WEEK (days)	5.00
PLANT OPERATING WEEKS PER YEAR (weeks)	52.14
CLOSED WEEKDAYS PER OPERATING YEAR (days)	10.00
WORKING HOURS PER PERSON - 1ST SHIFT (hours)	8.00
- 2ND SHIFT (hours)	8.00
- 3RD SHIFT (hours)	8.00
WORKING DAYS PER WORKING WEEK (days)	5.00
WORKING WEEKS PER OPERATING YEAR (weeks)	52.14
PAID HOLIDAYS PER OPERATING YEAR (days)	10.00
PAID VACATION DAYS PER OPERATING YEAR (days)	10.00
PAID SICK DAYS PER OPERATING YEAR (days)	10.00
SECOND SHIFT WAGE FACTOR (fraction)	1.10
THIRD SHIFT WAGE FACTOR (fraction)	1.20
TOTAL FIRM OPERATING TIME (min/yr)	361008
TOTAL ADMINISTRATIVE OPERATING TIME (min/yr)	120336
INDIRECT LABOR GROWTH RATES (M2 /WORKER)	
MANUFACTURING ENGINEERS	185000.
MACHINE SHOP WORKERS	185000.
SALESMEN	185000.
WAREHOUSE WORKERS	185000.
LABOR SHIFT MULTIPLIER - SHIFT NO. 1	1.09
- SHIFT NO. 2	1.09
- SHIFT NO. 3	1.09

HVAC PARAMETERS

GEOGRAPHIC REGION: DALLAS, TX
HEATING MODE: NATURAL GAS
MANUFACTURING PRODUCTION AREA: COOLED

CEILING HEAT TRANSFER COEFF UC (Btu/hr M2 F)	1.313
FLOOR HEAT TRANSFER COEFF UF (Btu/hr M2 F)	4.530
WALL HEAT TRANSFER COEFF UW (Btu/hr M2 F)	1.270
FLOOR ASPECT RATIO	1.240
CEILING HEIGHT (ft)	5.486
NUMBER OF HEATING DEGREE DAYS	2290
NUMBER OF COOLING DEGREE DAYS	2754
NUMBER OF HEATING MONTHS	5
NUMBER OF COOLING MONTHS	5
ELECTRIC HEAT COP	2.50
COOLING COP	2.50
FOSSIL FUEL CONVERSION EFFICIENCY	.80
FUEL OIL HEATING VALUE (Btu/gal)	138690
NATURAL GAS HEATING VALUE (Btu/ft3)	1032

MISCELLANEOUS PARAMETERS

PLANT CAPACITY FACTOR (fraction)	1.00
FACILITY SERVICE LIFE (years)	30.00
RAW MATERIAL INVENTORY TIME (months)	1.00

FINISHED GOODS INVENTORY TIME (months)	.00
RESEARCH AND DEVELOPMENT THRESHOLD (output units)	2
MANUFACTURING SPACE MULTIPLIER (fraction)	.00
OFFICE SPACE MULTIPLIER (fraction)	1.00
MISCELLANEOUS SPACE MULTIPLIER (M2 /person)	2.97
EXTERNAL SPACE MULTIPLIER (M2 /person)	15.06
MANUFACTURING LIGHTING MULTIPLIER (W/M2)	100.07
OFFICE LIGHTING MULTIPLIER (W/M2)	100.07
SHIPPING SPACE MULT. (M2 /million output units)	1.00
RECEIVING SPACE MULT (M2 /million output units)	1.00

WORK STATION LIST - TRUNK SEQUENCE

SEQUENCE NO.	NAME	DESCRIPTION
1	UNLDCOVR	UNLDCOVR: A-SI UNLOAD COVR GLS
2	CLNCOVR	CLNCOVR: A-SI CLEAN COVER GLAS
3	TCODEP	TCODEP: DEPOSIT TCO
4	BUFFER1	BUFFER1: A-SI BUFFER AT TCO
5	WASHTCO	WASHTCO: A-SI WASH AFTER TCO
6	SCRIBTCO	SCRIBTCO: A-SI SCRIBE TCO
7	LOADCAR	LOADCAR: A-SI LOAD BATCH CARRY
8	PHEATCAR	PHEATCAR: A-SI PREHEAT BATCH
9	ASIDEP	ASIDEP: A-SI P-I-N BATCH DEPOS
10	UNLDCAR	UNLDCAR: A-SI UNLOAD BATCH CAR
11	SCRIBASI	SCRIBASI: A-SI SCRIBE P-I-N
12	SPUTRAL	SPUTRAL: A-SI SPUTTER ALUMINUM
13	BUFFER2	BUFFER2: A-SI BUFFER ALUMINUM
14	SCRIBAL	SCRIBAL: A-SI SCRIBE ALUMINUM
15	ISOLATE	ISOLATE: A-SI ISOLATE
16	CONTACT	CONTACT: A-SI CONTACT
17	TESTCELL	TESTCELL: A-SI TEST UNENCAPSUL
18	ANELCOOL	ANELCOOL: A-SI ANNEAL & COOL
19	ENCAPSUL	ENCAPSUL: A-SI ENCAPSULATION
20	FRAMCONN	FRAMCONN: A-SI ADD FRAME/CONN
21	TESTMODL	TESTMODL: A-SI TEST FINAL PROD
22	SORTPACK	SORTPACK: A-SI SORT MODUL/PACK

WORK STATION LIST - REWORK STREAMS

REWORK STREAM NUMBER: 1
ORIGINATION POINT: TESTCELL TERMINATION POINT: TESTCELL

SEQUENCE NO.	NAME	DESCRIPTION
23	RWKCELL	RWKCELL: A-SI REWORK UNENCAPSL

WORK STATION LIST - REWORK STREAMS

REWORK STREAM NUMBER: 2
ORIGINATION POINT: TESTMODL TERMINATION POINT: TESTMODL

SEQUENCE NO.	NAME	DESCRIPTION
24	RWKMODL	RWKMODL: A-SI REWORK FINAL PRD

WORK STATION LIST - BRANCH PROCESSES

BRANCH NUMBER: 1 FOR TRUNK WORK STATION: ENCAPSUL

SEQUENCE NO.	NAME	DESCRIPTION
26	CLNBACK	CLNBACK: A-SI CLEAN BACK GLASS
25	UNLDBACK	UNLDBACK:A-SI UNLOAD BACK GLAS

The following pages contain process reports for Process B: Buy TCO-coated glass.

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01/06/93

PRODUCTION COST EXECUTIVE SUMMARY

MANUFACTURING PROCESS NAME: ASIBYTCO
A-SI BATCH PROCESS; INPUT OF TCO-COATED GLASS
CASE: PURCHASE TCO-COATED GLASS

ANALYSIS MODE: MINIMUM PLANT

ANNUAL PLANT PRODUCTION (M2 /YR) -	185874.
UNIT PRICE ($1993/M2) -	94.871
BASE YEAR -	1992
SIMULATION LENGTH (YEARS) -	10
PLANT CAPACITY FACTOR (%) -	100.000
ANNUAL PLANT OPERATING TIME (HRS/YR) -	6016
MAXIMUM NUMBER OF SHIFTS PER WORKING DAY -	3
REQUIRED RETURN ON INVESTMENT (FRACTION) -	.200
DEBT TO EQUITY RATIO (FRACTION) -	.250
COMBINED FED/STATE INCOME TAX RATE (FRACTION) -	.370

PRODUCT PRICE COMPONENTS FIRST FULL YEAR OF PRODUCTION
(END OF YEAR DOLLARS)

COMPONENT	$1993/M2	% OF TOTAL
ANNUAL SALES	94.871	100.00
ANNUAL MANUFACTURING EXPENSE -	69.706	73.47
ANNUAL DIRECT MATERIAL EXPENSE	28.972	30.54
ANNUAL DIRECT LABOR EXPENSE	13.330	14.05
ANNUAL MANUFACTURING OVERHEAD	27.403	28.88
NET ANNUAL WORK-IN-PROCESS	.045	.05
NET FINISHED GOODS INVENTORY	.000	.00
SELLING & ADMINISTRATIVE EXPENSE	4.791	5.05
CORPORATE INCOME TAXES PAYABLE	7.798	8.22
EXCESS REVENUE (INTEREST EARNED)	-.745	-.79
ANNUAL NET INCOME	13.277	14.00

INITIAL WORK STATION EQUIPMENT COST ($1992)	10567500
INITIAL FACILITY COST ($1992)	3994075
TOTAL MANUFACTURING AREA (SQ M)	3837
TOTAL NONMANUFACTURING AREA (SQ M)	999
TOTAL FACILITY AREA (SQ M)	4837
TOTAL LAND COST ($1992)	132813
TOTAL DIRECT MANUFACTURING LABOR (# WORKERS)	81
TOTAL INDIRECT MANUFACTURING LABOR (# WORKERS)	18
TOTAL INDIRECT NONMANUFACTURING LABOR (# WORKERS)	22
TOTAL PLANT LABOR (# WORKERS)	121

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CAPITAL EQUIPMENT COST SUMMARY
(JANUARY $1992)

