March 1992 • NREL/TP-214-4488

Monolithic Amorphous Silicon Modules on Continuous Polymer Substrate

Final Subcontract Report
9 January 1991 - 14 April 1991

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Iowa Thin Film Technologies
Ames, Iowa

National Renewable Energy Laboratory
A Division of Midwest Research Institute
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Under Contract No. DE-AC02-83CH10093

NREL/TP-214-4488 • UC Category: 271 • DE92001163

NREL/TP--214-4488

DE92 001163

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1617 Cole Boulevard
Golden, Colorado 80401-3393
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Prepared under Subcontract No. XC-1-10057-18

March 1992

On September 16, 1991 the Solar Energy Institute was designated a national laboratory, and its name was changed to the National Renewable Energy Laboratory.

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Microfiche A01
Printed Copy A06

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issue of the following publications which are generally available in most libraries: *Energy Research Abstracts (ERA)*; *Government Reports Announcements* and Index (*GRA* and I); *Scientific and Technical Abstract Reports (STAR)*; and publication NTIS-PR-360 available from NTIS at the above address.

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FINAL TECHNICAL REPORT

March 1991

Photovoltaic Manufacturing Technology--Phase I

"Monolithic Amorphous Silicon Modules on Continuous Polymer Substrate"

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This report has been prepared under subcontract XC-1-10057-18 under prime contract DE-AC02-83CH10093 with SERI.

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Significant work performed during the subcontract period of performance.

A thorough search was conducted for vendors of necessary manufacturing equipment applicable to the proposed processes. Information was gathered about makers of web cutting, sheet hole-punching, automatic sheet load and take off, web- and sheet-washing and drying systems, and similar types of equipment used for screen-printing and flexible circuit board processes in the semiconductor industry. The NEPCON-West '91 (National Electronic Packaging and Production Conference) Exposition was attended Feb. 25-28 in Anaheim, CA, at our company's expense, to gain first-hand knowledge of pertinent equipment and vendors. Information gathered on capital equipment costs and processing times has been used as inputs in the manufacturing simulation program, SIMAN IV (from Systems Modeling Corp., Sewickley, PA).

In addition to the vendor/equipment search, some experimental work was done to insure feasibility of certain steps in the improved-process. A preliminary screen-printable etching-gel was developed for patterning the ZnO top contact, to prove the concept. A corresponding extra-thick screen emulsion was developed to print the necessary gel thickness for etch-patterning. Experiments were also performed on laminating EVA and EAA as stiffener sheets to the backs of fully-coated web sheets. These stiffeners make handling sheets easier, and can be applied after all depositions are completed in the new process sequence. The polymer-backed sheets are then etch fabricated into functioning solar modules. To make modules with good performance, special conductor inks were developed with very low contact resistance. Stock inks from a number of vendors make unsatisfactory contact with ZnO, so an improved (but not optimized) ink was developed internally.

The manufacturing simulation program, SIMAN IV, was installed on our company's 386 PC to run continuing validation studies on the manufacturing processes used in the pilot-plant. As our manufacturing data base improves, the manufacturing simulation will be refined as an aid in the next generation of manufacturing facility.

We began developing simulation models of the manufacturing processes. These will allow us in the future to: (1) optimize production batch size; and (2) determine quality control policy as to where and when to do production-line testing. Economic models are used in tandem with the manufacturing simulation model, to obtain the lowest cost per module area or per watt. Hence, another use of these models is to decide where to allocate future capital resources in the production process.

The various manufacturing alternatives and improvements were evaluated using SIMAN IV and compared with the base-line pilot-plant processes. These are discussed in detail in Appendix 3.

To summarize briefly, the baseline case of roll-to-roll processing without print-etching steps, yielded a manufacturing cost per one ft2 module of $5.67. The case of roll-to-roll deposition with sheet module processing using automatic feed and a print-etch step yielded a cost of $5.84 per one ft2 module. Finally, the case of roll-to-roll deposition with roll-to-roll module processing and a print-etch step yielded a cost of $5.66 per one ft2 module. (Sheet module processing with hand-feed rather than automatic feed stations, yielded higher costs, around $6.70 per module). Since the various scenarios (except for hand-feed sheet or piece stations) were within $0.20 of each other for a one ft2 module, research will continue with alternative methods until a clear winner is distinguished technically and economically. As operational data is gathered on the pilot-line, the model will be updated and used in this analysis. From an industrial engineering perspective, methods that do all deposition processes first will be favored, because the station scheduling will be easier. Because the a-Si and ZnO depositions appear to be the bottleneck steps, adding one each additional a-Si and ZnO machines could double production output without increasing labor costs.

Assuming a 6 Wp one ft2 module, the case for the baseline, print-etch/sheet, and print-etch/roll-to-roll configurations are $0.95/Wp, $0.97/Wp, and $0.94/Wp, respectively.

SERI Manufacturing Initiative--Phase 1

Task 1.

Description of the overall procedure involved in manufacture of modules and/or cells. (Specify any technology from other companies/sources upon which reliant).

Module fabrication processes developed involve fabrication steps before the top transparent conducting contact (TCC) is deposited. These methods are described in the paper "Fabrication of Photovoltaic Module Series Interconnects Between a-Si:H Thin Film Solar Cells Deposited on Flexible Polyimide Substrates," D.P. Grimmer et al., Fourth International Photovoltaic Science and Engineering Conference (PVSEC-4), Sydney, Australia, 14-17 February 1989 (see Appendix 1).

The module fabrication processes require initial laser scribing through the a-Si:H and Al layers down to the bare polyimide and the screen printing of insulator inks over the open cuts in the deposited layers. This screen-printing step, as well as additional screen-printing and laser-scribing steps done after TCC deposition, require roll-to-roll registration on the initial scribe.

An itemized list of step-by-step module processes, procedures and the types of equipment used is described below and shown in Fig. 1:

(1) Metalization system.

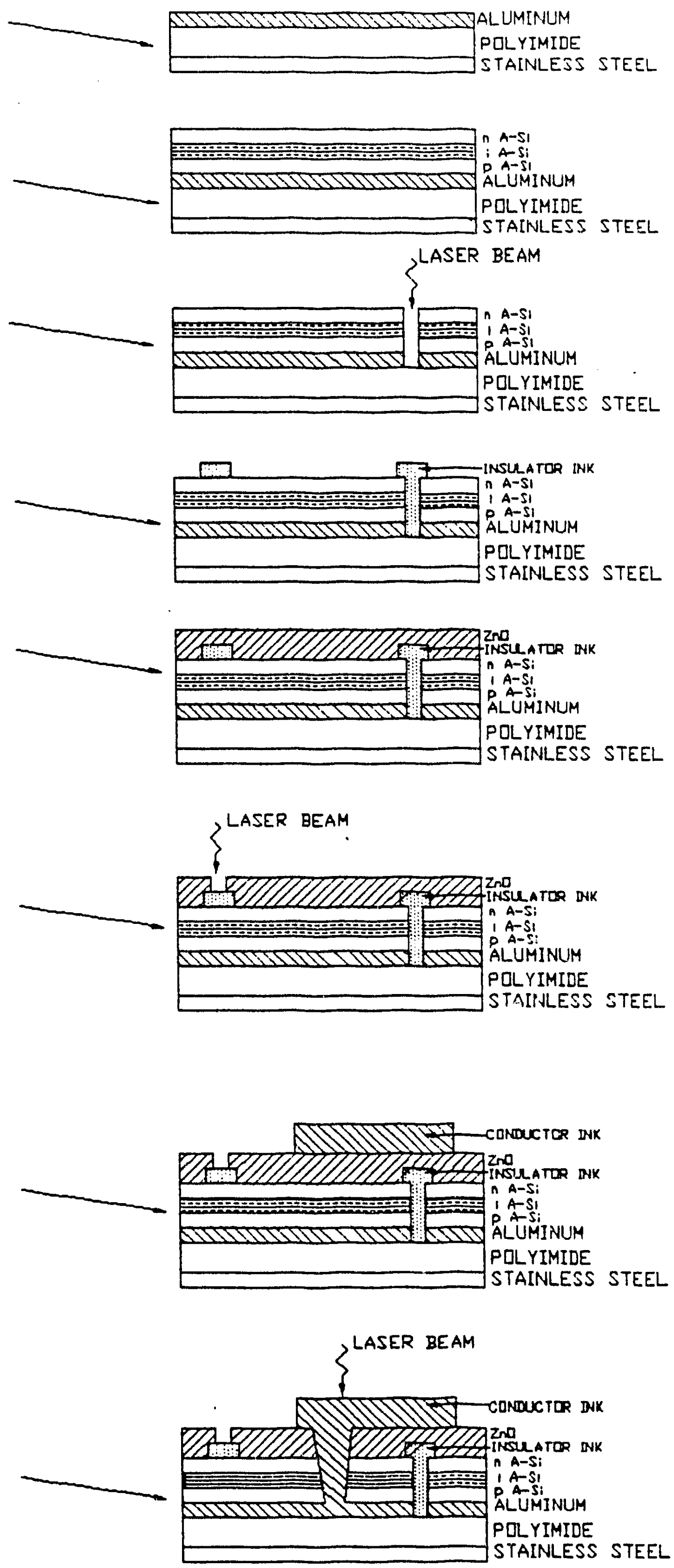
The first step in the manufacturing process is metalization of the polymer web. The polyimide web material is initially baked at 400 C prior to priming with stainless steel and depositing aluminum as the bottom electrode of the p-i-n device. The baking/outgasing, priming and metalization is done in a 5' diameter cylindrical deposition chamber capable of processing rolls of web material up to 15" in width. Depositions are done by DC sputtering from 7 different targets. The additional targets allow for multiple metalization layers and diffusion barrier depositions. Hence, the system is designed to allow single-pass preparation of the substrate for the silicon deposition system. Typical thickness of the textured Al deposited is 4000 A. The system is also designed to do double duty and deposit TCC and top protective films for certain environments. It will accomodate any of the sputter processes currently used for top contacts. A roll approximately 2400' long can be accommodated in all stages of the manufacturing process.

(2) Amorphous silicon deposition system.

The next step in the manufacturing process is deposition of a-Si p-i-n device material. A single junction a-Si device is deposited by plasma enhanced CVD (PECVD) or "glow discharge" of

Fig. 1 Current, Baseline Roll-to-Roll A-Si Thin Film PV Module Production Process Steps

Step #	Production Step
(1)	Metalization of Polydimide web
(2)	A-Si p-i-n deposition
(3)	Laser scribing of A-Si/metal coating
(4)	Screen-printing of insulator ink over scribe region
(5)	ZnO top contact deposition
(6)	Laser scribing of open in ZnO top contact
(7)	Screen-printing of Ag conducting ink
(8)	Laser welding of Ag ink/ZnO
(9)	Busbar attachment
(10)	Cutting web into sheets
(11)	Encapsulation



SiH_4 in a roll-to-roll multichamber system. The outer vacuum can is approximately 10′ long x 3′ wide x 4′ high, and is the vacuum plenum for separate, inner chambers to deposit phosphorous doped-n+, intrinsic, and boron-doped p+ layers. The multichamber design has been shown to have excellent dopant gas isolation between chambers. Typically, n+, i, and p+ layers have thicknesses of 150 A, 4000 A, and 250 A, respectively. A web speed of 6" per minute is planned. The amorphous silicon deposition is one of the throughput-limiting deposition processes: the metalization has significantly higher production rates, but the TCC deposition is comparable to a-Si throughput. The capacity of the 13" a-Si multichamber is calculated to be 1 MWp per year for single-junction devices.

(3) Laser scribing of a-Si/metal coating.

Next, laser scribing is used to pattern the deposits of a-Si/Al into individual cells on the polyimide substrate. A YAG laser, operating at 1064 nm, is used to scribe down to the bare insulating polyimide, thereby isolating the individual cells from one another. Initially, a single beam at 532 nm has been used to test the concept, and to have the convenience of a visible beam. However, the increased power available at 1064 nm and the need for multiple laser scribing beams, makes a switch to the YAG laser in the IR and the use of fiber optics for beam delivery an attractive alternative. The 1064 nm YAG laser with fiber-optic delivery will reduce capital costs and improve throughput. Due to its large size (5′ long support rails and 20" x 30" scribing platen), the 13" pilot plant scriber remains fixed except to rotate, and the fiber optic assembly head moves relative to the web via x-y translation stages overhead. Laser, translation stages, web stepper and tensioning motors are computer controlled, and registration for subsequent scribing and screen-printing steps is done with optical detector inputs to the computer. After a submodule is scribed on the scribing platen, a new submodule is rolled out on the platen for scribing and the just scribed web is rolled-up onto the take-up roll.

(4) Screen printing of insulator inks over scribe lines.

The next step in the manufacturing process is to screen print insulator inks over the scribe lines prior to TCC deposition to prevent electrical shorts. At the same time, an additional insulation ink line is printed on the a-Si parallel to, and a short distance away from (about 0.5 mm), the line printed over the scribe line. This second insulator line acts as a laser beam-stop for scribing an open in the TCC layer. The inks used are low outgasing so as to not adversely affect the deposition and conductivity of the TCC layer. The operation of the roll-to-roll screen printer involves stretching the scribed a-Si coated web over a printing platen and under a printing screen patterned to match the scribe lines. The platen is free to rotate under the web, in order to align the screen and scribe patterns. A commercial screen-printing machine has been modified to print the desired pattern on the web upon computer command.

After submodule printing, the next submodule is rolled out for printing, and the just-printed submodule enters an air-drying oven to cure the inks. After leaving the oven, the printed web is rolled-up onto the take-up roll. All operations are computer automated.

(5) ZnO transparent conducting contact (TCC) deposition.

Next, the scribed a-Si web, printed with insulator ink, is coated with ZnO top contact material to a thickness of around 4000 A. The ZnO deposition is done by thermal CVD, using diethyl zinc as the feed material. The decomposition and deposition takes place at around 150 C, and non-substrate surfaces are cooled with water lines to reduce undesired coatings and powder inside the chamber. In addition to the ZnO deposition chamber, there are plasma cleaning chambers to remove contamination occurring during the scribing and insulator printing steps. The ZnO TCC coater also uses the multichamber design with an outer can as pumping plenum. Like the other deposition chambers and major components of the scribing and printing stations, the ZnO deposition system was designed and constructed by ITFT. The outer can dimensions are 10' long x 4' wide x 3' high.

(6) Laser scribing of the open in the ZnO top contact.

In the next manufacturing step, an open is scribed in the ZnO top contact with a laser beam. The beam follows down along the top of the second, parallel insulator ink line. This ink line acts as a beam stop for the laser beam, to prevent thermal damage to the deposited layers below. The three laser operations, scribing the a-Si/Al, scribing the ZnO, and welding the Al to the top conductor, creates the submodule series electrical interconnect: an open in the bottom layer, an open in the top layer, and a short or shunt in between the two opens.

(7) Screen printing of the silver conducting ink.