MANUFACTURING PROCESS NAME: ASIBYTCO
A-SI BATCH PROCESS; INPUT OF TCO-COATED GLASS
CASE: PURCHASE TCO-COATED GLASS

WORK STATION		INITIAL MACH COST, $/mach	NUMBER OF MACH	TOTAL INITIAL MACH. COST, $
1	UNLDCOVR - UNLDCOVR: A-SI UNLOAD COVR GLS	80000	1	80000
2	CLNCOVR - CLNCOVR: A-SI CLEAN COVER GLAS	155000	1	155000
3	SCRIBTCO - SCRIBTCO: A-SI SCRIBE TCO	520000	1	520000
4	LOADCAR - LOADCAR: A-SI LOAD BATCH CARRY	270000	1	270000
5	PHEATCAR - PHEATCAR: A-SI PREHEAT BATCH	157500	1	157500
6	ASIDEP - ASIDEP: A-SI P-I-N BATCH DEPOS	765000	2	1530000
7	UNLDCAR - UNLDCAR: A-SI UNLOAD BATCH CAR	270000	1	270000
8	SCRIBASI - SCRIBASI: A-SI SCRIBE P-I-N	520000	1	520000
9	SPUTRAL - SPUTRAL: A-SI SPUTTER ALUMINUM	2530000	1	2530000
10	BUFFER2 - BUFFER2: A-SI BUFFER ALUMINUM	205000	1	205000
11	SCRIBAL - SCRIBAL: A-SI SCRIBE ALUMINUM	520000	1	520000
12	ISOLATE - ISOLATE: A-SI ISOLATE	210000	1	210000
13	CONTACT - CONTACT: A-SI CONTACT	210000	1	210000
14	TESTCELL - TESTCELL: A-SI TEST UNENCAPSUL	250000	1	250000
15	ANELCOOL - ANELCOOL: A-SI ANNEAL & COOL	160000	1	160000
16	ENCAPSUL - ENCAPSUL: A-SI ENCAPSULATION	2020000	1	2020000
17	FRAMCONN - FRAMCONN: A-SI ADD FRAME/CONN	110000	1	110000
18	TESTMODL - TESTMODL: A-SI TEST FINAL PROD	260000	1	260000
19	SORTPACK - SORTPACK: A-SI SORT MODUL/PACK	265000	1	265000
20	RWKCELL - RWKCELL: A-SI REWORK UNENCAPSL	50000	1	50000
21	RWKMODL - RWKMODL: A-SI REWORK FINAL PRD	40000	1	40000
22	UNLDBACK - UNLDBACK:A-SI UNLOAD BACK GLAS	80000	1	80000
23	CLNBACK - CLNBACK: A-SI CLEAN BACK GLASS	155000	1	155000
TOTAL MANUFACTURING EQUIPMENT COST				10567500

CAPITAL EQUIPMENT COST SUMMARY
(JANUARY $1992)

OTHER EQUIPMENT	NUMBER OF MACHINES	TOTAL INITIAL MACH. COST, $
TOTAL MANUFACTURING EQUIPMENT COST		10567500
PROCESS COMP		100000
BUSINESS COMP		50000
R&D LAB		500000
MANFACTURING OFFICE FURNITURE		23714
TOTAL MANFUFACTURING EQUIP & FURNITURE		11241214
TOTAL NON-MANFUFACTURING EQUIP & FURNITURE		56453
TOTAL CAPITAL EQUIPMENT COST		11297668

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COST AND YIELD SUMMARY - WORK STATION LEVEL
($1993 END OF YEAR DOLLARS)

MANUFACTURING PROCESS NAME: ASIBYTCO
A-SI BATCH PROCESS; INPUT OF TCO-COATED GLASS
CASE: PURCHASE TCO-COATED GLASS

WORK STATION	NET YIELD	HRS/ PART	UNIT COST ($/M2) LABOR	MATL	OVHD	TOTAL
1 UNLDCOVR: A-SI UNLOAD COVR GLS	99.50	.01	.14	17.44	.47	18.05
16 ENCAPSUL: A-SI ENCAPSULATION	99.00	.12	2.15	4.35	5.41	11.91
17 FRAMCONN: A-SI ADD FRAME/CONN	99.50	.05	.79	2.85	1.53	5.18
19 SORTPACK: A-SI SORT MODUL/PACK	99.80	.09	1.56	.18	3.17	4.91
9 SPUTRAL: A-SI SPUTTER ALUMINUM	99.70	.04	.77	.06	3.58	4.40
6 ASIDEP: A-SI P-I-N BATCH DEPOS	97.00	.04	.77	.42	2.75	3.94
22 UNLDBACK:A-SI UNLOAD BACK GLAS	99.50	.01	.14	3.08	.47	3.69
11 SCRIBAL: A-SI SCRIBE ALUMINUM	99.50	.03	.64	.11	1.49	2.24
8 SCRIBASI: A-SI SCRIBE P-I-N	99.50	.03	.64	.11	1.49	2.24
3 SCRIBTCO: A-SI SCRIBE TCO	99.50	.03	.64	.10	1.49	2.23
18 TESTMODL: A-SI TEST FINAL PROD	95.00	.04	.73	.01	1.44	2.18
14 TESTCELL: A-SI TEST UNENCAPSUL	92.00	.04	.73	.01	1.37	2.12
21 RWKMODL: A-SI REWORK FINAL PRD	80.00	.04	.73	.02	1.22	1.97
20 RWKCELL: A-SI REWORK UNENCAPSL	80.00	.04	.73	.01	1.23	1.96
7 UNLDCAR: A-SI UNLOAD BATCH CAR	98.00	.03	.48	.00	1.12	1.60
4 LOADCAR: A-SI LOAD BATCH CARRY	98.00	.03	.48	.00	1.12	1.60
10 BUFFER2: A-SI BUFFER ALUMINUM	99.80	.01	.18	.01	.67	.86
12 ISOLATE: A-SI ISOLATE	99.70	.01	.14	.01	.53	.68
13 CONTACT: A-SI CONTACT	99.70	.01	.14	.02	.52	.68
15 ANELCOOL: A-SI ANNEAL & COOL	99.80	.01	.14	.07	.43	.65
5 PHEATCAR: A-SI PREHEAT BATCH	99.00	.00	.05	.07	.29	.41
2 CLNCOVR: A-SI CLEAN COVER GLAS	99.70	.00	.03	.03	.20	.25
23 CLNBACK: A-SI CLEAN BACK GLASS	99.70	.00	.03	.03	.20	.25
	85.07	.71	12.83	28.97	32.19	74.00

* - Multi-Pass Work Station
OVHD = Manuf. Ovhd. + Selling & Admin. Expense

PRODUCT COST CENTER	NET YIELD	HRS/ PART	UNIT COST ($/M2)
1 CELL DEPOSITION	89.68	.26	37.83
2 MECHANICAL ASSEMBLY	96.51	.41	34.06
3 TESTING	98.29	.04	2.12
TOTAL MANUFACTURING COST	85.07	.71	74.00

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PROCESS TOTALS & LABOR REQUIREMENTS

MANUFACTURING PROCESS NAME: ASIBYTCO
A-SI BATCH PROCESS; INPUT OF TCO-COATED GLASS
CASE: PURCHASE TCO-COATED GLASS

DIRECT MANUFACTURING LABOR
(1993 END OF YEAR DOLLARS)

OVERALL PROCESS TOTAL

	LABOR CATEGORY	NO. OF PERSONS*	HRS/YR	SALARY	$/YR**
1	PROCESS OPERATOR	42	74742	16.5 $/HR	1410098
16	M/E MAINT	9	6987	14.3 $/HR	261875
21	MATL. HANDLER	30	49827	13.2 $/HR	805770
	TOTAL DIRECT LABOR	81	131556		2477744

* - INCLUDES LABOR SHIFT MULTIPLIER ** - INCLUDES WAGE SHIFT PREMIUMS

MANUFACTURING INDIRECT LABOR

	LABOR CATEGORY	NO. OF PERSONS	SALARY	TOTAL
	SHIFT EMPLOYEES			
1	Material Handlers	3	19042	62839
2	Production Supervisors	3	50178	165587
3	Clerks, Production Supervisors	3	22258	73452
4	Area Supervisors	0	42201	0
5	Clerks, Area Supervisors	0	17497	0
6	Plant Production Foremen	3	38984	128648
7	Mech/Elec Maint. Forman	0	38984	0
8	Material Handling Foremen	0	38984	0
9	Machine Shop Foremen	0	38984	0
10	Machine Shop Workers	3	33837	111665
11	Q/C Foremen	0	38984	0
	TOTAL INDIRECT MANF SHIFT LABOR	15	N/A	542193

* - INCLUDES LABOR SHIFT MULTIPLIER ** - INCLUDES WAGE SHIFT PREMIUMS

	NON-SHIFT EMPLOYEES			
1	Vice President Manufacturing	1	78740	78740
2	Director of R&D	1	59699	59699
3	Director of Manufacturing Engineeri	1	0	0
4	Engineers, Manufacturing Engineerin	1	0	0
5	Draftsmen, Manufacturing Engineerin	1	0	0
6	Director of Q/C	1	0	0
7	Manufacturing Sec I	2	0	0
8	Manufacturing Sec II	1	21057	21057
	R&D EXPENSE/YEAR	N/A	N/A	1102502
	TOTAL INDIRECT MANF NON-SHIFT LABOR	9	N/A	1261999
	TOTAL MANUFACTURING INDIRECT LABOR	24	N/A	1804193

DIRECT MANUFACTURING FACILITIES
(JANUARY $1992)