The next manufacturing step is to screen print Ag conducting ink to make contact between the weld interconnect region and the adjoining cell's TCC ZnO. This printing is done to bridge over the insulating ink line on the initial scribe (with a parallel bridging strip and/or perpendicular grid lines), and to present a target strip in the region between the two closely parallel insulator ink lines for laser welding the interconnect shunts.

(8) Laser welding of the Ag ink/ZnO to the Al layer to form the interconnect shunt.

Next, the Ag conducting ink is bonded to the aluminum layer underneath by the laser welding process. The laser beam impinges onto the Ag ink, driving Ag metal through the ZnO and Si to make contact with the underlying Al. Actually, what occurs is the formation of a conducting mixture of Ag, ZnO, Si and Al, with C added from the thermal decomposition of the polymer vehicle in the Ag ink. Note that the order of steps (7) plus (8) can be reversed with step (6). However, scribing the ZnO open first (prior to welding the interconnection) allows the Voc to be measured for isolated cells on the module.

(9) Busbar attachment.

Next, busbar strips are attached to the ends of submodule lengths. Current attachment methods use wet, conducting Ag ink to bond a copper busbar to preprinted conducting grid lines on the module. The Ag ink is cured to form a good electrical and mechanical contact between the busbar and module. Other busbar material consists of copper foil coated with a conducting adhesive, and is commercially available. Currently, the busbars are aligned and attached by hand to cut pieces of web, but busbars can be attached in a roll-to-roll process.

(10) Cutting submodule-sized sheets from the web.

The next step is to cut the submodule web into individual submodules, prior to encapsulation. Note that these steps (9) and (10) can be switched if busbar attachment is no more dificult with sheets than with roll-to-roll web. Automated sheet cutting can be done simultaneously with the bus bar registration and attachment, so that re-registration of the web need not be necessary.

(11) Encapsulation.

Next, the submodule sheets are encapsulated into finished modules. (Note: submodule sheets cut from the web are used, rather than web encapsulated roll-to-roll, to insure edge-sealing on all four edges of the module). Currently, polyester/EVA flexible polymer laminate material is used as a base encapsulant for handling. The final encapsulants, for both flexible and rigid module applications, depend on the application. The modules can at this point be laminated using a standard vacuum thermal laminator. However, a web slitter/rewinder/laminator can be used in a potentially more cost effective manufacturing process, based on prototype experiments using a small, pressure-heated, nip-roller laminator. The module completion steps (9)-(11) are the most labor intensive parts of the manufacturing process.

Photographs of the pilot-line equipment are shown in Appendix 2.

Technology from other companies/sources upon which this process is reliant includes:

(1) Polyimide substrate with desired physical properties.

(2) Silver conducting ink, with stable bonding to the TCC surface, low contact resistance, and low bulk resistivity. There is a wide variation in the contact resistance properties of a given Ag ink to a given TCO TCC surface.

SERI Manufacturing Initiative--Phase 1

Task 2.

Identify and describe:

1) Potential module/cell manufacturing processes (or changes in existing processes) that can lead to improved performance, reduced manufacturing costs, and significantly increased production; and
2) The long range potential benefits of these improved processses.

To reduce module production costs, increase module performance and expand U.S. commercial production capabilities, a number of process improvements and modifications are envisioned. These improvements are designed to reduce material, labor, and capital costs as well as improve production throughput, device efficiency and module stability. Specific modifications are delineated below.

A major component of the material cost is the polyimide substrate ($.80/ft2). Developing the process to allow use of 1 mil polyimide will cut that cost in half. The current preference for front transparent, outdoor encapsulant (DuPont Tefzel) is of the same order of cost ($.80/ft2). We envision development of a front encapsulant incorporating multilayers of lower cost material.

A-Si deposition, ZnO deposition and module laser scribing are the slowest steps in the manufacturing process. Research to increase deposition rates for the a-Si and ZnO layers are needed to improve throughputs for these deposition steps. Magnetic enhancement of the plasma in a-Si deposition promises to increase deposition rates and increase film quality and stability. Multi-beam fiber optic delivery systems for laser scribing are designed to keep throughput rate compatible with the a-Si and ZnO depositions. However, mechanical scribing systems are an attractive alternative, and promise even higher throughput than multiple laser beams.

Device efficiency and stability will be increased with the transition to tandem cells and as production experience increases. It is anticipated that module power will increase from the current 5 Wp/ft2 to 8 Wp/ft2, following the current situation with a-Si on glass superstrates.

Two alternative manufacturing processes are described below:

<u>Alternative Manufacturing Process A:</u>
<u>Procedures Involving Wet-Etching and</u> Sheet-Handling Steps.

In addition to improvements in the rate-limiting steps, alternative flow paths in the manufacturing process are envisioned which will improve throughput and yield (refer to Fig. 1 and Fig. 2).

A new module manufacturing process has been envisioned that allows all the deposition steps to be completed, including the top TCC layer deposition, prior to any module fabrication steps. The bottom metal contact layer (aluminum, for example), the amorphous silicon a-Si:H p-i-n layers, and the top TCC layer (ZnO for example) are done in roll-to-roll deposition chambers. With the roll-to-roll deposition steps completed, the product at this stage is one large cell, 12" wide and 2400′ long.

Note that depositing the ZnO onto a pristine a-Si surface eliminates the need for the web cleaning steps used in the present baseline process. Thus a single-pass, rather than double-pass, of the web through the ZnO deposition machine is necessary. This gives a significantly improved throughput.

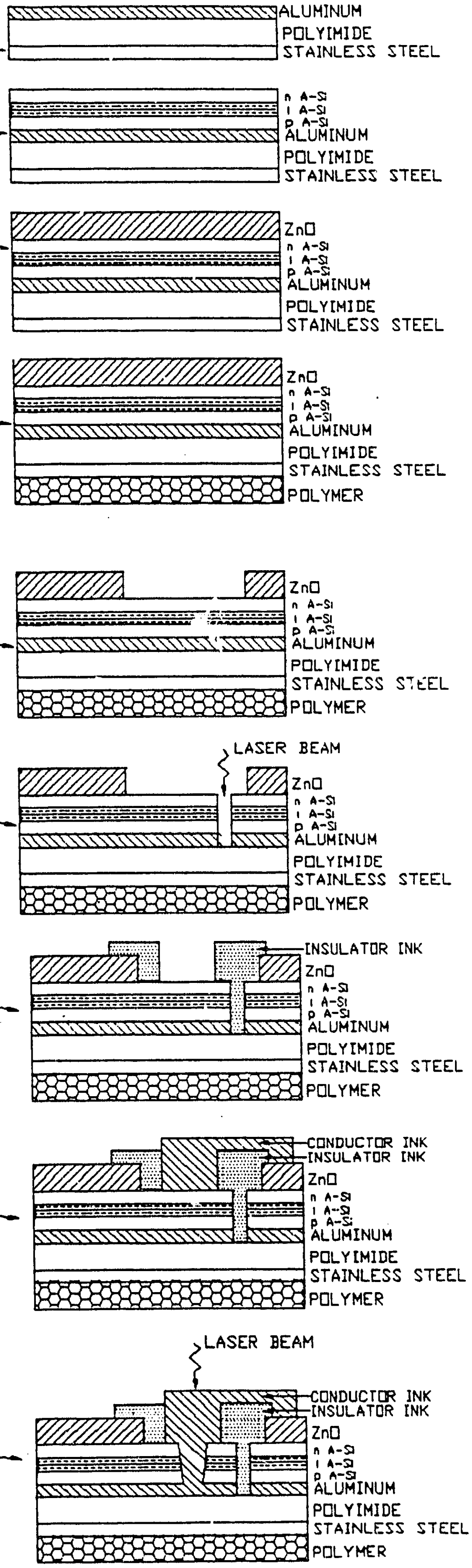
Also, with the TCC completed before module manufacture begins, the requirement of roll-to-roll registration is removed. The roll of cell material can be cut into sheets between any subsequent steps, and corner- or hole-registered for subsequent scribing and printing steps. The primary advantage of cutting the web after ZnO deposition is to take advantage of existing sheet handling equipment in related industries, while retaining the advantages of roll-to-roll depositions. Registration times for sheets using mechanical registration appear to be faster than for roll-to-roll registration with optical detectors.

Amorphous silicon coated web usually exhibits curl due to compressive stresses in the film (created by differences in the thermal expansion coefficients between the a-Si coating and the polyimide substrate). For ease in handling sheets of web cut from the roll, it will probably be necessary to eliminate web curl, e.g. by roll-to-roll lamination of the polyimide web to a low-cost polymer backing used as a stiffener. The deposition of ZnO TCC counteracts the curl created by the a-Si deposition, flattening the web and aiding the lamination process. A suitable polymer backing stiffener would be EVA, which is inexpensive, and can be laminated to polyimide. As an alternative to lamination, an anti-curl pretreatment deposition on the web back side can be done when the front side of the web is metalized. This would, however, curl the web in tension, making subsequent a-Si deposition more difficult, particularly if polyimide web thinner than 1 mil is used.

Once the roll of coated polyimide has curl eliminated, the roll can be cut into module-sized sheets. As the web is cut into sheets, registration holes simultaneously can be punched into the side of the web. The use of registration holes, a method adopted in the fabrication of printed circuit boards, eliminates the need for registration line detectors used in roll-to-roll module fabrication. The other alternative would be to perforate sprocket holes in the continuous web, and this appears to be a less desirable solution in terms of equipment cost and debris

Fig. 2 . Alternative A-Si Thin PV Module Production Process Steps Using Wet-etching and Sheet-Handling

Step #	Production Step
(1)	Metalization of polyimide web
(2)	A-Si p-i-n depostion
(3)	ZnO top contact deposition
(4)	Stiffening the web by lamination to backing polymer
(5)	Cutting the web into sheets and punching mechanical registration holes
(6)	Etching the TCC
(7)	Laser scribing of A-Si/metal coating
(8)	Screen-printing of insulator ink over scribe region
(9)	Screen-printing of Ag conducting ink
(10)	Laser welding of Ag ink/ZnO
(11)	Busbar attachment
(12)	Encapsulation



creation.

Using conventional sheet handling technology adapted from the screen-printing industry, a module sheet is placed on the registration pins on a screen-printing platen. As a vacuum pulls the sheet flat, the registration pins are retracted below the platen for printing. A water-soluble etchant gel is printed onto the ZnO TCC coating surrounding the scribe lines, either in a single wide strip, or two parallel strips. The printing screen is patterned to define individual cells by removing ZnO in narrow strips around the cells. At the same time, using the same patterning screen, designs for integral bypass diodes can be etched into the ZnO top contact surface. This method of patterning the ZnO (by printing an etching gel) is preferred to the alternative of printing the reverse- or negative-image with etch-resist ink (the strips of ZnO defining the cells are removed by immersing the etch-resist coated module in an etching bath). Stripping the greater area/amount of etch-resist also requires solvents such as toluene, and, in general, disposal of the etch-resists and required solvents presents a greater environmental problem than with using water-soluble etching gels.

After a suitable time for reaction (15-30 sec), the etchant gel is removed by water-spray cleaning. The wet, etched sheets are dried on a belt-dryer, as are subsequent printing steps. The etching gel cleaning solution is pH neutralized and solids are allowed to precipitate in a settling tank. Cleaning water is filtered and recirculated in the primary cleaning stages, to minimize environmental impact.

Next, the module sheet is placed on the registration pins on a scribing platen. A vacuum pulls the sheet flat onto the platen, and a laser or mechanical scriber patterns the coated module sheet, cutting through the ZnO, a-Si and Al layers down to the polyimide substrate.

Next, the module pieces are screen printed with an insulating ink. The insulating ink covers the scribe pattern in the amorphous silicon exposed by etching and also overlaps slightly onto the TCC ZnO of the adjoining cell, to cover any shunts in the area between the scribe and that cell's ZnO. A line of insulating ink, parallel to the insulating ink covering the scribe region, is simultaneously printed over a strip of the amorphous silicon overlapping the cell's own TCC ZnO. This second series of insulating ink lines guarantees an open in the top contact. An open in the top contact, along with the open in the Al created by scribing and the interconnect weld/shunt to be described, is necessary to create a series interconnect between cells. Between the two insulating ink lines is a region of bare amorphous silicon. This is the region where the conducting Ag ink is to be printed and welded to create the cell interconnect shunt. As an alternative to leaving a single, wide bare silicon region exposed by etching, a central strip of unetched TCC ZnO can be left between two strips of amorphous silicon exposed by etching and covered by the aforementioned insulating ink prints.

This unetched TCC ZnO reduces the amount of conducting ink necessary to create the interconnect shunt to be discussed.

Next, conducting Ag ink lines are printed to make contact between the weld interconnect region and the adjoining cell's TCC ZnO. These conducting ink patterns bridge over the insulating ink strip covering the scribe through the Al layer. If a single, wide etched amorphous silicon strip is exposed, it is necessary to print a conducting ink line between the two insulating ink strips along the scribe. If an unetched TCC strip is left between the insulating ink strips, a continuous conducting ink strip between the insulating ink strips is not necessary. The ZnO strip can be welded to the Al layer and create the conducting shunt. A silver ink grid is still necessary to bridge over the insulator ink to make contact with the adjoining cell's TCC. The connection lines to make contact with the busbars are printed at this time also.

To create the interconnect shunt, it is necessary to create a path of minimum resistance in-between the open in the TCC top contact and the Al bottom contact. A laser has been used to weld a Ag conducting ink strip to the Al bottom layer. The laser weld can be effected by directing a focussed beam down onto the coated web or by shining the beam through the polyimide onto the backside of the deposited Al. By shining through the web, less laser power is needed to weld the ZnO and Al directly together, without using the Ag ink. Note that it is easier to weld sheets cut from the web by shining the laser beam through the back, rather than using roll-to-roll web. With sheets there would be no scraping damage to the web as there might be with dragging a coated web across the scribing platen. Alternative welding methods include electronic and ultrasonic spot-welding.

Next, copper busbars are attached to the modules, at the ends of the series string of cells. Current attachment methods use wet, conducting Ag ink applied to the busbar to contact preprinted conducting grid lines on the module. The Ag ink is cured to form a bond between the busbar and module. Spot-welding techniques are also under test. For corrosion resistance, tinned, copper-foil strips are attached by soldering to the busbars, for external circuit connection.

Shunt removal is obtained by reverse biasing the modules, thereby heating shunt regions and changing the conductive properties of the ZnO to an insulator.