PRODUCT COST CENTER:
CELL DEPOSITION

FACILITY CATEGORY	AREA (SQ M)	$/SQ M	$
2 FACTORY FLOOR	1487	1248.00	1855776
TOTAL DIRECT FACILITIES	1487	N/A	1855776

DIRECT MANUFACTURING FACILITIES
(JANUARY $1992)

DIRECT MANUFACTURING FACILITIES
(JANUARY $1992)

OVERALL PROCESS TOTAL

FACILITY CATEGORY	AREA (SQ M)	$/SQ M	$
2 FACTORY FLOOR	2546	1248.00	3178007
TOTAL DIRECT FACILITIES	2546	N/A	3178007

OTHER MANUFACTURING FACILITIES
(JANUARY $1992)

FACILITY CATEGORY	AREA (SQ M)	$/SQ M	$
MACHINE SHOP FLOOR SPACE	55	724.79	40414
SHIPPING FLOOR SPACE	185	724.79	134719
RECEIVING FLOOR SPACE	185	724.79	134719
MANUFACTURING OFFICE FLOOR SPACE	124	724.79	90250
MISC. MANUFACTURING FLOOR SPACE	121	790.86	96432
MANUFACTURING EXTERIOR SPACE	617	10.76	6642
INDIRECT MANUFACTURING FACILITIES	1291	N/A	503179
TOTAL MANUFACTURING FACILITIES	3837	N/A	3681186

DIRECT MANUFACTURING UTILITIES
($1993 END OF YEAR DOLLARS)

OVERALL PROCESS TOTAL

UTILITY CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
1 ELECTRICITY	KW	3090905.	.04	136309.
TOTAL DIRECT UTILITIES		N/A	N/A	136308

INDIRECT MANUFACTURING UTILITIES
($1993 END OF YEAR DOLLARS)

MATERIAL CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
MANUFACTURING SPACE LIGHTING	kwh	1790641	.04410	78967
MANUFACTURING OFFICE LIGHTING	kwh	148390	.04410	6544
NATURAL GAS	ft3	0	.07828	0
COOLING ELECTRICITY	kwh	1000536	.04410	44123
TOTAL MANUFACTURING UTITLIIES		N/A	N/A	129634

DIRECT MANUFACTURING MATERIALS
($1993 END OF YEAR DOLLARS)

OVERALL PROCESS TOTAL

MATERIAL CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
1 SILANE	GM	180620.	.19	33853.
2 LIQUID NITROGEN	LITER	396524.	.00	63.
4 DEMINERALIZED WATER	M3	15088.	.52	7901.
5 COVER GLASS	M2	218501.	14.83	3240069.
6 BACK GLASS	M2	192600.	2.97	571198.
10 AL. SPUTTER SOURCE	GM	876031.	.00	1795.
11 ARC LAMP	EA	62.	192.94	11930.
12 EVA	M2	191062.	4.16	794135.
13 AIR FILTER & PARTS	EA	4.	220.50	840.
14 ALUMINUM FOIL	M2	11624.	.30	3447.
15 MOLDED RUBBER BOOTS	2EA	154915.	.66	102477.
16 CABLE CONN. & ADHESV	UNIT	154915.	.88	136635.
17 POLYCARB. U-FRAME	M	724263.	.18	130954.
18 PACKING MATL	EA	152535.	.21	31952.
19 ALUM SUPP STRUTS	GM	48052170.	.00	158933.
20 SILICONE RESIN	GM	40188.	.06	2570.
21 LIQ. N2 TANK LEASE	MIN	520517.	.04	20085.
TOTAL DIRECT MATERIALS		N/A	N/A	5248828

DIRECT MANUFACTURING MATERIALS BYPRODUCTS
($1993 END OF YEAR DOLLARS)

OVERALL PROCESS TOTAL

MATERIAL CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
10 AL. SPUTTER SOURCE	GM	438015.	.00	0.
TOTAL DIRECT MATERIAL BYPRODUCTS		N/A	N/A	0

MISCELLANEOUS MANUFACTURING ITEMS
($1993 END OF YEAR DOLLARS)

CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
MANF. OFFICE SUPPLIES		24	275.625	6614
FACILITY REPAIR		N/A	N/A	135283
TOTAL MISCELLANEOUS MANF COST		N/A	N/A	141898
MANF. OFFICE FURNITURE ($1992)			190.450	23714

NON-MANUFACTURING TOTALS AND REQUIREMENTS

NON-MANUFACTURING LABOR
($1993 END OF YEAR DOLLARS)

LABOR CATEGORY	NO. OF PERSONS	SALARY	TOTAL
NON-SHIFT EMPLOYEES			
1 President	1	88199	88199
2 Vice President Finance	1	48620	48620
3 Cost Accountant	1	0	0
4 Payroll Accountant	1	29266	29266
5 Manager of Credits and Collection	1	0	0
6 Manager of Data Processing	1	29877	29877
7 Clerks, Finance	4	0	0

8	Vice President Facility Administrat	1	46966	46966
9	Director of Recruitment	1	0	0
10	Clerks, Personnel	1	18191	18191
11	Director of General Facility Operat	1	31862	31862
14	Receptionist	1	13781	13781
15	Vice President Sales	1	67472	67472
16	Salesmen	0	44099	0
19	Administrative Sec I	10	0	0
20	Administrative Sec II	4	21057	84230
	SHIFT EMPLOYEES			
21	Security Personnel	3	16316	48950
22	General Facility Maintenance Worker	6	16647	99886
	TOTAL NON-MANUFACTURING LABOR COST	39	N/A	607307

NON-MANUFACTURING FACILITIES
(JANUARY $1992)

FACILITY CATEGORY	AREA (SQ M)	$/SQ M	$
ADMINISTRATIVE OFFICE SPACE	296	724.79	214842
MISC. ADMINISTRATIVE SPACE	115	790.86	91728
NON-MANUFACTURING EXTERIOR SPACE	587	10.76	6318
TOTAL NON-MANUFACTURING FACILITIES	999	N/A	312889

NON-MANUFACTURING INDIRECT UTILITIES
($1993 END OF YEAR DOLLARS)

UTILITY CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
ADMINISTRATIVE SPACE LIGHTING	kwh	82770	.04410	3650
NATURAL GAS	ft3	0	.07828	0
COOLING ELECTRICITY	kwh	35856	.04410	1581
TOTAL NON-MANUFACTURING UTITLIIES		N/A	N/A	5231

MISCELLANEOUS NON-MANUFACTURING ITEMS
($1993 END OF YEAR DOLLARS)

MATERIAL CATEGORY	UNITS	QTY/YR	$/QTY	$/YR
ADMIN. OFFICE SUPPLIES		39	275.625	10749
FACILITY REPAIR		N/A	N/A	8127
TOTAL MISCELLANEOUS ADMIN COST		N/A	N/A	18877
ADMIN. OFFICE FURNITURE ($1992)			190.450	56453
LAND ($1992)	M2	5321	24.960	132813

The following pages contain financial reports for Process B: Buy TCO-coated glass.

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ANNUAL CORPORATE FINANCIAL REPORTS
INCOME STATEMENT

MANUFACTURING PROCESS NAME: ASIBYTCO
A-SI BATCH PROCESS; INPUT OF TCO-COATED GLASS
CASE: PURCHASE TCO-COATED GLASS

(END OF YEAR DOLLARS)

YEAR	1992	1993	1994
SALES	12837080.	17634070.	18034240.
COST OF GOODS SOLD			
BEGINNING FINISHED GOODS	0.	0.	0.
MANF GOODS ADDED TO FINISHED GOODS	8617920.	12964750.	13504130.
GOODS AVAILABLE FOR SALE	8617920.	12964750.	13504130.
ENDING FINISHED GOODS	0.	0.	0.
COST OF GOODS SOLD	8617920.	12964750.	13504130.
GROSS PROFIT	4219162.	4669325.	4530106.
SELLING AND ADMINISTRATIVE EXPENSES	849769.	890463.	933192.
INCOME FROM OPERATIONS	3369394.	3778862.	3596914.
OTHER REVENUE AND EXPENSES			
INTEREST EARNED	887294.	477827.	659775.
INTEREST EXPENSE	339340.	339340.	339340.
EXCESS	547954.	138487.	320435.
INCOME BEFORE TAXES	3917348.	3917348.	3917348.
CORPORATE INCOME TAX EXPENSE	1449419.	1449419.	1449419.
INCOME TAXES PAYABLE	1216823.	718095.	1234321.
DEFERRED INCOME TAXES	232596.	731324.	215097.
NET INCOME	2467929.	2467929.	2467929.