Finally, the completed modules are encapsulated, with a border of flexible encapsulating material surrounding the four sides of the module. As the current encapsulant (Tefzel) is quite expensive, a multilayer substitute is an option for cost reduction. Whatever encapsulating materials are used, the encapsulating layers should have the following properties, on the illuminated side of the modules, in addition, of course, to high optical transparency:

1) the outermost layer should be scratch- and UV-damage-

resistant;
2) the next layer should be a UV-light barrier to protect UV-sensitive layers underneath (a film can be UV-damage resistant, but not a UV-barrier, and transmit UV light through it to layers below);
3) the next layer should be a vapor barrier;
4) the innermost layer should be chemically non-reactive in contact with the module surface.
(The principal function of the back layer to the module is as a vapor barrier, and as the place where the busbar wires are connected to an external junction-box). Some of these layer-functions can be filled with one material. For example, DuPont's Tefzel is scratch-resistant, UV resistant, a UV barrier and a vapor barrier. EVA (ethylene vinyl acetate) is generally accepted as a good material to place in contact with the cell surface.

In summary then, the steps identified in this new, proposed method for module manufacture are as follows (see Fig. 2):

(1) metalization of the web:
(2) deposition of the a-Si:H device;
(3) deposition of the transparent conducting contact (TCC);
(4) treatment of the web to eliminate curl (e.g. by stiffener lamination, or anti-curl pretreatment deposition);
(5) cutting the web into sheets and punching mechanical registration holes;
(6) etching the TCC around the metalization layer scribe-area, creating an open in the TCC and forming integral bypass diode pads;
(7) scribing the metalization layer;
(8) printing an insulating ink over the scribe lines (to prevent cell shorting), and over the region of exposed a-Si:H surface (to protect the open in the TCC);
(9) printing a conductor ink to bridge over the insulating ink line, and to complete integral bypass diodes;
(10) welding the conducting ink to the metal back contact of the cell (i.e. creating the interconnect shunt);
(11) attachment of busbars to the module ends, and shunt removal;
(12) encapsulation of the module with suitable encapsulant glazing materials.

Specifically, these new process steps differ from the present pilot-line process in the following ways. Referring to Fig. 2, and comparing it with Fig. 1 of the baseline case:

(a) For step (3), rather than scribe the a-Si/metal layers, the ZnO TCC would be deposited. This would mean all depositions would be completed before further submodule fabrication, avoiding handling and contamination.

(b) For step (4), the web is treated to eliminate curl.

(c) For step (5), the fully coated web would be cut into sheets of finished module size, and registration holes punched into the edges of the sheets.

(d) For step (6), the ZnO TCC would be patterned with an etchant gel developed for this process, and washed clean. This is a wet step in the process, although the gel developed is water-soluble.

(e) For step (7), the submodule sheet is laser scribed in a method similar to the original step (3). Note that it may be possible to switch steps (6) and (7).

(f) For step (8), insulator inks are printed over scribe lines, in a method similar to the original step (4). However, a beam-stopping line is not necessary, since the ZnO electrical open will not be laser scribed, but will be created by the etching process in the new step (6) above.

(g) For step (9), conducting Ag lines are printed in a method similar to the original step (6) in Fig. 1.

(h) For step (10), the Ag ink/ZnO is welded to the Al back contact in a method similar to the original step (7).

(i) For step (11), busbars are attached in a manner similar to the original step (10), except here submodule sheets are used rather than roll-to-roll web. Actually, the original steps (9) and (10) can be switched if busbar attachment is no more difficult with sheets than with roll-to-roll web.

(j) For step (12), the submodules are encapsulated into modules as in the original step (11) in Fig. 1.

Note that steps (6) and (7), the metalization scribe and TCC etch steps, may be reversible. Scribing before etching allows the etch to clean up scribe debris and undesired shunt path layers. However, the etchant gel or bath may attack the Al too vigorously, undercutting the a-Si overlayer adjacent to the scribe, or leave a residue that corrodes the Al over time. The cleaning steps would have to remove, and/or pH neutralize, all residue.

In any case, if it is possible to scribe before etching, the scribe line provides a precision mark for opto-electronic alignment. This would be important if micro-registration is required, even with the mechanical registration holes.

There are advantages in the above alternative process: all three coatings are deposited in sequence, and registration of sheets would be simpler than roll-to-roll web. However, a wet etching process is necessary, and specialized sheet-handling equipment would be needed for other than the lamination process. ITFT is currently working with personnel in the ISU School of Industrial Engineering under subcontract to develop a manufacturing process model to evaluate the relative costs of the various alternatives, using the manufacturing simulation program SIMAN IV (see Appendix 3).

Alternative Manufacturing Process B:
Procedures involving wet-etching and roll-to-roll fabrication steps.

Actually, the process described above, completing the depositions prior to module manufacture, can also be done roll-to-roll, rather than as cut sheets. This process, shown in Fig. 3, is an alternative roll-to-roll process and requires the least amount of new equipment, as compared to sheet handling. A roll-to-roll washing and drying step is required. Optical detectors could align the web on the etched region preparatory to scribing, although more precise registration would be allowed if scribing could precede etching, and web alignment done on the scribe lines. Alternatively, just the edges of the web could be scribed, preparatory to etch-printing. The etch-print alignment would be done on the edge-scribes, and the etching would not be near them. The full module scribe patterning, done after etching, would realign on these preliminary scribe marks. An extra process step through the scriber would be necessary, but it would be rapid, requiring a 1/2" long scribe on both sides of the web, for each module length. Screen-printed insulator ink registration marks are also a possibility. Printed registration lines would have higher throughput, but poorer resolution: typical laser scribe lines are 2 mil wide, whereas 10 mil screen-printed registration marks are standard.

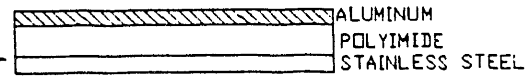
The processing of modules by roll-to-roll etch-patterning would share many of the details previously mentioned for processing by sheet etch-patterning. The steps identified in this second new, proposed method for module manufacture are as follows (see Fig. 3):

(1) metalization of the web;
(2) deposition of the a-Si:H device;
(3) deposition of the transparent conducting contact (TCC);
(4) etching the TCC around the area of the metalization scribe, creating an open in the TCC and forming integral bypass diode pads;
(5) scribing the metalization layer;
(6) printing an insulating ink over the scribe lines (to prevent cell shorting), and over the region of exposed a-Si:H surface (to protect the open in the TCC);
(7) printing a conductor ink to bridge over the insulating ink line, and to complete the integral bypass diodes;
(8) welding the conducting ink to the metal back contact of the cell (i.e. creating the interconnect shunt);
(9) attachment of busbars to the module ends, and shunt removal (by heating and reverse-biasing, and/or by electrochemical methods);
(10) cutting the web into sheets;
(11) encapsulation of the module with suitable encapsulant/glazing materials.

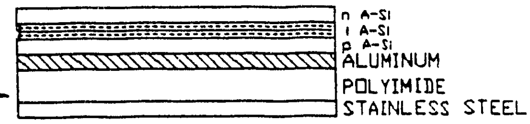
Specifically, these new process steps differ from the present pilot-line process in the following ways. Referring to

Fig. 3' Alternative A-Si Thin Film PV Module Production Process Steps using Wet-etching and Roll-to-roll Handling

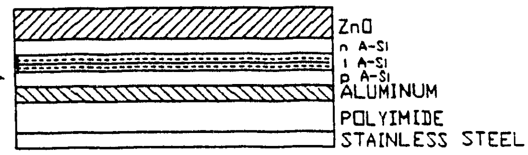
Step #	Production Step
(1)	Metalization of polyimide web



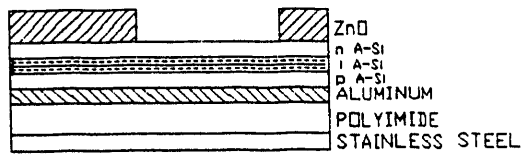
(2)	A-Si p-i-n depostion



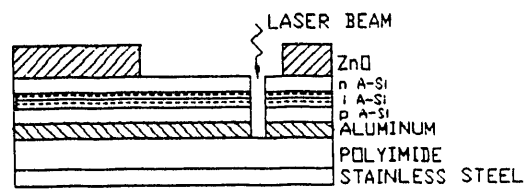
(3)	ZnO top contact deposition



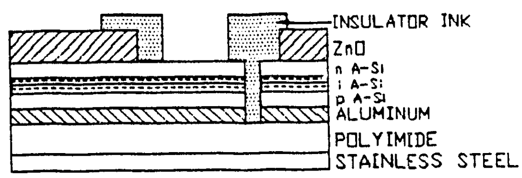
(4)	Etching the TCC



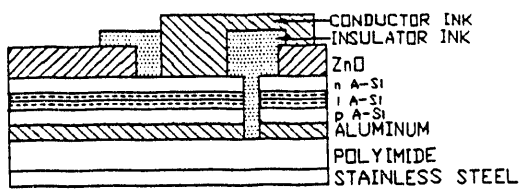
(5)	Laser scribing of A-Si/metal coating



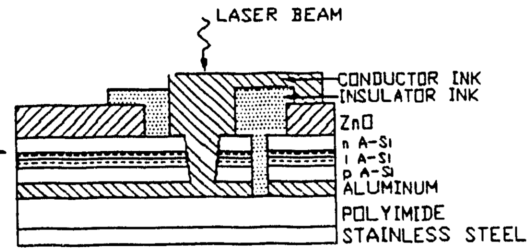
(6)	Screen-printing of insulator ink over scribe region



(7)	Screen-printing of Ag conducting ink



(8)	Laser welding of Ag ink/ZnO



(9)	Busbar attachment
(10)	Cutting web into sheets
(11)	Encapsulation

Fig. 3, and comparing it with Fig. 1 of the baseline case:

(a) For step (3), rather than scribe the a-Si/metal layers, the ZnO TCC would be deposited. This would mean that all depositions would be completed before further submodule fabrication, avoiding handling and contamination.

(b) For step (4), the ZnO TCC would be patterned with an etchant gel developed for this process, and washed clean. This is a wet step in the process, although the gel developed is water soluble.

(c) For step (5), the submodule pattern is laser scribed in a method similar to the original step (3). Note that it may be possible to switch steps (4) and (5).

(d) For step (6), insulator inks are printed over scribe lines, in a method similar to the original step (4). However, a beam-stopping line is not necessary, since the ZnO electrical open will not be laser scribed, but will be created by the etching process in the new step (4) above.

(e) For step (7), conducting Ag lines are printed in a method similar to the original step (7) in Fig. 1.

(f) For step (8), the Ag ink/ZnO is welded to the Al back contact in a method similar to the original step (8).

(g) For step (9), busbars are attached in a manner similar to the original step (9).

(h) For step (10), the web is cut into sheets in a manner similar to the original step (10).

(i) For step (11), the submodules are encapsulated into modules as in the original step (11) in Fig. 1.

The long range potential benefits of these improved processes can be projected by using a manufacturing simulation program, such as SIMAN IV. The results of these simulations are summarized below, and discussed in detail in Appendix 3.

Increased automation is envisioned in the last several steps of the process to reduce labor costs. Simulations with the SIMAN IV program indicate that the cost/ft2 module using the current or baseline manufacturing methods (schematically shown in Fig. 1) is given by $5.67 (see Appendix 3). Simulations with SIMAN IV for the alternative process involving print-etching and sheet-handling, indicate that the cost/ft2 are given by $5.84. Finally, simulations for the alternative process using print-etching and roll-to-roll processing indicate that the cost/ft2 are given by $5.66.

SERI Manufacturing Initiative--Phase 1

Task 3.

Identify and describe the problems that may impede the achievement of the potential benefits described in Task 2. Also, identify all generic problems for which solutions are sought (e.g. encapsulation).

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(1) To institute the alternate manufacturing flows, an appropriate etching process must be developed to remove ZnO for cell patterning. Suitable etching materials, printing screen emulsions, etching patterns and processing machinery need to be developed.

(2) At some point between the roll-to-roll TCC deposition, and the final encapsulation of submodule sheets into finished modules, the web roll must be cut into sheets. We have indicated that the best point to do the sheet handling rather than roll-to-roll is immediately after the TCC deposition. With adequate registration (less than 0.005") using pin-holes in the cut sheets and guide pins in the platens, the time-consuming roll-to-roll registration on 0.002" wide laser scribe lines can be avoided. Also, sheet handling avoids queue build-up between process equipment stages as occurs with roll-to-roll processing, and avoids stress damage caused by stretching web at high tension over a platen. However, suitable sheet cutting, hole punching/drilling, and handling equipment needs to be developed. Rapid alignment/positioning of submodule sheets needs to be developed. As for flexible printed circuit boards, punched hole registration may be adequate, but secondary optical registration may also be necessary in conjunction with alignment pin-holes.

(3) Throughput must be increased in the a-Si deposition step. There are two basic ways to increase the throughput in this process-rate limiting step. One way is to construct a second, parallel output a-Si deposition system. A second way is to increase the a-Si deposition rate. The first way necessitates a considerable infusion of new capital, whereas the second way does not.

(4) Improvement in the throughput of the ZnO transparent conducting contact (TCC) step is required. Like the a-Si deposition, the ZnO deposition is a rate limiting step. Again, like the a-Si deposition case, there are two basic ways to increase the throughput in this process-rate limiting step. One way is to construct a second, parallel output ZnO deposition system. A second way is to increase the ZnO deposition rate. The first needs considerable new capital, whereas the second way does not.

(5) Higher throughput in the laser scribing and welding processes is required to reduce capital and production costs in those steps. Laser scribing and welding of cell interconnects

are "linear" processes in that the laser beam produces a scribed or welded line on the module. By contrast, screen-printing is an "areal" process in that an area of material is printed at one time. Higher throughput in the scribing and welding processes can be achieved either by having multiple laser beams to process more than one scribed or welded line at a time, or by using alternate scribing and welding methods that have higher throughput and/or lower capital cost.

(6) For the bottleneck process steps (a-Si deposition, ZnO deposition and laser scribing/welding) the tradeoff in parallel systems (e.g. more than one 13" wide-web a-Si deposition system) versus a larger capacity, higher throughput machine (e.g. using 1 meter wide web), needs to be examined. Capital costs, repair or "down" times and scaling effects of equipment size need to be considered in determining the lowest cost per watt or cost per m2.

(7) Computer automation is a key to the success of any of our module manufacturing processes. A significant number of automated processes need to be solved or optimized. Computer process times and algorithms require continual updates and refinements. Certain of the manufacturing stations have operational programs (e.g. scribing and printing), whereas others do not (e.g. busbar attachment).

(8) Reductions in flexible substrate cost must be obtained. Such cost reductions could be obtained by development of a low-cost, high-temperature polymer.

(9) In the current, baseline process, reduction of the outgasing effects from the insulating inks on the subsequent ZnO deposition is needed to improve performance of the flexible modules.

(10) The process for producing the series interconnect by using semi-flexible, non-brittle Ag conducting inks must be improved to reduce series resistance in the full modules. Both Ag ink properties (ink adhesion, contact resistance to the ZnO surface and bulk resistivity), and appropriate contact grid design need to be considered. Ag ink properties will also affect the construction of bypass diodes.

(11) A lower cost top transparent flexible polymer encapsulant must be developed. Current available encapsulants suitable for outdoor terrestial power applications are expensive.

(12) In the current, baseline process, web wander or skew is controlled by collar-guides on the rollers. The ability to control web-skew is limited by this method, even with web-guide actuators.

The generic problems for which solutions are sought include the following:

(1) Stability of the devices must be improved. Improvements in

material quality, particularly in the i-layer, can improve stability somewhat. However, most improvement in device stability has been obtained by using appropriate device construction, e.g. p-layer vs. n-layer window, and tandem p-i-n-p-i-n vs. single-junction p-i-n device.

(2) Passivation layers are needed for the top contact/transparent encapsulant interface, for corrosion resistance of the busbars under the encapsulant, and for the generic problem of hermetic sealing of flexible electronic devices.

(3) Modeling of the reaction rate and plasma properties of the a-Si deposition process is needed, so as to increase the deposition rate in a controlled manner.

(4) Deposition and control of electronic and optical properties of ZnO is common to many thin-film photovoltaic devices (e.g. a-Si, CIS, CdTe). A thorough understanding of growth chemistry and doping properties for large area deposition of ZnO is needed.

(5) Shunt defects in thin-film photovoltaic devices is a common problem. Methods to eliminate or reduce them include thermal and electrical annealing, and electrochemical etching/deposition. Effects of remaining shunt defects can be minimized by appropriate module design. Both material processing and module design need further refinement.

Task 4.

Identify and describe the approaches which can be taken for the solution of those problems identified in Task 3, including time- and cost-estimates for achieving those solutions.

Three different module manufacturing paths were outlined in Task 1 and Task 2. The first such path is based on the 13" pilot-plant, with modification of certain steps and equipment from earlier work done at 3M on SERI contract. Some development has been done on the alternate manufacturing paths, but no equipment has been built and the process is conceptual. However, the critical step, to pattern the ZnO TCC with a screen printable etching gel, has been performed. The perceived benefits of depositing ZnO directly onto pristine a-Si for maximum device quality are considerable. The problems with a wet etching process are present but not insurmountable. The problems of developing equipment to handle pieces of submodule material for processing and encapsulation have solutions that already exist in the printing industry: designs seem straightforward. Nevertheless, to do an adequate study of these alternative module manufacturing steps, equipment designs and costing need to be undertaken, and prototype equipment needs to be constructed and operated. The anticipated increases in throughput rate, decreases in capital equipment and operating expenses, and increases in reliability need to be incorporated into production models for their verification. Simulation studies done using SIMAN IV will indicate the best methods to process cut-web pieces in the steps leading to final encapsulation.

Approaches to solve the problems identified in Task 3 for the alternate manufacturing flows (see Task 2) are discussed below:

(1) To institute the alternate manufacturing flows, an appropriate etching process must be developed.

Development of etching gels to pattern the TCC ZnO coating for cell definition and interconnection by screen printing will be required. Also, screen emulsions need to be found that are stable to attack by the etching gel; equipment needs to be designed and built to wash off the etchant; and methods of disposal of the waste liquids from this wet process need to be environmentally safe. A first effort, screen-printable etching gel has been developed from commercially available constituents, to pattern the ZnO. A candidate etch-resistant emulsion has been identified to pattern the screen. The gel is water soluble, so that the waste-liquid from the wet process is not solvent-based, but essentially is an aqueous solution. Machinery for ZnO removal has been designed but not built.

Based on information obtained from vendors and our own engineering analysis, cost and time estimates for etching equipment are approximately $5,000 initial capital cost; $5,000 engineering, installation and shake-down cost; and 6 weeks start-up time after arrival of the equipment. These costs are part of the printer system and consist of a water-spray cleaner integrated into an existing system, and would not greatly affect the estimated value ($86,000) used in the manufacturing simulation cost for the printer. The cost of the research and development for the process is $100,000 over 2 years.

(2) In order to reduce labor costs in the final process steps, the steps must be adapted for easy automation and equipment designed for the processes.

Equipment for automated rolling-off submodule material from a web; registering submodule lengths of web; cutting off web lengths; punching registration holes; attaching busbars; handling sheets for scribing, printing and welding; and sheet encapsulation and junction-box attachment, all need to be developed. Fortunately, this is an area where suitable equipment already exists (or can be modified) to handle roll-to-sheet processing. The printing industry is one source of such expertise. The polyimide sheets may exhibit too much curl to handle, may be too "floppy" to avoid creasing-damage, or may otherwise need back lamination with a low-cost plastic sheet stiffener or back vacuum-coating with an anti-curl layer, prior to cutting the web into sheets. Evaluation and selection of a registration process will drive much of this development.

Based on information obtained from vendors and our own engineering analysis, cost and time estimates for a sheet-cutter are approximately $20,000 initial capital cost; $12,500 engineering, installation and shake-down cost; and 6 weeks start-up time after arrival of equipment. Similar costs and times for the registration-hole punching equipment are: $15,000 capital cost; $12,500 engineering costs; and 6 weeks start-up time. Costs and times for busbar attachment are: $30,000 capital cost; $12,500 engineering costs; and 6 weeks start-up time. Cost and time estimates for the automatic sheet feeders (needed on the printing, scribing, hole punching, and busbar attachment stations) are $40,000 initial cost each; and 6 weeks start up time. Finally, costs and times for encapsulating equipment are: $6,000 (for two systems operating in parallel) capital cost; $12,500 engineering costs; and 6 weeks start-up time. Associated R & D costs are $400,000 over 2 years.

(3) Throughput must be increased in the a-Si deposition step.

The most cost effective way of achieving this is to increase the deposition rate of the a-Si i-layer. Care must be taken when doing this to minimize powder formation which would lead to shunt defects. Our primary technical approach to accomplishing this is to pursue the use of magnetic enhancement of the plasma for deposition of a-Si i-layers. A range of powers, gas flow rates and magnetic field patterns are planned. The effects on deposition rate, uniformity and powder generation will be investigated.

Estimated associated R & D costs and times: $300,000 over 3 years.

(4) Improvement in the throughput of the ZnO transparent conducting contact step is required.

ZnO deposition rate may be increased by raising the substrate temperature. However, it is critical to maintain proper doping levels to insure adequate conductivity. Alternative dopant feedstocks and variations in the inflow gas manifolding will be evaluated for their ability to maintain conductivity at higher deposition rates. In the ZnO TCC deposition system constructed, several plasma and chemical vapor etching/cleaning in-line stages are provided to prepare the p+ layer for ZnO deposition by CVD. Process development to minimize the time needed for these steps will be performed. In particular, ZnO deposition on a pristine a-Si coated web may preclude need for a predeposition cleaning.

Estimated R & D costs and times: $200,000 over 2 years.

(5) Higher throughput in the laser scribing and welding processes is required to reduce capital and labor costs in those steps.

To this end, we have developed a multiple-beam 1064 nm fiber optic laser-scribing and welding system with minimum spot size consistent with laser power densities allowable in fiber transmission. The single-beam laser scribing system was capable of 50 micron spot size using an open beam. Using fiber optics, we have managed to scribe a 70 micron wide line in an a-Si/Al coating with a single fiber. Using beam splitting, we have built a 4 fiber optic beam system for laser scribing at 1064 nm, using a Q-switched YAG laser nominally rated at 15 W TEM(00).

A second alternative which must be evaluated is the development of mechanical scribing methods. Scribing blade methods have been examined and appear feasible. Electro-chemical scribing and ultrasonic engraving techniques are also possibilities, particularly for cutting the ZnO open on top of insulator lines in the present baseline roll-to-roll process. Tolerances for scribing through a 1 micron thick coating without cutting deeper than 5 micron are necessary (polyimide film thickness is 50+-5 micron, and printed insulator lines are typically 20 micron thick).

Alternate, high throughput methods of establishing welded shunts in cell interconnects include spot welding the Al bottom contact to the ZnO top contact of the adjoining cell, via the Ag ink grid lines. Both electronic- and ultrasonic- spot welding techniques need evaluation.

Estimated R & D costs and times: $100,000 for 1 year, each, for the scribing and welding processes.

(6) To examine easing the problems of bottleneck steps, the manufacturing simulation program, SIMAN IV, will be used to evaluate the universe of alternatives.

Manufacturing simulation is an ongoing process (ITFT has its own copy of SIMAN IV). Data gathered from manufacturing experience will be used as inputs to the program, whose algorithms will be updated as changes in the manufacturing process are made.

Yearly simulation expenses (labor) of $10,000 are expected.

(7) Computer automation of manufacturing processes needs to be optimized.

ITFT needs a full time motion-control specialist, familiar with hardware and software of automation equipment, and having the ability to write custom programs in a structured format.

Yearly expenses of $100,000 are expected for 3 years.

(8) Substrate is a major component of the material cost and must be reduced.

To accomplish this, a process modification must be developed to allow use of 1 mil or thinner polyimide substrate. Various thicknesses of polyimide will be used in the deposition systems to determine the lower limit of polyimide thickness which can be used without suffering defects due to physical distortion. Laminating lower cost polymers as stiffeners onto the back of the polyimide after the high temperature deposition processes are completed will be studied.

Estimated R & D costs and times: $50,000 for 1 year.

(9) Reduction of the effects from the insulating inks on the ZnO are needed to improve performance of the full modules in the baseline process.

Accomplishing this requires development of insulator inks that are low outgasing and resistant to environmental degradation. In the present module construction, where the ZnO is deposited after insulator inks are printed, low outgasing inks are crucial to preserve the most conductive stoichiometry of the oxide. Inks have been selected using the NASA database for low-outgasing materials. Qualification of the insulator (and conductor) inks needs to be established for the terrestial and space environments. Temperature-humidity tests, and thermal expansion cycling are necessary tests for module durability.

Estimated R & D costs and times: $50,000 for 1 year.

(10) The process for producing the series interconnect must be improved to reduce series resistance in the full modules.

Obtaining conducting (Ag) inks that have the highest conductivity, make low resistance contact with the ZnO TCC, have weld points that are stable over time to changes in conductivity, are resistant to environmental degradation, and are curable at temperatures compatible with the other module materials is required. A variety of Ag conductive inks (two part epoxy, one-part epoxy, etc.) were examined and a promising candidate is currently being used. However, the list of possible inks that can be cured at low temperatures (less than 130 C) has not been exhausted. A systematic study of the conductivity of welded Ag inks needs to be undertaken. Modifying the chemistry of the conducting inks to reduce the contact resistance to the ZnO surface also needs to be examined. Very thin priming layers, such as indium oxide, deposited on the ZnO prior to Ag ink printing may be necessary to achieve optimum electrical contact. Also, appropriate grid line designs that overlap the insulator line and contact the TCC of the adjoining cell need to be examined. Of interest also is a design of Ag ink stitches perpendicular to and overlapping the insulator line, but which allow welding of a strip of ZnO material (in the welded interconnect region) to the underlying Al.

Estimated R & D costs and times: $100,000 for 1 year.

(11) A lower cost top transparent encapsulant must be developed.

Multiple layers of lower cost transparent polymers will be investigated as a replacement for the current high-cost materials. The envisioned multiple layer stack would have a top layer with good abrasion and UV resistance, a second layer with UV absorbing properties, a 3rd layer with excellent moisture barrier properties and a very inert bottom layer which bonds and seals well to the cell. Some of these layer properties may be combined if the proper material can be found.

Estimated R & D costs and times: $200,000 over 2 years.

(12) Web guide must be improved to eliminate skew.

For roll-to-roll processes, particularly for the ZnO deposition and subsequent stages, sprocket guide holes are possible. These are best punched into bare web substrate, but the creation of dust/debris by the punching process may create shunts (this has been observed to occur with web slitting). For the baseline process, where all scribing and printing steps are done roll-to-roll, punching of sprocket holes would be best done after a-Si deposition, and before laser scribing, insulator ink printing, and TCC deposition. The roll-to-roll web skew for the metalization and a-Si depositions is acceptable for these steady state, constant web motion processes. However, the ZnO TCC requires closer web-motion tolerance, to avoid dust build-up in process gas exit slits and to provide for uncoated, bare a-Si strips of uniform width along the web edge. Punching sprocket holes after the a-Si deposition will not create further shunts. Another possibility is to use nip rollers to grab the edges of the web and pull it taut across its width. If feasible, this would accomplish the same purpose as sprocket holes.

Estimated R & D costs and times: $180,000 for 1 year.

Approaches to solve the generic problems identified in Task 3 are discussed below:

(1) Stability of the devices must be improved.

Our most direct approach to solving this problem is to transfer the tandem cell construction which has been developed in the laboratory, to the pilot-plant a-Si deposition system by using two passes through the chamber. This requires examining the effects of rerolling the web to create tandem cells by a double-pass through the 13" pilot-line a-Si multichamber. Coated surface contamination and shunt defect creation are two possible problems. The addition of the second junction may, however, add protection against shunt defects.

Estimated costs and times: Unknown for stability in general. For the approach here, $100,000 for 1 year.

(2) Passivation layers are needed for hermetic sealing of flexible electronic devices.

The general approach of G. Chandra at Dow-Corning, MI, under DARPA contract 49620-86-C-0110 should be followed: a stack of planarizing, passivation and barrier layers should be tried.

Estimated R & D costs and times: $200,000 over 2 years.

(3) Modelling of the reaction rate and plasma properties of the a-Si deposition process.

Commercial modelling programs exist and need to be modified to be the basis of a-Si deposition modelling studies. FLUENT (Creare, Hanover, NH), and FIDAP (Fluid Dynamics International, Evanston, IL) are examples of such codes.

Estimated R & D costs and times: $200,000 over 2 years, including the cost of the software.

(4) Deposition and control of electronic and optical properties of ZnO.

Deposition temperature, reaction gas flow rates and dopants and doping levels will be varied to obtain optimum electronic, optical and mechanical properties of the ZnO layer.

Estimated R & D costs and times: $200,000 over 2 years.

(5) Shunt-defect reduction/elimination.

Methods available include: thermal and electrical annealing, electrochemical etching/deposition, and clever series/ parallel module design. Shunt analysis using infra-red microscope cameras would help to determine the physical nature of shunt defects, and direct efforts into eliminating the various classes of shunts.

Estimated costs and times: $200,000 over 2 years.

APPENDIX 1.

FABRICATION OF PHOTOVOLTAIC MODULE SERIES INTERCONNECTS BETWEEN a-Si:H THIN FILM SOLAR CELLS DEPOSITED ON FLEXIBLE POLYIMIDE SUBSTRATES

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Abstract: Hydrogenated amorphous silicon device material, deposited on flexible polyimide web substrate by glow-discharge, can be fabricated into photovoltaic modules of series interconnected cells. The roll-to-roll module fabrication process uses automated laser scribing/welding and screen-printing of insulating and conducting inks.

1. INTRODUCTION

Photovoltaic modules consist of individual cells connected in series or parallel to provide a desired voltage or current, respectively. Discrete cells consisting of single or polycrystalline wafers are wired in the appropriate series/parallel pattern. Thin film solar cells deposited on an insulating substrate provide a unique opportunity to construct modules of monolithically interconnected cells.