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ANNUAL CORPORATE FINANCIAL REPORTS
BALANCE SHEET (TAX BASIS)

MANUFACTURING PROCESS NAME: ASIBYTC0
A-SI BATCH PROCESS; INPUT OF TCO-COATED GLASS
CASE: PURCHASE TCO-COATED GLASS

(END OF YEAR DOLLARS)

YEAR	1992	1993	1994
ASSETS			
CURRENT ASSETS			
CASH	133713.	188048.	197450.
MARKETABLE SECURITIES	4293095.	6325280.	8336380.
ACCOUNTS RECEIVABLE	0.	0.	0.
INVENTORIES			
MATERIALS	208287.	437403.	459273.
WORK IN PROCESS	70337.	62044.	64526.
FINISHED GOODS	0.	0.	0.
TOTAL INVENTORIES	278624.	499447.	523799.
TOTAL CURRENT ASSETS	4705432.	7012775.	9057630.
PROPERTY PLANT & EQUIPMENT			
LAND	132814.	132814.	132814.
BUILDINGS	3994075.	3994075.	3994075.
ACCUMULATED DEPRECIATION (BUILDINGS)	133136.	266272.	399408.
NET BOOK VALUE (BUILDINGS)	3860940.	3727804.	3594668.
EQUIPMENT AND FURNITURE	11297670.	11297670.	11297670.
ACCUMULATED DEPRECIATION (EQUIP/FURN)	1567565.	3135131.	4702696.
NET BOOK VALUE (EQUP/FURN)	9730103.	8162538.	6594973.
TOTAL PROPERTY PLANT AND EQUIPMENT	13723860.	12023160.	10322450.
TOTAL ASSETS	18429290.	19035930.	19380080.
LIABILITIES			
TAXES PAYABLE	304206.	179524.	308580.
DEFERRED INCOME TAXES	232596.	963920.	1179017.
DIVIDENDS PAYABLE	2467929.	2467929.	2467929.
BONDS PAYABLE	3084912.	3084912.	3084912.
TOTAL LIABILITIES	6089642.	6696284.	7040438.
STOCKHOLDERS EQUITY			
COMMON STOCK	12339650.	12339650.	12339650.
RETAINED EARNINGS	0.	0.	0.
TOTAL STOCKHOLDERS EQUITY	12339650.	12339650.	12339650.
TOT LIABILITIES AND STOCKHOLDERS EQUITY	18429290.	19035930.	19380080.

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ANNUAL CORPORATE FINANCIAL REPORTS
MANUFACTURING & NON-MANUFACTURING OVERHEAD

MANUFACTURING PROCESS NAME: ASIBYTC0
A-SI BATCH PROCESS; INPUT OF TCO-COATED GLASS
CASE: PURCHASE TCO-COATED GLASS

(END OF YEAR DOLLARS)

YEAR	1992	1993	1994
MANUFACTURING OVERHEAD			
DEPRECIATION	1688390.	1688390.	1688390.
MISCELLANEOUS OVERHEAD			
INDIRECT LABOR	1718280.	1804194.	1894404.
INDIRECT UTILITIES	123462.	129635.	136117.
MATERIALS & SUPPLIES	135142.	141899.	148994.
TOTAL MISCELLANEOUS OVERHEAD	1976883.	2075727.	2179514.
SOCIAL SECURITY	230131.	240825.	252054.
UNEMPLOYMENT INSURANCE	25725.	25725.	25725.
PROPERTY TAXES	73624.	73624.	73624.
PROPERTY INSURANCE	149224.	149224.	149224.
FRINGE BENEFITS			
HOSPITALIZATION & MEDICAL BENEFITS	198450.	208373.	218791.
PENSION (EMPLOYER CONTRIBUTION)	300798.	315838.	331630.
OTHER FRINGE BENEFITS	300798.	315838.	331630.
TOTAL FRINGE BENEFITS	800046.	840048.	882050.
TOTAL MANUFACTURING OVERHEAD	4944023.	5093563.	5250581.
NON-MANUFACTURING OVERHEAD			
DEPRECIATION	12311.	12311.	12311.
MISCELLANEOUS OVERHEAD			
INDIRECT LABOR	578388.	607308.	637673.
INDIRECT UTILITIES	4982.	5231.	5493.
MATERIALS & SUPPLIES	17978.	18877.	19821.
TOTAL MISCELLANEOUS OVERHEAD	601349.	631416.	662987.
SOCIAL SECURITY	42328.	44242.	46250.
UNEMPLOYMENT INSURANCE	9555.	9555.	9555.
PROPERTY TAXES	6258.	6258.	6258.
PROPERTY INSURANCE	3693.	3693.	3693.
FRINGE BENEFITS			
HOSPITALIZATION & MEDICAL BENEFITS	73710.	77396.	81265.
PENSION (EMPLOYER CONTRIBUTION)	50282.	52796.	55436.
OTHER FRINGE BENEFITS	50282.	52796.	55436.
TOTAL FRINGE BENEFITS	174274.	182988.	192137.
TOTAL NON-MANUFACTURING OVERHEAD	849769.	890463.	933192.
TOTAL ANNUAL OVERHEAD EXPENSE	5793792.	5984026.	6183773.

The following pages contain input data summaries for Process B: Buy TCO-coated glass.

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COST CATALOG

MANUFACTURING PROCESS NAME: ASIBYTCO
A-SI BATCH PROCESS; INPUT OF TCO-COATED GLASS
CASE: PURCHASE TCO-COATED GLASS

DIRECT MANUFACTURING FACILITIES COST YEAR: 1992

	CATEGORY	UNITS	COST UNITS	COST
1	CLEAN ROOM FLOOR	M2	$/M2	2152.00
2	FACTORY FLOOR	M2	$/M2	1248.00

DIRECT LABOR - PRODUCTION WORKERS COST YEAR: 1992

	CATEGORY	UNITS	COST UNITS	SALARY
1	PROCESS OPERATOR	PER/MACH/SHIFT	$/HR	15.00

DIRECT LABOR - MECH/ELEC MAINT WORKERS COST YEAR: 1992

	CATEGORY	UNITS	COST UNITS	SALARY
16	M/E MAINT	PER/MACH/SHIFT	$/HR	13.00

DIRECT LABOR - MATERIAL HANDLERS COST YEAR: 1992

	CATEGORY	UNITS	COST UNITS	SALARY
21	MATL. HANDLER	PER/MACH/SHIFT	$/HR	12.00

DIRECT LABOR - QUALITY CONTROL HANDLERS COST YEAR: 1992

	CATEGORY	UNITS	COST UNITS	SALARY

DIRECT MANUFACTURING UTILITIES COST YEAR: 1992

	CATEGORY	UNITS	COST UNITS	COST
1	ELECTRICITY	KW	$/KWH	.0400
2	NATURAL GAS	M3/MIN	$/M3	.0710
3	FUEL OIL	LITER/MIN	$/LITER	.0000

DIRECT MANUFACTURING MATERIALS COST YEAR: 1992

	CATEGORY	UNITS	COST UNITS	PRICE	DISPOSAL COST
1	SILANE	GM	$/GM	.1700	.0000
2	LIQUID NITROGEN	LITER	$/LITER	.0001	.0000
3	TIN TETRACHLORIDE	KG	$/KG	6.6000	.0000
4	DEMINERALIZED WATER	M3	$/M3	.4750	.0000
5	COVER GLASS	M2	$/M2	13.4500	.0000
6	BACK GLASS	M2	$/M2	2.6900	.0000
7	OXYGEN	LITER	$/LITER	.0071	.0000
8	FREON	LITER	$/LITER	.2100	.0000
9	HELIUM	LITER	$/LITER	.0000	.0000
10	AL. SPUTTER SOURCE	GM	$/GM	.0019	.0000
11	ARC LAMP	EA	$/EA	175.0000	.0000
12	EVA	M2	$/M2	3.7700	.0000
13	AIR FILTER & PARTS	EA	$/EA	200.0000	.0000
14	ALUMINUM FOIL	M2	$/M2	.2690	.0000

15	MOLDED RUBBER BOOTS	2EA	$/2EA	.6000	.0000
16	CABLE CONN. & ADHESV	UNIT	$/UNIT	.8000	.0000
17	POLYCARB. U-FRAME	M	$/M	.1640	.0000
18	PACKING MATL	EA	$/EA	.1900	.0000
19	ALUM SUPP STRUTS	GM	$/GM	.0030	.0000
20	SILICONE RESIN	GM	$/GM	.0580	.0000
21	LIQ. N2 TANK LEASE	MIN	$/MIN	.0350	.0000

INDIRECT MANUFACTURING LABOR COST YEAR: 1992

	CATEGORY	COST UNITS	SALARY	FLOOR SPACE (FT2)
1	Material Handlers	($/yr)	17272.00	.00
2	Production Supervisors	($/yr)	45513.00	11.15
3	Clerks, Production Supervisors	($/yr)	20189.00	6.97
4	Area Supervisors	($/yr)	38278.00	11.15
5	Clerks, Area Supervisors	($/yr)	15871.00	6.97
6	Plant Production Foremen	($/yr)	35360.00	6.97
7	Mech/Elec Maint. Forman	($/yr)	35360.00	6.97
8	Material Handling Foremen	($/yr)	35360.00	6.97
9	Machine Shop Foremen	($/yr)	35360.00	46.47
10	Machine Shop Workers	($/yr)	30692.00	9.29
11	Q/C Foremen	($/yr)	35360.00	6.97
12	Vice President Manufacturing	($/yr)	71420.00	13.94
13	Director of R&D	($/yr)	54149.00	13.94
14	Director of Manufacturing Engineering	($/yr)	.00	.00
15	Engineers, Manufacturing Engineering	($/yr)	.00	.00
16	Draftsmen, Manufacturing Engineering	($/yr)	.00	.00
17	Director of Q/C	($/yr)	.00	.00