A series interconnect between photovoltaic cells, whether discrete wafers or thin film depositions, consists of an electrical connection between the top contact of one cell to the bottom contact of an adjacent cell. This series electrical connection must not create shunt paths between the top and bottom contacts of either cell. Thus, the module voltage is the sum of the voltages from each cell. To obtain maximum module efficiency, the current output from each cell must be equalized.

A schematic representation of a monolithic, series interconnect between cells in a thin film photovoltaic module is shown in Fig. 1. The current path between the bottom contact of one cell and the top contact of an adjacent cell is indicated by the arrow in Fig. 1. This "idealized" thin film interconnect construction illustrates the elements of every monolithic interconnect scheme: an electrical open in the top contact and an open in the bottom contact, separated by a low-resistance electrical shunt path connecting the bottom and top contacts of adjacent cells.

2. DISCUSSION

The "idealized" monolithic cell interconnect scheme of Fig. 1

can be fabricated by masking, scribing and/or etching the successive layers of deposited bottom contact, a-Si:H device and top contact. Cleaning of each processed layer is necessary before the next deposition is done. While ultrasonic cleaning in suitable solvents is possible using glass, stainless steel or other rigid substrates, ultrasonic cleaning of layers deposited on polymeric substrates, such as polyimide, resulted in a fracturing of the deposited films and deterioration of device quality. To avoid ultrasonic cleaning, necessary to remove shunt-producing slag created by scribing the metal contact, module construction is not started until after the a-Si:H device layers are deposited.

The optimum method of module fabrication is to begin after the final, top contact is deposited. This method assures maximum cleanliness of the deposited layers and, especially, of the contact interfaces between the layers. However, to avoid creating shunts between top and bottom contacts, the top contact, usually a conducting oxide, must be removed in the vicinity of the interconnect line. Removal of the conducting oxide can be done by HCl acid etch. Unfortunately, the acid can also arrive at the polyimide/metal contact interface through pin-hole defects and along substrate edges, causing substrate-film delamination in a self-propagating effect, even after the acid residues are removed by solvent washing and neutralization with a base.

Hence, to avoid immediate and long-term problems, ultrasonic cleaning and acid-etching are techniques not used in thin film module fabrication methods described here. [1], [2], [3] It was felt that wet-cleaning processes are to be avoided in module fabrication from thin film devices on polyimide substrates, Dry cleaning steps, such as plasma etching, can be substituted where necessary to clean contaminated silicon-conducting oxide interfaces.

The module interconnect fabrication method judged to be the most successful, and amenable to roll-to-roll web production, involves fabrication after the a-Si:H layers are deposited, but before the top contact is deposited. This preferred interconnect method involves five fabrication steps and is schematically shown in Fig. 2. The current path through the laser-welded interconnect shunt is shown by the arrow in Fig. 2. Note the electrical opens, created by laser scribing in the top and bottom contacts, on either side of the electrical shunt in Fig. 2.

Starting with web-substrate coated with bottom contact and a-Si:H layers, the construction steps for fabrication are as follows:
(1) The a-Si:H/bottom contact layers are laser-scribed down to the polyimide substrate. This creates the individual cell strips by producing the electrical opens in the bottom contact.
(2) Insulating ink lines are screen-printed. Two, parallel ink lines, separated by about an ink-line width, are registered so that one of the insulating lines covers the initial scribe line. These parallel insulating ink lines thus serve two puposes: (a) the first line electrically isolates the exposed bottom contact from the subsequently deposited top contact (preventing shunts); and (b) the second line provides an ablative, beam-stopping surface for subsequent laser-scribing of the electrical open in

the transparent top contact.

After the top transparent contact is deposited over the partially completed module, the series interconnect fabrication process continues:
(3) A conducting ink line is screen-printed over the top contact between the two previously printed insulator ink lines. Depending on the top contact used, it may be necessary to print a wider conducting ink line overlapping the first insulator ink line, to make good contact with the top contact of the adjacent cell. Alternatively, thin conducting grid lines can be printed perpendicular to the main conducting ink lines described above, to make good contact with the adjacent top contact. Because of aesthetic concerns, the grid-line pattern is generally not used.
(4) The screen-printed conducting ink line is laser-welded to the bottom contact beneath it. The resulting conducting shunt region is composed of a mixture of metals and metal silicides. The laser welding step is one that requires careful control. The laser power is adjusted so that the beam just barely avoids cutting through the deposited layers.
(5) Finally, an electrical open in the top contact is laser-scribed along the second insulating ink line, which acts as an ablative, beam-stopping region, preventing thermal damage to the layers below.

A variation in this fabrication method is shown schematically in Fig. 3. In this fabrication method, six steps are used. Again, one starts with the bottom contact and a-Si:H layers deposited on the substrate:
(1) A solvent-washable ink strip is printed on the a-Si:H layer. The width of this ink strip is indicated by the gap in the top-contact layer shown in Fig. 3. Inks are used that can be baked up to temperatures that do not damage devices, are low outgassing yet remain removable by solvents.

After the web is coated with the top contact, module fabrication continues:
(2) The web is laser scribed, at high power, through the solvent washable ink, down through the deposited layers to the substrate. This step creates the individual cells.
(3) The web is immersed in a suitable solvent, which dissolves the solvent-washable ink via the laser scribe cut. Hence, the top contact is undercut and removed along with the dissolvable ink. Although this is a wet-cleaning process, the deposited layers and substrate are stable to most solvent washing.
(4) A single insulator ink line is printed over the scribe that goes down to the substrate.
(5) A conducting ink line is printed to bridge over the insulator ink line and make contact with the top contact, as shown. Note the conducting ink does not touch the top contact of the cell to the left.
(6) The conducting ink is laser welded to the bottom contact.

Automated, roll-to-roll laser scribing and screen-printing equipment has been developed for a 4" wide prototype web system, using the module fabrication method described by Fig. 2. The same equipment can be used for the method shown in Fig. 3, but a

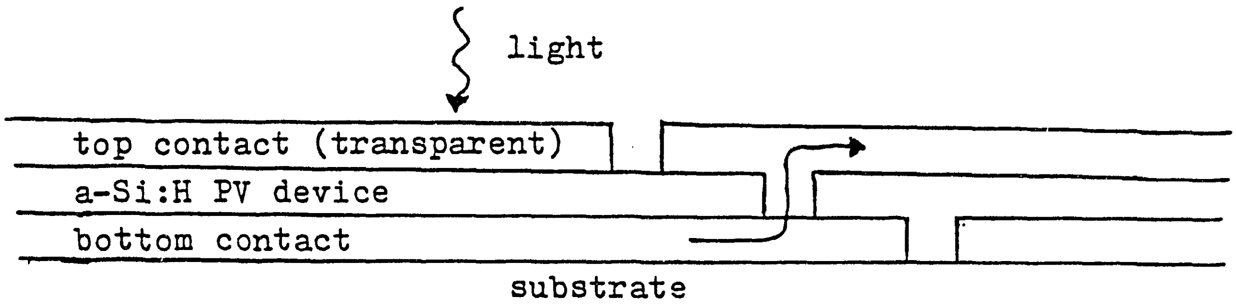

Figure 1. Cross-section of "idealized" thin-film photovoltaic module interconnect line. Arrow indicates current path.

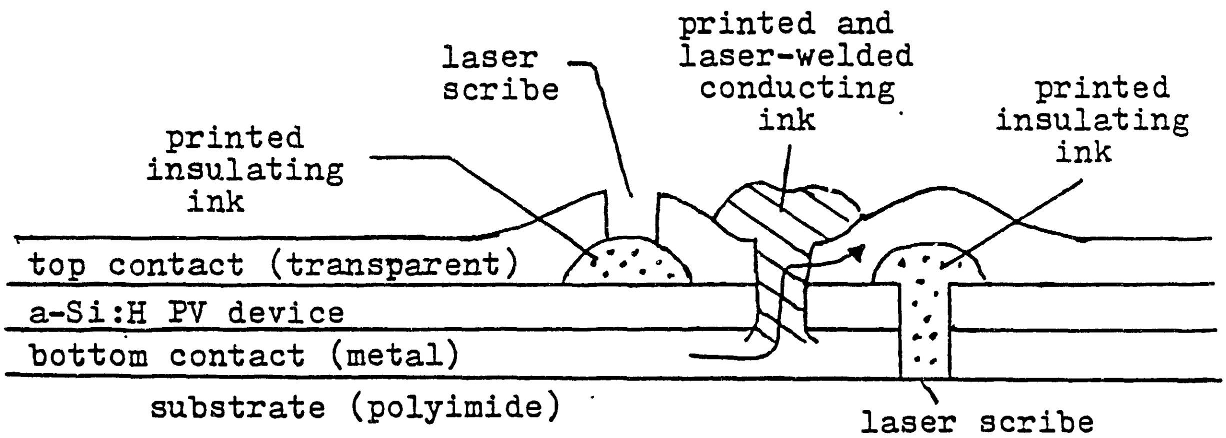

Figure 2. Preferred monolithic series-interconnect construction. Arrow indicates current path.

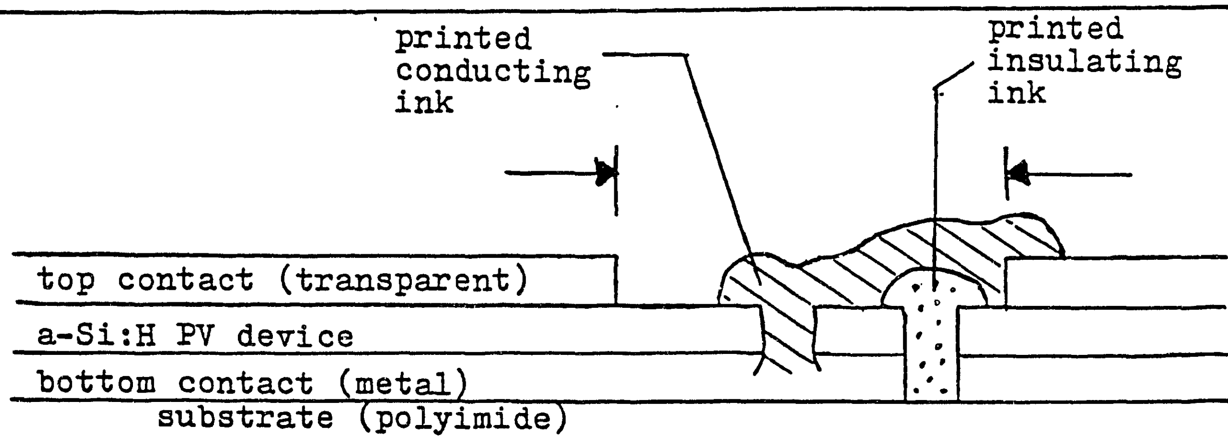

Figure 3. Alternate method of monolithic series-interconnect construction. The arrows indicate the gap created by printing solvent washable ink on a-Si:H surface.

solvent-washing system is required also.

The methods described here produce modules with active area efficiencies of 5.6%. Devices produced on polyimide substrates generally have lower yields (more defect shunts) than devices deposited on glass or stainless steel. However, the yields on polyimide are steadily improving, and there is reason to expect that such modules can be produced that equal those obtained on non-polymeric substrates,

Problems peculiar to module fabrication using the methods described here revolve around the choice of insulating and conducting inks. The insulating inks used should be fully curable at 160°C, low-outgassing and cleanable by plasma discharge. The conducting inks should have as high a conductivity as possible, provide stable welds and be unaffected by moisture and other solvents.

3. CONCLUSION

Two methods of fabricating photovoltaic module series interconnects between a-Si:H thin film solar cells on polyimide substrate have been described. Polymer substrates, such as polyimide, present unique opportunities and difficulties for the fabrication of photovoltaic modules with monolithic series interconnections between cells. The advantages of roll-to-roll production are high volume throughput. The difficulties include ultrasonic cleaning, acid etching, coating adhesion to a polymer substrate, and choice of appropriate inks for electrical isolation and connectivity. However, these are fundamentally engineering problems that are resolvable by an Edisonian approach. The volume throughput of a roll-to-roll process enables a large number of modules to be statistically analyzed to evaluate parametric changes.

4. ACKNOWLEDGEMENTS

The authors would like to thank W. Wallace of the Solar Energy Research Institute for his suggestions. The authors would also like to thank F. Jeffrey,* M. Weber, K. Epstein, and N. Tran for helpful discussions, and R. Thompson of Doradus, Inc., for software development in the automated roll-to-roll processes. The support of the U.S. Department of Energy, Solar Energy Research Institute, under subcontract ZB-4-03056-2 is also gratefully acknowledged.

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APPENDIX 2.

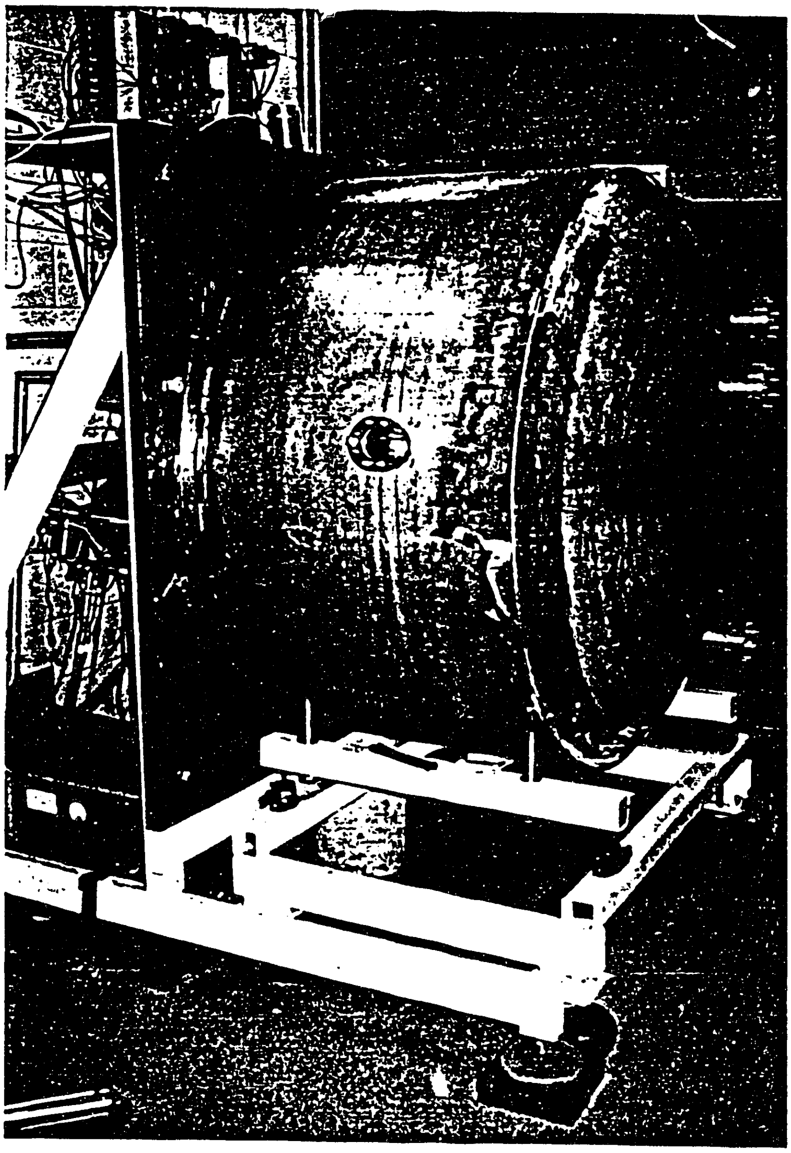

Figure A-2-1

Roll-to-roll metalization deposition sytem.