INDIRECT NON-MANUFACTURING LABOR COST YEAR: 1992

	CATEGORY	COST UNITS	SALARY	FLOOR SPACE (FT2)
1	President	($/yr)	80000.00	13.94
2	Vice President Finance	($/yr)	44100.00	13.94
3	Cost Accountant	($/yr)	.00	.00
4	Payroll Accountant	($/yr)	26546.00	13.94
5	Manager of Credits and Collection	($/yr)	.00	.00
6	Manager of Data Processing	($/yr)	27100.00	11.15
7	Clerks, Finance	($/yr)	.00	.00
8	Vice President Facility Administration	($/yr)	42600.00	13.94
9	Director of Recruitment	($/yr)	.00	.00
10	Clerks, Personnel	($/yr)	16500.00	9.29
11	Director of General Facility Operations	($/yr)	28900.00	13.94
12	Security Personnel	($/yr)	14800.00	.00
13	General Facility Maintenance Workers	($/yr)	15100.00	.00
14	Receptionist	($/yr)	12500.00	6.97
15	Vice President Sales	($/yr)	61200.00	13.94
16	Salesmen	($/yr)	40000.00	11.15
17	Manufacturing Sec I	($/yr)	.00	.00
18	Manufacturing Sec II	($/yr)	19100.00	9.29
19	Administrative Sec I	($/yr)	.00	.00
20	Administrative Sec II	($/yr)	19100.00	9.29

MISCELLANEOUS ITEMS COST YEAR: 1992

	ITEM	COST UNITS	COST
1	Shipping Floor SpaceCost	$/M2	724.79
2	Receiving Floor Space Cost	$/M2	724.79
3	Machine Shop Floor Space	$/M2	724.79
4	Manufacturing OfficeFloor Space Cost	$/M2	724.79
5	Non-Manufacturing Office Space Cost	$/M2	724.79
6	Manufacturing Misc. Space Cost	$/M2	790.86
7	Non-Manufacturing Misc. Space Cost	$/M2	790.86

8	Manufacturing Exterior Space Cost	$/M2	10.76
9	Non-Manuf. Exterior Space Cost	$/M2	10.76
10	Land	$/M2	24.96
11	Manuf. Office Furniture cost	$/M2	190.45
12	Non-Manuf. Office Funiture Cost	$/M2	190.45
13	Research and Development Cost	$/OUTPUT UNIT	5.38
14	Manufacturing Office Supply Cost	$/PERSON	250.00
15	Non-Manufacturing Office Supply Cost	$/PERSON	250.00

MISCELLANEOUS EQUIPMENT COST YEAR: 1992

	ITEM	COST
1	PROCESS COMP	100000.00
2	BUSINESS COMP	50000.00
3	R&D LAB	500000.00

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FINANCIAL MODEL INPUT DATA

MANUFACTURING PROCESS NAME: ASIBYTCO
A-SI BATCH PROCESS; INPUT OF TCO-COATED GLASS
CASE: PURCHASE TCO-COATED GLASS

SIMULATION LENGTH (yrs)	10
BASE YEAR	1992
TAX DEPRECIATION METHOD (ACRS OR STRAIGHT LINE)	ACRS
BOOK DEPR METHOD (STRAIGHT LINE, SYD, OR DDB)	STRAIGHT LINE
REQUIRED RETURN ON EQUITY (fraction)	.200
DEBT TO EQUITY RATIO (fraction)	.250
BOND INTEREST RATE (fraction)	.110
MARKETABLE SECURITIES INTEREST RATE (fraction)	.090
COMBINED FED/STATE INCOME TAX RATE (fraction)	.370
PROPERTY TAX RATE (fraction)	.020
PROPERTY INSURANCE RATE (fraction)	.010
FICA SALARY CUTOFF LEVEL ($/yr)	53400.000
FICA RATE (fraction)	.076
UNEMPLOYMENT INSURANCE ($/person/yr)	245.000
HOSPITALIZATION & MEDICAL BENEFITS ($/person/mo)	150.000
FRINGE BENEFITS (fraction)	.100
PENSIONS (fraction)	.100

INFLATION RATE TABLE 1980-2000

YEAR	RATE
1980	.103
1981	.089
1982	.059
1983	.043
1984	.043
1985	.036
1986	.019
1987	.036
1988	.041
1989	.049
1990	.052
1991	.054
1992	.050
1993	.050
1994	.050
1995	.050
1996	.050
1997	.050
1998	.050
1999	.050
2000	.050

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PROCESS INPUT PARAMETERS AND WORK STATION SEQUENCE

MANUFACTURING PROCESS NAME: ASIBYTCO
A-SI BATCH PROCESS; INPUT OF TCO-COATED GLASS
CASE: PURCHASE TCO-COATED GLASS

ANNUAL PLANT PRODUCTION (1000 units/yr)	185.87
FINAL PRODUCT UNITS	M2

LABOR UTILIZATION

MAXIMUM NUMBER OF SHIFTS PER WORKING DAY	3.00
PLANT OPERATING HOURS - 1ST SHIFT (hours)	8.00
- 2ND SHIFT (hours)	8.00
- 3RD SHIFT (hours)	8
PLANT OPERATING DAYS PER WEEK (days)	5.00
PLANT OPERATING WEEKS PER YEAR (weeks)	52.14
CLOSED WEEKDAYS PER OPERATING YEAR (days)	10.00
WORKING HOURS PER PERSON - 1ST SHIFT (hours)	8.00
- 2ND SHIFT (hours)	8.00
- 3RD SHIFT (hours)	8.00
WORKING DAYS PER WORKING WEEK (days)	5.00
WORKING WEEKS PER OPERATING YEAR (weeks)	52.14
PAID HOLIDAYS PER OPERATING YEAR (days)	10.00
PAID VACATION DAYS PER OPERATING YEAR (days)	10.00
PAID SICK DAYS PER OPERATING YEAR (days)	10.00
SECOND SHIFT WAGE FACTOR (fraction)	1.10
THIRD SHIFT WAGE FACTOR (fraction)	1.20
TOTAL FIRM OPERATING TIME (min/yr)	361008
TOTAL ADMINISTRATIVE OPERATING TIME (min/yr)	120336
INDIRECT LABOR GROWTH RATES (M2 /WORKER)	
MANUFACTURING ENGINEERS	185000.
MACHINE SHOP WORKERS	185000.
SALESMEN	185000.
WAREHOUSE WORKERS	185000.
LABOR SHIFT MULTIPLIER - SHIFT NO. 1	1.09
- SHIFT NO. 2	1.09
- SHIFT NO. 3	1.09

HVAC PARAMETERS

GEOGRAPHIC REGION: DALLAS, TX
HEATING MODE: NATURAL GAS
MANUFACTURING PRODUCTION AREA: COOLED

CEILING HEAT TRANSFER COEFF UC (Btu/hr M2 F)	1.313
FLOOR HEAT TRANSFER COEFF UF (Btu/hr M2 F)	4.530
WALL HEAT TRANSFER COEFF UW (Btu/hr M2 F)	1.270
FLOOR ASPECT RATIO	1.240
CEILING HEIGHT (ft)	5.486
NUMBER OF HEATING DEGREE DAYS	2290
NUMBER OF COOLING DEGREE DAYS	2754
NUMBER OF HEATING MONTHS	5
NUMBER OF COOLING MONTHS	5
ELECTRIC HEAT COP	2.50
COOLING COP	2.50
FOSSIL FUEL CONVERSION EFFICIENCY	.80
FUEL OIL HEATING VALUE (Btu/gal)	138690
NATURAL GAS HEATING VALUE (Btu/ft3)	1032

MISCELLANEOUS PARAMETERS

PLANT CAPACITY FACTOR (fraction)	1.00
FACILITY SERVICE LIFE (years)	30.00

RAW MATERIAL INVENTORY TIME (months)	1.00
FINISHED GOODS INVENTORY TIME (months)	.00
RESEARCH AND DEVELOPMENT THRESHOLD (output units)	2
MANUFACTURING SPACE MULTIPLIER (fraction)	.00
OFFICE SPACE MULTIPLIER (fraction)	1.00
MISCELLANEOUS SPACE MULTIPLIER (M2 /person)	2.97
EXTERNAL SPACE MULTIPLIER (M2 /person)	15.06
MANUFACTURING LIGHTING MULTIPLIER (W/M2)	100.07
OFFICE LIGHTING MULTIPLIER (W/M2)	100.07
SHIPPING SPACE MULT. (M2 /million output units)	1.00
RECEIVING SPACE MULT (M2 /million output units)	1.00

WORK STATION LIST - TRUNK SEQUENCE

SEQUENCE NO.	NAME	DESCRIPTION
1	UNLDCOVR	UNLDCOVR: A-SI UNLOAD COVR GLS
2	CLNCOVR	CLNCOVR: A-SI CLEAN COVER GLAS
3	SCRIBTCO	SCRIBTCO: A-SI SCRIBE TCO
4	LOADCAR	LOADCAR: A-SI LOAD BATCH CARRY
5	PHEATCAR	PHEATCAR: A-SI PREHEAT BATCH
6	ASIDEP	ASIDEP: A-SI P-I-N BATCH DEPOS
7	UNLDCAR	UNLDCAR: A-SI UNLOAD BATCH CAR
8	SCRIBASI	SCRIBASI: A-SI SCRIBE P-I-N
9	SPUTRAL	SPUTRAL: A-SI SPUTTER ALUMINUM
10	BUFFER2	BUFFER2: A-SI BUFFER ALUMINUM
11	SCRIBAL	SCRIBAL: A-SI SCRIBE ALUMINUM
12	ISOLATE	ISOLATE: A-SI ISOLATE
13	CONTACT	CONTACT: A-SI CONTACT
14	TESTCELL	TESTCELL: A-SI TEST UNENCAPSUL
15	ANELCOOL	ANELCOOL: A-SI ANNEAL & COOL
16	ENCAPSUL	ENCAPSUL: A-SI ENCAPSULATION
17	FRAMCONN	FRAMCONN: A-SI ADD FRAME/CONN
18	TESTMODL	TESTMODL: A-SI TEST FINAL PROD
19	SORTPACK	SORTPACK: A-SI SORT MODUL/PACK

WORK STATION LIST - REWORK STREAMS

REWORK STREAM NUMBER: 1
ORIGINATION POINT: TESTCELL TERMINATION POINT: TESTCELL

SEQUENCE NO.	NAME	DESCRIPTION
20	RWKCELL	RWKCELL: A-SI REWORK UNENCAPSL

WORK STATION LIST - REWORK STREAMS

REWORK STREAM NUMBER: 2
ORIGINATION POINT: TESTMODL TERMINATION POINT: TESTMODL

SEQUENCE NO.	NAME	DESCRIPTION
21	RWKMODL	RWKMODL: A-SI REWORK FINAL PRD

WORK STATION LIST - BRANCH PROCESSES

BRANCH NUMBER: 1 FOR TRUNK WORK STATION: ENCAPSUL

SEQUENCE NO.	NAME	DESCRIPTION
23	CLNBACK	CLNBACK: A-SI CLEAN BACK GLASS
22	UNLDBACK	UNLDBACK:A-SI UNLOAD BACK GLAS

Appendix B

Description of Module Required Price Model

STAMPP Version 4.01

Motivation

In today's world of sophisticated technology, the introduction of a new product is often preceded by years of research and development that is very costly. The process often requires tradeoffs to establish product features or performance and to select the appropriate manufacturing methods. Those tradeoffs have implications for the eventual product price that can be difficult and complex to understand. The choices made can be critical, however, because acceptance of the product in the market is influenced by the combination of features, performance and price when the customer evaluates them against competitive products. The manufacturer needs to understand, in as much detail as possible, how to produce the product at the acceptable price, and, at the same time, to maintain his own profitability.

Decisions to resolve tradeoff issues during product development can involve all corporate functions: research, development, manufacturing, marketing, and management. But the diverse backgrounds of that spectrum of people can make effective communication difficult without some means to quantify the impact of the choices to be made. Communication can be improved by a model that reflects the manufacturing choices and includes the effect of corporate financial practices as well. The Research Triangle Institute has developed such a model, called Strategic Analysis of Manufacturing Process and Price (STAMPP). STAMPP models the manufacturing operations of a company and its overhead and financial structure to calculate the price of the product produced. The product price provides a specified rate of return on equity investment at a specified level of production. Among the outputs of the model are a corporate income statement and balance sheet that allows financial analysts and managers to view the financial performance of the projected business over a period of years specified by the modeler. These reports are based on accepted accounting procedures whose input data is developed by a simulation of the product manufacturing operations required. On the manufacturing side, reports are provided that summarize the equipment, labor, materials, floor space, and utilities required in terms of both quantity and cost. Also reported are personnel and associated costs for administrative functions. The result is a complete picture of all aspects of the cost structure underlying the required product price. The STAMPP model provides the capability to define the major price drivers and the sensitivity of price to those drivers. Thus, product feature and performance choices can be made intelligently, and financial and technical resources can be directed to the manufacturing areas where the greatest reductions in price can be expected.

Model Framework

The objective of the STAMPP approach is to model at a specified level of detail all of the costs associated with manufacturing a product by a corporation or business unit, to determine the price the corporation must charge to operate a profitable business, and to provide sufficient detail on costs that price drivers can be identified. This information provides guidance on issues of resource allocation in research, development and manufacturing, and on assessing marketability of a prospective product. STAMPP models the physical manufacturing operations, the personnel organization of the corporation and the physical facilities that houses these operations and people in order to capture their associated costs. STAMPP runs on a personal computer such as the IBM PC-AT (or XT) with 640k of memory, hard drive and floppy drive. Two modes of operation for the STAMPP model have been implemented. Both model the direct manufacturing

operations and their costs in the same manner, but two levels of detail for including indirect costs are available. The more detailed one is discussed here to introduce the modeling framework. The other, less detailed, level is discussed in the Modeling Procedure section that follows.

STAMPP allows the modeling of a hypothetical corporate organization shown in Figure B-1 that covers most, if not all, of the functions necessary to operate a company. The top level positions in the organization are assumed to be filled. The number of employees in the manufacturing area who operate machines or perform maintenance, materials handling or quality control duties are determined from the simulation of the manufacturing operations (described subsequently). Foremen and area supervisors are determined based on the number of these employees directly associated with production. The support staffing in the administrative areas is a function of the total employment of the company. Thus, the employment has a fixed base level of management people, and the total employment is a function of the employment in the manufacturing area, which, in turn, is a function of the production volume and the manning specified for each production machine.

The physical operations of manufacturing are modeled in STAMPP as illustrated by Figure B-2. In order to define the product manufacturing operations flow, STAMPP uses a block called the "workstation". A workstation is defined as a collection of identical machines (one or more), each performing the same operations in parallel. The user specifies the work flow among the workstations. An arbitrary path ending at the output of the final product is designated the "trunk" sequence. "Branch" sequences of workstations are allowed to model subassemblies or component fabrication. The model also allows rework of partially completed product, either with or without additional workstations in the rework sequence. Sampling of the workstation output for inspection is also allowed, with reinsertion of product when inspection is nondestructive or scrapping of inspected product when the testing is destructive. For the purpose of aggregating cost data developed by the model, workstations may be assigned to cost centers.

The operations performed at a workstation are defined by the user on a per-machine basis. The workstation may have more than one machine and the number of machines for each workstation is determined by the model based on a specified annual volume of the final product and the specified individual machine parameters. The workstation is characterized by the nominal operating parameters of one of its machines. Those parameters are illustrated in Figure B-3, and are defined as long-term average values. The production rate defines the nominal or design value in units of intermediate or final product (for the last trunk station) output per unit time when the machine is running. Materials-, labor- and utilities-use rates can be specified on a per-unit-time or per-unit-product basis. The calculated quantities shown in Figure B-3 are all at the workstation level. The product data flow values are calculated by the model using steady-state product/materials balance procedure that begins with the final product volume specified and moves backwards along the trunk process, taking into account the yield, rework, inspection and branch flow parameters to determine the product input to each workstation and the materials, labor facilities and utilities requirement quantities at each station. The same type of product/materials balance is then carried out along each of the branch processes.