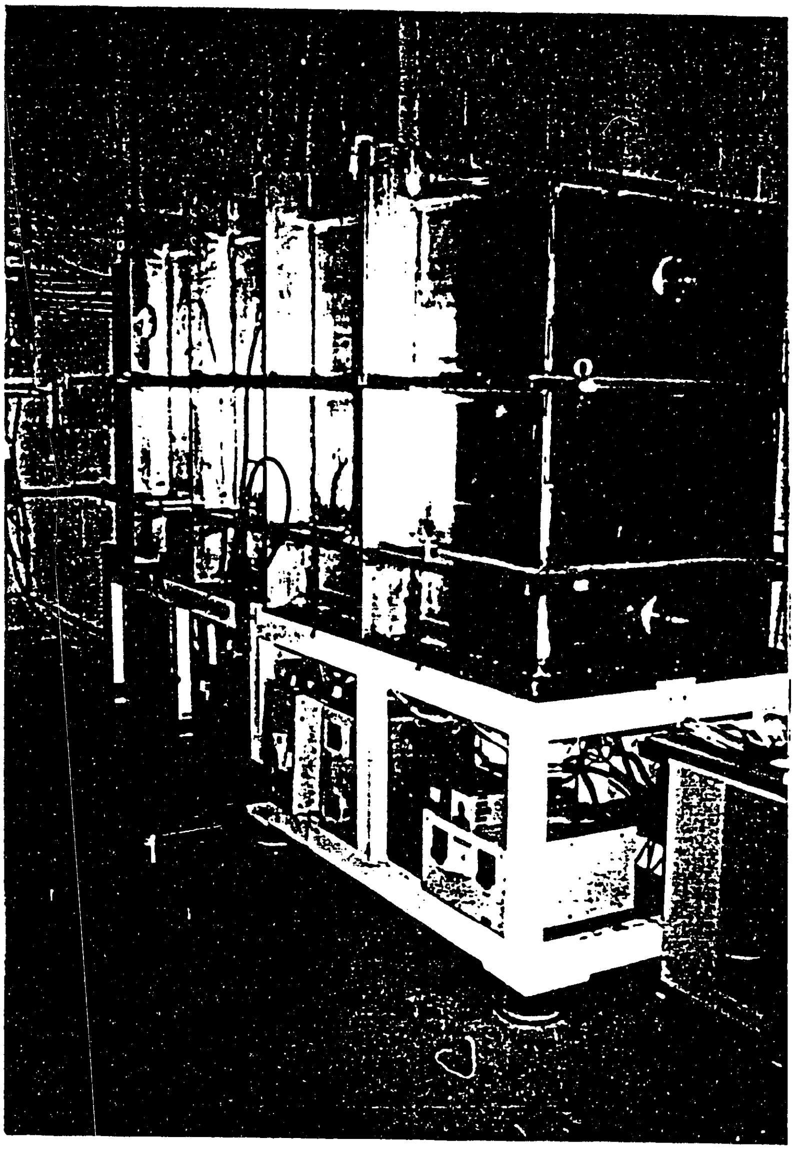

Figure A-2-2

Roll-to-roll a-Si deposition system.

Figure A-2-3

Roll-to-roll ZnO deposition system.

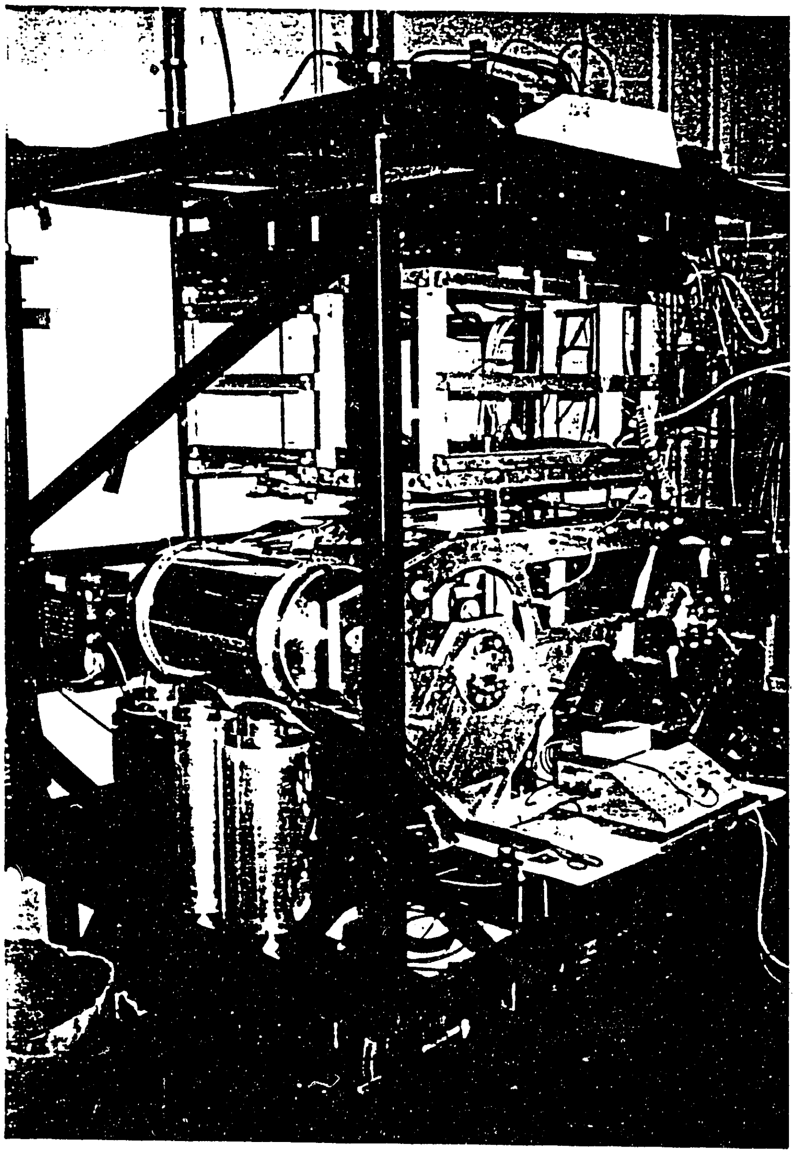

Figure A-2-4

Roll-to-roll laser scribing system.

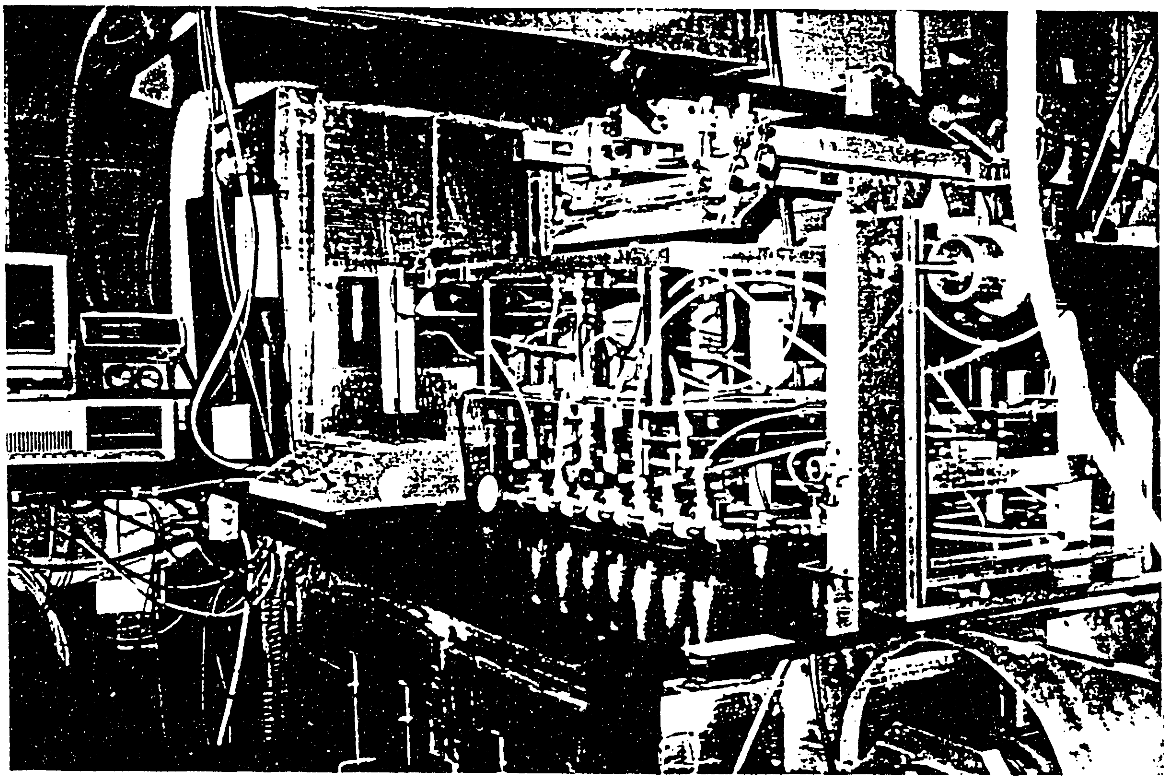

Figure A-2-5

Roll-to-roll screen-printing system.

APPENDIX 3

Computer Simulation of Various Manufacturing Processes.

Executive Summary:

The operation of the pilot-line has been modelled using a simulation and the performance results input to an economic model allowing the development of a cost per module. The basic pilot line configuration recommended consists of one station of each needed type served by three operators. The cost to produce each module from this basic line is $5.67, including materials and outdoor encapsulation, and the annual output is 72 rolls (assuming no station failures and 100% yield). A lower cost per module is not achievable until the number of each type of deposition station is doubled. Reducing the deposition times will increase output but the impact cannot be assessed until the additional investment required is known. Failure modes will decrease annual production by 15% to 62 rolls. The configuration using roll-to-roll deposition with sheet-module processing using automatic feed and a print-etch step yielded a cost of $5.84 per one ft2 module. Finally, the case of roll-to-roll deposition with roll-to-roll module processing and a print-etch step yielded a cost of $5.66 per one ft2 module.

Assuming a 6 Wp one ft2 module, the cost per peak watt for the baseline, print-etch/sheet and print-etch/roll-to-roll configurations are $0.95/Wp, $0.97/Wp, and $0.94/Wp, respectively.

1.0 Introduction.

1.1 Purpose of the Study.

This study provides information on the probable behavior of a prototype manufacturing system. The interaction between components of the system and their interdependencies are investigated. This study considers five issues important to successful operation of the ITFT Pilot Line:

* manufacturing performance
* alternate line configurations
* operating parameters
* manufacturing costs
* alternate investment strategies
* failure modes

Each issue is investigated through the use of a simulation model of the functioning ITFT pilot line. The simulation model's parameters were altered in a systematic way to obtain line performance measures under a variety of operating strategies. The simulation results were statistically analyzed to develop the conclusions presented in this report.

1.2 Tools of the Study

Two basic tools were used in the development and analysis of the pilot line simulation model. Those tools are the following software packages: SIMAN and Lotus 1-2-3. Some statistical analysis was carried out with the MINITAB software, although the majority of the work was done using the output processor capabilities of SIMAN.

2.0 Description of Models Used in the Study

The analysis of the pilot line required the develoment of two models. The first, a simulation model, depicts the pilot line as a running system with known operating parameters. The second model is an economic model of the pilot line. The economic model develops the cost per amorphous silicon solar module by combining the costs of materials and production facilities.

2.1 SIMAN Model of Pilot Line

2.1.0 Description of the SIMAN Model

The pilot line is modelled as a series of processing stations that act upon rolls of material passing through each station. Processing is interrupted by line or station failures. Deposition stations are operated up to 24 hours a day in all line configuration scenarios. The operating schedules for other stations vary among line configuration scenarios.

The line is operated as a "push" system with buffer storage in front of each station. The priming station is the first visited by each roll. A batch of rolls is periodically processed through the priming station. This batch processing was selected since the primer process is less than 10% of the time required for the next process, silicon deposition. Batch priming of rolls appears to be the most effective use of the station and does not affect later processing of the rolls (or sheets).

2.1.1.1.a Modelling Line Operation

The SIMAN model simulates the movement of rolls or sheets of modules through a series of stations for processing. The processing stations are:

Processing Station	Operation
Primer	Priming and Metalization of Web.
a-Si Deposition	Silicon Deposition.
Laser Scriber	Scribing Cell Patterns in Metal and Top Contact Electrode Layers, and Welding of Conductor Inks.
Screen Printer	Print Etching Gels, Insulator Inks and Conducting Inks.
Top Contact Deposition	Deposition of Top Contact Layer.
Cutter	Cut Web into Sheets for Modules.
Hole Puncher	Punch Registration Holes in Substrate for Mechanical Registration.
Busbar	Attach Busbars to Modules.
Encapsulation	Encapsulate Modules for Outdoor Use.

Not all of these stations are used in each of the three different process scenarios examined here: baseline roll-to-roll (no etching); etching steps plus sheet handling; and etching steps plus roll-to-roll. For example, hole punching is used only for sheet handling. For the processes that are roll-to-roll until module sheets are cut for encapsulation, registration is by optoelectronic methods using registration marks. Encapsulation remains a manual operation.

2.1.1.b Modeling Operation Times

The station loading, set-up, processing and unloading times are estimates. Ideally, actual times will be obtained during line operation and substituted in the model.

Exponential and uniform distribution times for loading and unloading of a roll are taken from an exponential distribution with a mean of .25 hours. Start-up and set-up times are also taken from exponential distributions.

The loading, unloading, start-up, and set-up operations are all performed manually by operators. Modeling these times by an exponential distribution reflects the high nature of variability in manual operations.

Processing times are represented by a uniform distribution. The approximate mean process time for each station was taken as the lower limit of the range of possible times. The upper limit was set as the mean plus 10%.

2.1.2 Research on Potential Failure Modes

Equipment failure data was obtained from equipment manufacturers and professionals in industries in which similar equipment is used. Power failure data was obtained from City of Ames data on actual power disturbance data during 1990. A description of failure modes, mean time to failures, and mean time to repair equipment was obtained.

In every case, conservative estimates on equipment reliability are used. In the future, model failure parameters should be obtained from equipment log data.