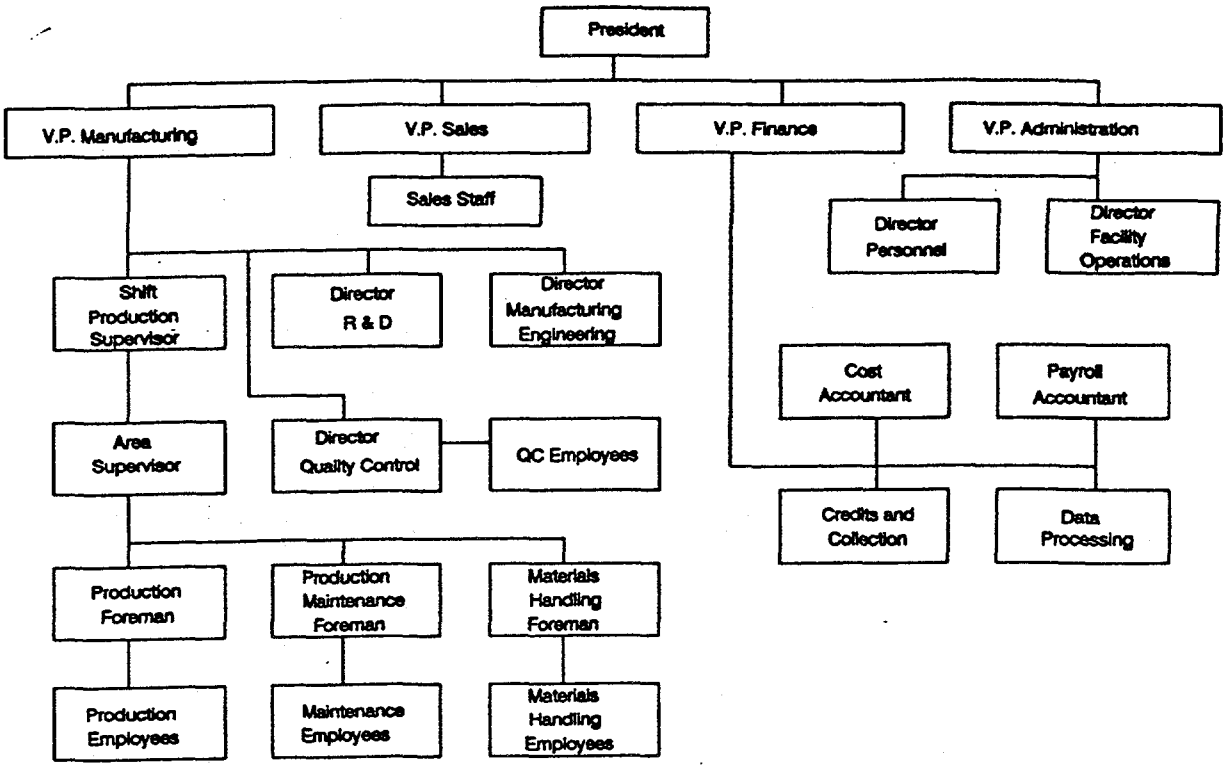

Figure B-1. Corporate Organizational Structure

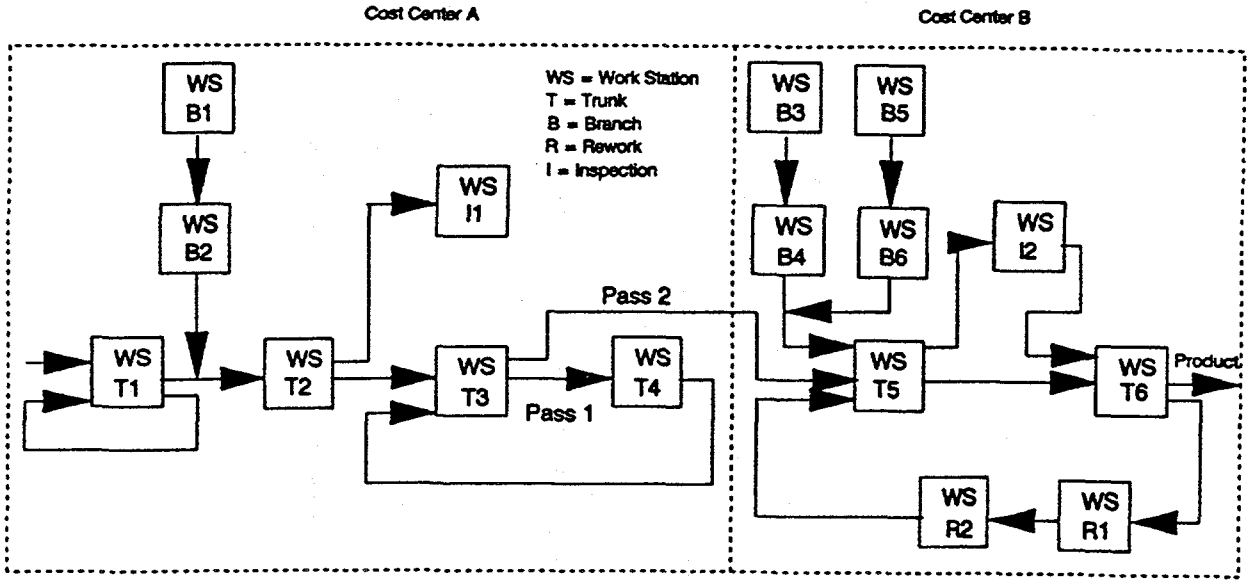

Figure B-2. Production Flow Features

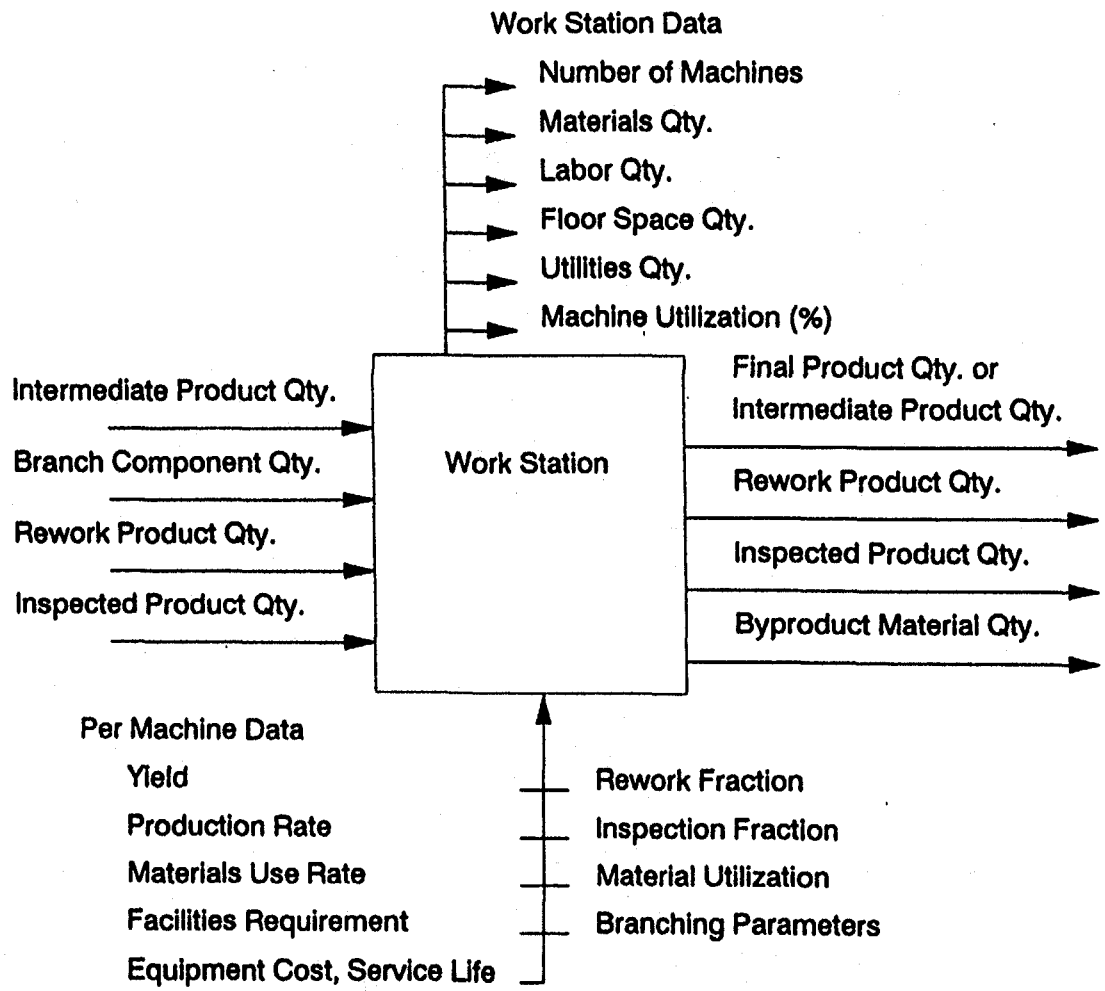

Figure B-3. Work Station Data Definition

Modeling Procedure

The STAMPP model might better be called a modeling approach or technique rather than a model in the conventional sense of a fixed computer code. Each previous application of STAMPP has been unique in certain details, although some major aspects of the methodology have remained constant. In the following, two approaches are described that differ primarily in their method of determining the indirect costs. In the first and most detailed approach discussed previously, indirect costs are derived from an organization structure built into the model. The number of personnel within that organization is scaled by a set of rules in the model and reflects the level of annual production. In the second approach, indirect costs are specified in terms of certain cost factors that are applied against direct labor. The first approach is best suited to analysis of the manufacture of a new product and/or process where the organization, facilities, and financial context must be hypothesized for the future. For manufacture of a product in a mature industrial setting, or in a particular existing corporation, where indirect cost rates are less speculative or even fixed, the second method may be more appropriate.

Method 1 - Detailed Indirect Cost Structure

An overview of the STAMPP modeling approach is shown in Figure B-4. In order to use the software, it is first necessary to have a concept of the product design and the necessary manufacturing operations. Those manufacturing operations must be translated into specifications of manufacturing equipment in terms of specified input data items or categories of data items, many of which were defined in Figure B-3. All input to the model is carried out interactively by response to queries on the screen or by filling in tables. Selection of output data formats is also interactive and menu-driven.

Production Routing. A list of trunk workstations by user- selected name in the order of product flow and ending with the final product is provided by the user. For trunk stations having branches, a sequence of branch workstations is also input, followed by rework sequences and inspection sequences where appropriate.

Cost Catalog. All job titles required by the organization in Figure B-1 are listed in a table called the Cost Catalog. The user supplies annual salaries for these. The job titles necessary to a particular simulation for the production area (i.e., those categories defined in Figure B-1) can be defined by the user by adding them to the cost catalog along with their annual salary or wages. For example, the production employees category might include up to 15 different job titles representing different skills or skill levels and different pay rates. The user also lists, by name, in the cost catalog all material and utilities required in the production of the product along with their unit costs.

Workstation Data. Figure B-3 defines the most important workstation data items or categories. Specific materials, facilities, or job titles particular to each workstation are selected by the user from the master list in the Cost Catalog.