2.1.3 Experimental Method Used in Simulating the Pilot Line

The model parameters were altered and line operation was simulated for individual runs of one year during which statistics were collected. The model was run for anywhere from 1000 to 3000 hours without statistics collection in order for the line to achieve a steady state condition.

2.2 Economic Model of Pilot Line

Pilot line performance statistics, averaged from simulation runs, are entered into a Lotus 1-2-3 spread sheet to develop a cost per module for rolls/sheets produced under any given scenario. Scenario data describing the configuration of the pilot line and its operating parameters must also be entered. The resulting cost per module is a direct manufacturing and material cost.

The inputs required by the spread sheet are as follows:

<u>Inputs to the Economic Model:</u>

* name of scenario
* yield per roll produced
* watt capacity per module
* tax rate
* interest rate (rate of return)
* labor cost per hour
* capital cost and salvage value of each station
* number of stations, hours operating, # of operators assigned, and power cost per hour
* annual production (# rolls per year)
* # of repair/maintenance occurrences per year
* # of rolls in queue for each station

The last three items are obtained from simulation results.

2.2.1 Assumptions Used in Economic Model

A cost per module is developed that includes the direct production cost (equipment, labor, power), direct material cost, and work in process costs. Certain assumptions were used in calculating the cost per module. The assumptions are divided into general categories and listed below.

2.2.1.a Tax Handling Assumptions:

* equipment is depreciated over 5 years using the ACRS schedule
* salvage value at the end of 5 years is taxed as ordinary income to the manufacturer
* depreciation and operating expenses are used as offsets to the manufacturer's income and provide annual tax credits which are treated as reducing the total cost of production

2.2.1.b Operating Assumptions:

* power, maintenance and labor costs are assumed to increase at the rate of 5% each year
* equipment and operators work the exact number of hours given in the scenario
* maintenance and repairs are performed by line operators
* operators are trained in all aspects of line operation and can perform all necessary tasks
* no rolls are damaged during failures

2.2.1.c Items NOT INCLUDED in the Economic Model:

* overhead of the pilot line, including all indirect manufacturing expenses
* cost of stocking spare parts for equipment repair

3.0 Results

3.1 Manufacturing Performance

This section contains the economic data and simulation data for three basic manufacturing process scenarios:

(1) the basic line using roll-to-roll stations and no wet-etching steps (i.e. module manufacture begins before all deposition steps are ended);

(2) the hybrid process using roll-to-roll deposition stations before module manufacture begins, using etching to pattern the top contact layer and sheet module processing;
(3) the roll-to-roll process with depositions completed before

module manufacture begins, using etching to pattern the top contact layer and roll-to-roll module processing.

Process scenario (1), the basic line, the configuration that the pilot line has presently, has been the most studied. The most notable feature (obtained from graphical analysis) of the pilot line's operation is the cyclical nature of the line's performance. This emphasizes the interdependence of the stations. Early in the study it became obvious that line performance is dominated by the two lengthy deposition processes, the a-Si and top-contact (ZnO). No gains in output will occur unless these processes can be shortened either by installing additional deposition stations (for each of these two deposition processes) or by speeding up the process. Another interesting note about the basic line, from failure analysis, is that allowing for line failures slows down the average roll processing time so much that fewer operators are actually required on the line.

In the following Results of Economic Comparison, the baseline process is Scenario 1A. This Scenario 1A in turn was the optimum scenario of seven baseline variations done in an earlier study by ISU's Dept. of Industrial Engineering. Also in the Results of Economic Comparison summary, the hybrid etching/sheet process with manual sheet or piece feed are listed under Scenarios 2B and 2C. The corresponding etching/sheet processes with automatic sheet or piece feed are listed under Scenarios 4A, 4B and 4C. Finally in the Results of Economic Comparison, the etching/roll-to-roll process are listed under Scenarios 3A and 3B.

Results of Economic Comparison

Scenario	Cost per Module Outdoor Encapsulation	First Yr Pre-Tax Operating Cost Total	First Yr After Tax Operating Cost Total (35% discount)	Annual Production (# Rolls * 2400 Modules)	First Yr After Tax Operating Cost per Module	Operating Cost as Percent of Total Cost
1 A	5.668	404350	262828	172800	1.521	26.83%
2 B	6.728	653243	424608	172800	2.457	36.52%
2 C	6.183	518575	337074	172800	1.951	31.55%
3 A	5.688	404350	262828	172800	1.521	26.74%
3 B	5.663	398472	259007	172800	1.499	26.47%
4 A	5.838	404350	262828	172800	1.521	26.05%
4 B	6.708	394128	256183	136800	1.873	27.92%
4 C	5.863	399239	259505	172800	1.502	25.61%

Scenario 1A: Baseline roll-to-roll process with all equipment running 24 hours a day. The optimized cost will not differ from scenario 3B util the additional cost for print etching equipment is included.

Scenario 2B: Piece processing with manual feed at all stations following the sheet cutting station.

Scenario 2C: Piece processing with manual feed at all stations following the cutting station. Non-deposition stations operate 12 hours out off every 24.

Scenario 3A: Roll-to-roll with etch print and with all equipment running 24 hours per day.

Scenario 3B: Roll-to-roll with etch print and with non-deposition equipment running 24 hours 5 days out of 7 days.

Scenario 4A: Auto feed of non-deposition equipment and all equipment running 24 hours per day.

Scenario 4B: Auto feed of non-deposition equipment and non-deposition equipment running 12 hours of every 24 hours.

Scenario 4C: Auto feed of non-deposition equipment and non-deposition equipment running 18 hours of every 24 hours.

Note: In all scenarios a 24 hour line supervisor assists with operating tasks and the encapsulation station is run 24 hours per day by a dedicated operator.

SCENARIO 1A

INPUT DATA REQUIRED FOR ANALYSIS   DATE EVALUATED: 3/27/91

Name of Scenario Being Evaluated: SCENARIO 1 A BASIC LINE

Yield per Roll Produced (# of modules 2400

Average Watts per Module: 5

Tax Rate: 0.35

Interest Rate: 0.10

Labor Rate per/hr for line supervisor 17.00

Station Input Data Name	Number	Deprcble First Cost	Non-Depr First Cost	Salvage (@5 Yrs)	Number Operators @ Station	Effective Operator Rate per Hr	Cost of Material/Module When it reaches Station
Metalization	1	154000	120000	32500	0.000	0.00	0.80
a-Si Deposition	1	220000	120000	50000	0.167	15.00	1.00
ZnO Deposition	1	81000	80000	10000	0.167	15.00	1.25
Sheeter	1	20000	12500	2000	0.000	9.50	1.35
Punch	0	15000	12500	1500	0.000	9.50	1.35
Laser	1	108000	120000	25000	0.333	15.00	1.35
Screen Printer	1	46000	40000	8000	0.333	15.00	1.35
Bus Bar Attachment	1	30000	12500	10000	0.000	9.50	1.50
Encapsulator	2	3000	12500	0	1.000	9.50	1.55
							1.65 @end

Station Input Data Name	Number	Scheduled Hours Operating	Direct Labor* Cost per Hr	Power Cost per Hr	Maint/Repair Cost per Occur
Metalization	1	900	0.000	1.80	0
a-Si Deposition	1	8736	2.505	1.80	0
ZnO Deposition	1	8736	2.505	0.30	0
Sheeter	1	8736	0.000	0.08	0
Punch	0	8736	0.000	0.08	0
Laser	1	8736	4.995	1.80	0
Screen Printer	1	8736	4.995	0.30	0
Bus Bar Attachment	1	8736	0.000	0.08	0
Encapsulator	2	8736	9.500	0.08	0

* Does not include line supervisor

RESULTS FROM SIMULATION

Annual Production (# of Rolls): 72

Station	Maint. # Occur per Yr	Average # Rolls in Queue for Station	Average Station Use per Year 100% = 1	Average Station Use while Scheduled
Metalization	0.00	0.23	0.07	0.07
a-Si Deposition	0.00	2.45	0.89	0.89
ZnO Deposition	0.00	0.05	0.90	0.90
Sheeter	0.00	0.00	0.02	0.02
Punch	0.00	0.00	0.10	0.10
Laser	0.00	0.08	0.47	0.47
Screen Printer	0.00	0.01	0.36	0.36
Bus Bar Attachment	0.00	0.00	0.11	0.11
Encapsulator	0.00	0.02	1.56	1.56

Average Operator Utilization:

Assignment	Average Number of Operators Busy/YR	Number of Operators Assigned	Average Utilization
Deposition Operators*	1.08	1.000	1.08
Sheeter, Punch & Bus Bar	N/A	N/A	ERR
Laser Station	N/A	N/A	ERR
Printing Station	N/A	N/A	ERR
Encapsulation Station	0.61	1.000	0.61
Total	1.690	2.000	0.845

* Line Supervisor primarily operates deposition equipment

DIRECT PRODUCTION COST PER MODULE   Evaluation for: SCENARIO 1 A BASIC LINE

Assumptions:

Tax Rate:	0.35
Interest Rate:	0.10

Annual Production (# rolls) :	72
Yield per Roll Produced (# of modules) :	2400
Average Watts per Module:	5

*************************** Direct Production Cost ***************************

Annual Cost to Implement and Operate Line :	$	436641
Annual WIP Cost (approximate figure):		9000
Annual Line Supervision Cost (some overhead):		96533
Total Annual Production Cost:	$	542174
Total Production Cost per Roll:	$	7530
Production Cost per Module:	$	3.138

**************************** Direct Material Cost ***************************

2 Mil Polyimide Substrate

Material Cost	$/Module
Material -- no encaps:	1.550
Material indoor encaps:	1.650
Material outdoor encaps:	2.550

1 Mil Polyimide Substrate

Material Cost per Module	$/Module
Material -- no encaps:	1.150
Material indoor encaps:	1.250
Material outdoor encaps:	2.150

NOTE: This calculation assumes 100% yield per roll. No scrap material charges are included.

****** Direct Production and Material Cost *******

PRODUCTION & MATERIAL COSTS	2 MIL SUBSTRATE		1 MIL SUBSTRATE	
	$/Module	$/Watt	$/Module	$/Watt
Production Cost Alone (no material):	3.138	0.628	3.138	0.628
Cost with NO Encapsulation:	4.688	0.938	4.288	0.858
Cost with INDOOR Encpsulation:	4.788	0.958	4.388	0.878
Cost with OUTDOOR Encapsulation:	5.688	1.138	5.288	1.058

DIRECT PRODUCTION COST -- COST TO INSTALL AND OPERATE THE LINE

STATION DATA: Name	Number Machines @ Station	AEC Including Op Cost* per Station	1st Yr Op Cost* (Pre-tax) per Station	ECONOMIC INPUT DATA: Deprcble First Cost	Non-Deprc First Cost	Salvage (@5 Yrs)
Metalization	1	59312	1620	154000	120000	32500
a-Si Deposition	1	95904	37608	220000	120000	50000
ZnO Deposition	1	53239	24504	81000	80000	10000
Sheeter	1	7473	699	20000	12500	2000
Punch	0	3795	0	15000	12500	1500
Laser	1	92255	59361	108000	120000	25000
Screen Printer	1	51571	46257	46000	40000	8000
Bus Bar Attachment	1	8567	699	30000	12500	10000
Encapsulator	2	64525	84390	3000	12500	0
* Total for Line:	------>	436641 *	255139	677000	530000	139000

* Cost of Line Supervisor is not included

The after-tax 1st year Cost is 96533

ANNUAL MACHINE OPERATING PARAMETERS INPUT

MACHINE DATA: Station Name	Number Machines @ Station	Scheduled Operating Hrs per Yr per Mchn	Labor Cost per Hr per Mchn	Power Cost per Hr per Mchn	Number Maintnc per Yr per Mchn	Cost per Mntnc per Mchn
Metalization	1	900	0.00	1.80	0	0
a-Si Deposition	1	8736	2.51	1.80	0	0
ZnO Deposition	1	8736	2.51	0.30	0	0
Sheeter	1	8736	0.00	0.08	0	0
Punch	0	8736	0.00	0.08	0	0
Laser	1	8736	5.00	1.80	0	0
Screen Printer	1	8736	5.00	0.30	0	0
Bus Bar Attachment	1	8736	0.00	0.08	0	0
Encapsulator	2	8736	4.75	0.08	0	0

Annual Equivalent Cost for Priming and Metalization Station

First Cost:	274000
Salvage:	32500
Operating Cost:	1620

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	274000					
1		23100	1620		8652	-7032
2		33880	1701		12453	-10752
3		32340	1786		11944	-10158
4		32340	1875		11975	-10100
5		32340	1969	32500	633	-31164
		154000				

Present Value of After-Tax Cash Flow:	-49160
First Cost of Equipment:	274000
Total Present Value of Equipment:	224840
Annual Equivalent Cost to Install and Operate (5yr):	59312

Annual Equivalent Cost for a-Si Deposition Station

First Cost: 340000
Salvage: 50000
Operating Cost: 37608

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	340000					
1		33000	37608		24713	12896
2		48400	39489		30761	8728
3		46200	41463		30682	10781
4		46200	43537		31408	12129
5		46200	45713	50000	14670	-18956
		220000				

Present Value of After-Tax Cash Flow:	23550
First Cost of Equipment:	340000
Total Present Value of Equipment:	363550
Annual Equivalent Cost to Install and Operate (5yr):	95904

Annual Equivalent Cost for ZnO (top contact coating) Deposition Station

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First Cost: 161000
Salvage: 10000
Operating Cost: 24504

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	161000					
1		12150	24504		12829	11675
2		17820	25730		15242	10487

3		17010	27016		15409	11607
4		17010	28367		15882	12485
5		17010	29785	10000	12878	6907
		81000				

Present Value of After-Tax Cash Flow: 40818
First Cost of Equipment: 161000
Total Present Value of Operating Station: 201818

Annual Equivalent Cost to Install and Operate (5yr): 53239

Annual Equivalent Cost for Sheet Cutting Station

First Cost: 32500
Salvage: 2000
Operating Cost: 699

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	32500					
1		3000	699		1295	-596
2		4400	734		1797	-1063
3		4200	771		1740	-969
4		4200	809		1753	-944
5		4200	849	2000	1067	-2218
		20000				

Present Value of After-Tax Cash Flow: -4170
First Cost of Equipment: 32500
Total Present Value of Operating Station: 28330

Annual Equivalent Cost to Install and Operate (5yr): 7473

Annual Equivalent Cost for Sheet Punching Station

First Cost: 12500
Salvage: 0
Operating Cost: 699

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	12500					
1		0	699		245	454
2		0	734		257	477
3		0	771		270	501
4		0	809		283	526
5		0	849	0	297	552
		0				