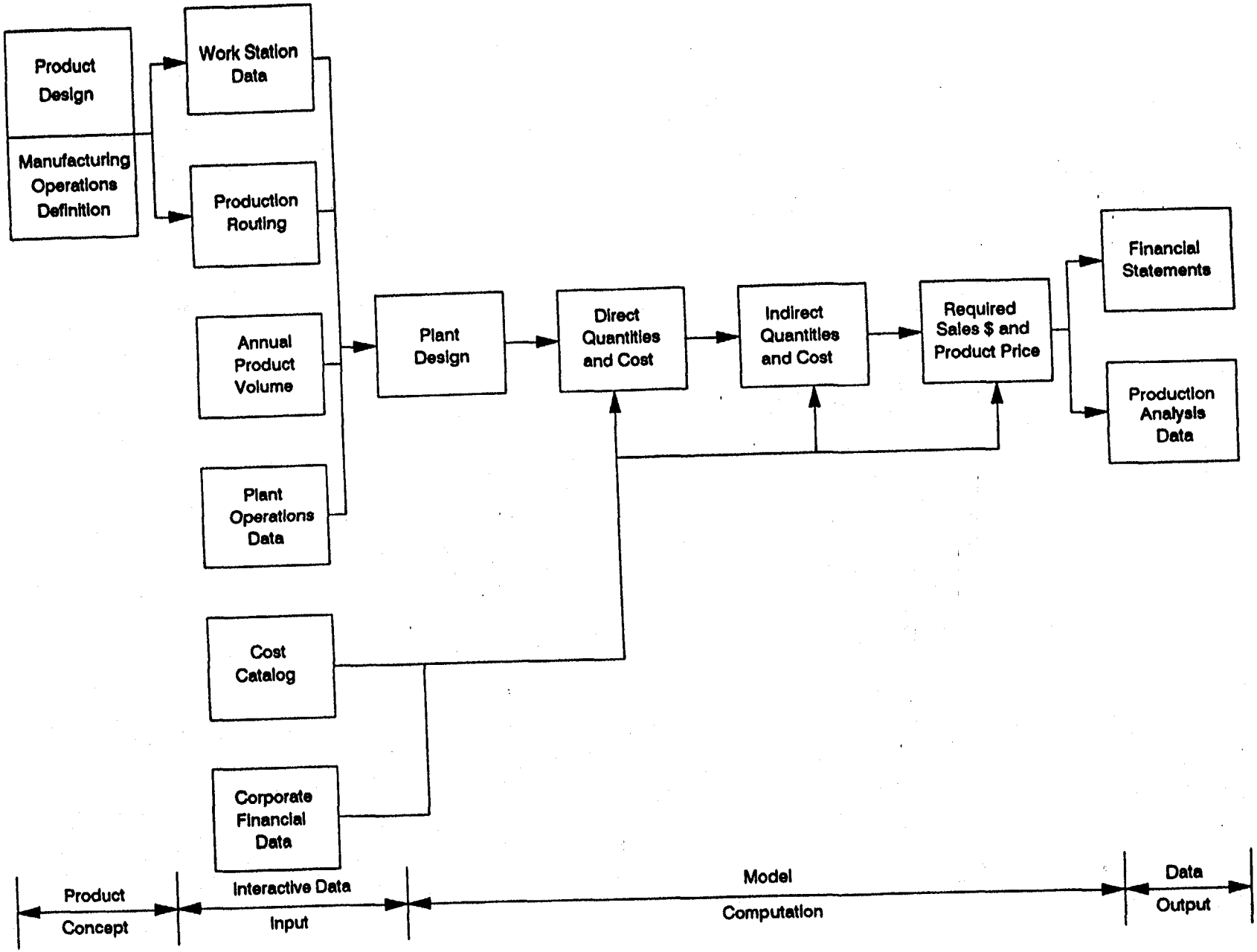

Figure B-4. STAMPP Modeling Overview

Plant Operations Data. The following input data allow the model to scale the production equipment complement based on the available operating time and the production capability of each type of equipment. The data also allow the model to determine the total number of employees in each job position and subsequently the total labor costs.

-Number of shifts per working day
-Operating hours per shift (hours)
-Operating days per week (days)
-Operating weeks per year (weeks)
-Closed weekdays per fiscal year (days)
-Working hours per person per shift (hours)
-Working days per working week (days)
-Working weeks per fiscal year (weeks)
-Paid holidays per operating year (days)
-Paid vacation days per operating year (days)
-Paid sick days per operating year (days)
-Second-shift wage multiplier (fraction)
-Third-shift wage multiplier (fraction)

Corporate Financial Data. The input data items below allow STAMPP to determine labor overhead costs for the corporate entity being modeled and to account for the cost of money. The data also allow determination of earnings required by the shareholders, as well as certain other costs such as taxes and insurance.

-Base year
-Required return on equity (fraction)
-Debt to equity ratio (fraction)
-Bond interest rate (fraction)
-Marketable securities interest rate (fraction)
-Combined Federal/State income tax rate (fraction)
-Property tax rate (fraction)
-Property insurance rate (fraction)
-FICA salary cutoff level ($/yr)
-FICA rate (fraction)
-Unemployment insurance ($/employee/yr)
-Hospitalization and other medical benefits ($/employee/month)
-Fringe benefits (fraction)
-Pensions (fraction)

STAMPP will simulate operation over a user-specified period of years. The base year defines the first year of operations. All wage rates and unit costs for materials and equipment are escalated over the period according to annual user-specified escalation (inflation) rates. Depreciation of equipment and facilities is done according to a user-selected method. Equipment and facilities are replaced at the end of their service life.

Annual product volume. The final product volume on an annual basis produced by the corporate entity. This figure is used by the model to scale all of the direct manufacturing and

indirect support used by the corporation in accordance with the manufacturing input data and the organizational span-of-control rules built into the model.

After data input has been completed the STAMPP model carries out the plant design step. As alluded to previously, a steady- state process balance is performed starting at the end of the process which defines the quantity of intermediate product at the input to every workstation, using the data supplied for yields, production rates, rework and inspection at every workstation. The primary result is the number of individual machines (or equipment) at every workstation. Since labor, materials, and facilities are defined on a per-machine basis, the total quantities of those can then be determined in the "direct quantities and cost" step. Based on unit costs in the Cost Catalog, the individual direct costs for all categories at each workstation are determined.

Having determined the employment in the direct manufacturing operations, it is then added to the fixed management positions. The total is used to determine the remaining administrative support staff employment using a set of rules in the model. The total employment is thus determined, and facilities, utilities and other costs to support them are then determined in the "indirect quantities and costs" step.

With direct and indirect costs determined for all operations of the corporate entity, STAMPP proceeds to determine the annual dollar sales required to support the entity. The unit product price required is calculated as sales dollars divided by annual product volume. In order to determine sales volume, STAMPP, in essence, constructs a corporate income statement beginning with required earnings defined as a return on equity investment. Equity is determined by the necessary investment in production equipment and support facilities as previously computed based on the specified annual product volume and machine production capabilities. A capitalization structure is determined by the debt/equity ratio. All equipment and facilities are depreciated over their specified service life by user-selected depreciation rules. Cash generated is assumed to be invested in short-term securities. Interest earned or paid, taxes, and all operating expenses are accounted by accepted procedures to determine the annual sales. The resulting sales required, along with the intermediate calculations, are displayed in the form of an annual income statement. STAMPP also produces a corporate balance sheet, cost-of-goods-manufactured report and a sources-and-uses-of-funds report.

The financial statements are available from the video terminal or in hard copy if a printer is available. In addition, an executive summary report provides selected data identifying a particular simulation case and aggregated price-component information that is useful in suggesting which of the more detailed reports should be examined. These reports include

-Input Data
  Labor Utilization
  Miscellaneous Parameters
  HVAC Parameters
  Financial Parameters
  Inflation Rate Table
  Cost Catalog
  Work Station Input Data

-Output Data

Process Equipment Summary
Manufacturing Direct Labor Summary
Manufacturing Indirect Labor Summary
Manufacturing Facilities Summary
Manufacturing Direct Utilities Summary
Manufacturing Indirect Utilities Summary
Manufacturing Direct Commodities Summary
Manufacturing Byproduct Summary
Manufacturing Miscellaneous Summary
Nonmanufacturing Labor Summary
Nonmanufacturing Facilities Summary
Nonmanufacturing Utilities Summary
Nonmanufacturing Miscellaneous Summary

Method 2. Simplified Indirect Cost Structure

For instances in which the manufacturing operation modeled is expected to exist within an established corporate structure and indirect costs for administrative and management functions are well known, STAMPP provides for including these costs by applying labor and labor-rate multipliers to the direct labor requirements calculated in the simulation of the manufacturing operations. The details of this calculation tend to be specific to the company. Typically, the direct labor for machinery operation is calculated by the model and appropriate labor rates applied. Direct materials used in manufacture are also accumulated by the manufacturing simulation and their cost determined from the unit costs in the cost catalog. Supporting or supervisory labor-hour requirements (e.g., manufacturing engineering, production control, or quality assurance) are calculated as a proportion of direct labor-hours and costed at a rate specified. The direct labor, indirect labor and materials costs are added together, and various overhead cost items are calculated using multipliers on this total. Examples of these costs include selling expense, G&A, cost-of-money, and profit. The total of all direct and indirect costs is the equivalent of the sales in Method 1. However, this type of aggregation of indirect costs does not allow the preparation of the income statement and balance sheet reports as in Method 1. Specialized reports to summarize costs are usually designed in such cases.

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This report describes the development of baseline manufacturing cost data to assist PVMaT monitoring teams in assessing current and future subcontracts, with an emphasis on commercialization and production. A process for the manufacture of a single-junction, large-area, a-Si module was modeled using an existing Research Triangle Institute (RTI) computer model. The model estimates a required, or breakeven, price for the module based on its production process and the financial structure of the company operating the process. Sufficient detail on cost drivers is presented so the relationship of the process features and business characteristics can be related to the estimated required price.

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