Present Value of After-Tax Cash Flow: 1885

First Cost of Equipment: 12500
Total Present Value of Operating Station: 14385

Annual Equivalent Cost to Install and Operate (5yr): 3795

Annual Equivalent Cost for Laser Scribing Station

First Cost: 228000
Salvage: 25000
Operating Cost: 59361

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	228000					
1		16200	59361		26446	32915
2		23760	62329		30131	32198
3		22680	65446		30844	34602
4		22680	68718		31989	36729
5		22680	72154	25000	24442	22712
		108000				

Present Value of After-Tax Cash Flow: 121718
First Cost of Equipment: 228000
Total Present Value of Operating Station: 349718

Annual Equivalent Cost to Install and Operate (5yr): 92255

Annual Equivalent Cost for Screen Printing Station

First Cost: 86000
Salvage: 8000
Operating Cost: 46257

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	86000					
1		6900	46257		18605	27652
2		10120	48570		20541	28028
3		9660	50998		21230	29768
4		9660	53548		22123	31425
5		9660	56226	8000	20260	27966
		46000				

Present Value of After-Tax Cash Flow: 109496
First Cost of Equipment: 86000
Total Present Value of Operating Station: 195496

Annual Equivalent Cost to Install and Operate (5yr): 51571

Annual Equivalent Cost for Bus Bar Attachment Station

First Cost: 42500
Salvage: 10000
Operating Cost: 699

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	42500					
1		4500	699		1820	-1121
2		6600	734		2567	-1833
3		6300	771		2475	-1704
4		6300	809		2488	-1679
5		6300	849	10000	-998	-8153
		30000				

Present Value of After-Tax Cash Flow: -10023
First Cost of Equipment: 42500
Total Present Value of Operating Station: 32477

Annual Equivalent Cost to Install and Operate (5yr): 8567

Annual Equivalent Cost for Encapsulation Station

First Cost: 18500
Salvage: 0
Operating Cost: 84390

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	18500					
1		900	84390		29851	54538
2		1320	88609		31475	57134
3		1260	93040		33005	60035
4		1260	97692		34633	63059
5		1260	102576	0	36343	66234
		6000				

Present Value of After-Tax Cash Flow: 226099
First Cost of Equipment: 18500
Total Present Value of Operating Station: 244599

Annual Equivalent Cost to Install and Operate (5yr): 64525

SCENARIO 2B

INPUT DATA REQUIRED FOR ANALYSIS   DATE EVALUATED: 3/27/91

Name of Scenario Being Evaluated: SCENARIO 2 B Piece Processing
Yield per Roll Produced (# of modules 2400
Average Watts per Module: 5
Tax Rate: 0.35
Interest Rate: 0.10
Labor Rate per/hr for line supervisor 17.00

Station Input Data Name	Number	Deprcble First Cost	Non-Depr First Cost	Salvage (@5 Yrs)	Number Operators @ Station	Effective Operator Rate per Hr	Cost of Material/Module When it reaches Station
Metalization	1	154000	120000	32500	0.000	0.00	0.80
a-Si Deposition	1	220000	120000	50000	0.500	15.00	1.00
ZnO Deposition	1	81000	80000	10000	0.500	15.00	1.25
Sheeter	1	20000	12500	2000	0.333	9.50	1.35
Punch	1	15000	12500	1500	0.333	9.50	1.35
Laser	1	108000	120000	25000	1.000	9.50	1.35
Screen Printer	1	46000	40000	8000	1.000	9.50	1.35
Bus Bar Attachment	1	30000	12500	10000	0.333	9.50	1.50
Encapsulator	2	3000	12500	0	1.000	9.50	1.55
							1.65 @end

Station Input Data Name	Number	Scheduled Hours Operating	Direct Labor* Cost per Hr	Power Cost per Hr	Maint/Repair Cost per Occur
Metalization	1	900	0.000	1.80	0
a-Si Deposition	1	8736	7.500	1.80	0
ZnO Deposition	1	8736	7.500	0.30	0
Sheeter	1	8736	3.164	0.08	0
Punch	1	8736	3.164	0.08	0
Laser	1	8736	9.500	1.80	0
Screen Printer	1	8736	9.500	0.30	0
Bus Bar Attachment	1	8736	3.164	0.08	0
Encapsulator	2	8736	9.500	0.08	0

* Does not include line supervisor

RESULTS FROM SIMULATION

Annual Production (# of Rolls): 72

Station	Maint. # Occur per Yr	Average # Rolls in Queue for Station	Average Station Use per Year 100% = 1	Average Station Use while Scheduled
Metalization	0.00	0.23	0.07	0.07
a-Si Deposition	0.00	2.43	0.88	0.88
ZnO Deposition	0.00	0.08	0.90	0.90
Sheeter	0.00	0.02	0.12	0.12
Punch	0.00	0.00	0.10	0.10
Laser	0.00	0.00	0.40	0.40
Screen Printer	0.00	0.00	0.29	0.29
Bus Bar Attachment	0.00	0.01	0.10	0.10
Encapsulator	0.00	0.00	1.44	1.44

Average Operator Utilization:

Assignment	Average Number of Operators Busy/YR	Number of Operators Assigned	Average Utilization
Deposition Operators*	1.03	1.000	1.03
Sheeter, Punch & Bus Bar	0.21	0.999	0.21
Laser Station	0.40	1.000	0.40
Printing Station	0.29	1.000	0.29
Encapsulation Station	0.62	1.000	0.62
Total	2.550	4.999	0.510

* Line Supervisor primarily operates deposition equipment

DIRECT PRODUCTION COST PER MODULE — Evaluation for: SCENARIO 2 B Piece Processing

Assumptions:

Tax Rate:	0.35
Interest Rate:	0.10

Annual Production (# rolls) :	72
Yield per Roll Produced (# of modules) :	2400
Average Watts per Module:	5

************************** Direct Production Cost **************************

Annual Cost to Implement and Operate Line :	$ 616536
Annual WIP Cost (approximate figure):	8971
Annual Line Supervision Cost (some overhead):	96533
Total Annual Production Cost:	$ 722040
Total Production Cost per Roll:	$ 10028
Production Cost per Module:	$ 4.178

*************************** Direct Material Cost **************************

2 Mil Polyimide Substrate: Material Cost	$/Module	1 Mil Polyimide Substrate: Material Cost per Module	$/Module
Material -- no encaps:	1.550	Material -- no encaps:	1.150
Material indoor encaps:	1.650	Material indoor encaps:	1.250
Material outdoor encaps:	2.550	Material outdoor encaps:	2.150

NOTE: This calculation assumes 100% yield per roll. No scrap material charges are included.

**** Direct Production and Material Cost *****

PRODUCTION & MATERIAL COSTS	2 MIL SUBSTRATE		1 MIL SUBSTRATE	
	$/Module	$/Watt	$/Module	$/Watt
Production Cost Alone (no material):	4.178	0.836	4.178	0.836
Cost with NO Encapsulation:	5.728	1.146	5.328	1.066
Cost with INDOOR Encpsulation:	5.828	1.166	5.428	1.086
Cost with OUTDOOR Encapsulation:	6.728	1.346	6.328	1.266

DIRECT PRODUCTION COST -- COST TO INSTALL AND OPERATE THE LINE

STATION DATA: Name	Number Machines @ Station	AEC Including Op Cost* per Station	1st Yr Op Cost* (Pre-tax) per Station	ECONOMIC INPUT DATA: Deprcble First Cost	Non-Deprc First Cost	Salvage (@5 Yrs)
Metalization	1	59312	1620	154000	120000	32500
a-Si Deposition	1	126959	81245	220000	120000	50000
ZnO Deposition	1	84295	68141	81000	80000	10000
Sheeter	1	27142	28335	20000	12500	2000
Punch	1	26222	28335	15000	12500	1500
Laser	1	120264	98717	108000	120000	25000
Screen Printer	1	79581	85613	46000	40000	8000
Bus Bar Attachment	1	28236	28335	30000	12500	10000
Encapsulator	2	64525	84390	3000	12500	0
* Total for Line: ------>		616536 *	504731	677000	530000	139000

* Cost of Line Supervisor is not included

The after-tax 1st year Cost is 96533

ANNUAL MACHINE OPERATING PARAMETERS INPUT

MACHINE DATA: Station Name	Number Machines @ Station	Scheduled Operating Hrs per Yr per Mchn	Labor Cost per Hr per Mchn	Power Cost per Hr per Mchn	Number Maintnc per Yr per Mchn	Cost per Mntnc per Mchn
Metalization	1	900	0.00	1.80	0	0
a-Si Deposition	1	8736	7.50	1.80	0	0
ZnO Deposition	1	8736	7.50	0.30	0	0
Sheeter	1	8736	3.16	0.08	0	0
Punch	1	8736	3.16	0.08	0	0
Laser	1	8736	9.50	1.80	0	0
Screen Printer	1	8736	9.50	0.30	0	0
Bus Bar Attachment	1	8736	3.16	0.08	0	0
Encapsulator	2	8736	4.75	0.08	0	0

Annual Equivalent Cost for Priming and Metalization Station

First Cost:	274000
Salvage:	32500
Operating Cost:	1620

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	274000					
1		23100	1620		8652	-7032
2		33880	1701		12453	-10752
3		32340	1786		11944	-10158
4		32340	1875		11975	-10100
5		32340	1969	32500	633	-31164
		154000				

Present Value of After-Tax Cash Flow: -49160
First Cost of Equipment: 274000
Total Present Value of Equipment: 224840

Annual Equivalent Cost to Install and Operate (5yr): 59312

Annual Equivalent Cost for a-Si Deposition Station

First Cost: 340000
Salvage: 50000
Operating Cost: 81245

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	340000					
1		33000	81245		39986	41259
2		48400	85307		46797	38510
3		46200	89572		47520	42052
4		46200	94051		49088	44963
5		46200	98754	50000	33234	15520
		220000				

Present Value of After-Tax Cash Flow: 141276
First Cost of Equipment: 340000
Total Present Value of Equipment: 481276

Annual Equivalent Cost to Install and Operate (5yr): 126959

Annual Equivalent Cost for ZnO (top contact coating) Deposition Station

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First Cost: 161000
Salvage: 10000
Operating Cost: 68141

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	161000					
1		12150	68141		28102	40039
2		17820	71548		31279	40269

3		17010	75125		32247	42878
4		17010	78881		33562	45319
5		17010	82826	10000	31442	41383
		81000				

Present Value of After-Tax Cash Flow:	158544
First Cost of Equipment:	161000
Total Present Value of Operating Station:	319544
Annual Equivalent Cost to Install and Operate (5yr):	84295

Annual Equivalent Cost for Sheet Cutting Station

First Cost: 32500
Salvage: 2000
Operating Cost: 28335

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	32500					
1		3000	28335		10967	17368
2		4400	29752		11953	17799
3		4200	31240		12404	18836
4		4200	32802		12951	19851
5		4200	34442	2000	12825	19617
		20000				

Present Value of After-Tax Cash Flow:	70389
First Cost of Equipment:	32500
Total Present Value of Operating Station:	102889
Annual Equivalent Cost to Install and Operate (5yr):	27142

Annual Equivalent Cost for Sheet Punching Station

First Cost: 27500
Salvage: 1500
Operating Cost: 28335

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	27500					
1		2250	28335		10705	17630
2		3300	29752		11568	18184
3		3150	31240		12036	19203
4		3150	32802		12583	20219
5		3150	34442	1500	12632	20310
		15000				

Present Value of After-Tax Cash Flow: 71903

First Cost of Equipment: 27500
Total Present Value of Operating Station: 99403

Annual Equivalent Cost to Install and Operate (5yr): 26222

Annual Equivalent Cost for Laser Scribing Station

First Cost: 228000
Salvage: 25000
Operating Cost: 98717

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	228000					
1		16200	98717		40221	58496
2		23760	103653		44594	59058
3		22680	108835		46030	62805
4		22680	114277		47935	66342
5		22680	119991	25000	41185	53806
		108000				

Present Value of After-Tax Cash Flow: 227895
First Cost of Equipment: 228000
Total Present Value of Operating Station: 455895

Annual Equivalent Cost to Install and Operate (5yr): 120264

Annual Equivalent Cost for Screen Printing Station

First Cost: 86000
Salvage: 8000
Operating Cost: 85613

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	86000					
1		6900	85613		32379	53233
2		10120	89893		35005	54889
3		9660	94388		36417	57971
4		9660	99108		38069	61039
5		9660	104063	8000	37003	59060
		46000				

Present Value of After-Tax Cash Flow: 215673
First Cost of Equipment: 86000
Total Present Value of Operating Station: 301673

Annual Equivalent Cost to Install and Operate (5yr): 79581

Annual Equivalent Cost for Bus Bar Attachment Station

First Cost: 42500
Salvage: 10000
Operating Cost: 28335

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	42500					
1		4500	28335		11492	16843
2		6600	29752		12723	17029
3		6300	31240		13139	18101
4		6300	32802		13686	19116
5		6300	34442	10000	10760	13682
		30000				

Present Value of After-Tax Cash Flow: 64536
First Cost of Equipment: 42500
Total Present Value of Operating Station: 107036

Annual Equivalent Cost to Install and Operate (5yr): 28236

Annual Equivalent Cost for Encapsulation Station

First Cost: 18500
Salvage: 0
Operating Cost: 84390

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	18500					
1		900	84390		29851	54538
2		1320	88609		31475	57134
3		1260	93040		33005	60035
4		1260	97692		34633	63059
5		1260	102576	0	36343	66234
		6000				

Present Value of After-Tax Cash Flow: 226099
First Cost of Equipment: 18500
Total Present Value of Operating Station: 244599

Annual Equivalent Cost to Install and Operate (5yr): 64525

WORK IN PROCESS COST — SCENARIO 2 ~~A~~ B Piece Processing

Tax Rate:	0.35
Interest Rate:	0.10
Annual # Rolls:	72
Modules per Roll:	2400

Station Type	Total AEC Equip+Op Cost Per Station	Material Value Added @ Station per Module	Material Value Added @ Station per Roll	Allocation Of Station AEC per Roll	Cumualtive Value per Roll in Station Queue	Average Number Rolls in Station Queue	Average Annual WIP Cost per Station
(Beginning Web)		0.80	1920.00	0			
Metalization	59312	0.20	480.00	824	1920	0.230	442
a-Si Deposition	126959	0.25	600.00	1763	3224	2.430	7834
ZnO Deposition	84295	0.10	240.00	1171	5587	0.080	447
Sheeter	27142	0.00	0.00	377	6998	0.020	140
Punch	26222	0.00	0.00	364	7375	0.000	0
Laser	120264	0.00	0.00	1670	7739	0.000	0
Screen Printer	79581	0.15	360.00	1105	9409	0.000	0
Bus Bar Attachment	28236	0.05	120.00	392	10875	0.010	109
Encapsulator	64525	0.10	240.00	896	11387	0.000	0
Total:	616536	1.65	3960.00	8563		2.770	8971

	WIP Burden
Line WIP Cost for Year:	8971.06
WIP Cost per roll produced:	124.60
WIP Cost per module:	0.052
Final Value Added per Roll:	12523

SCENARIO 2C

INPUT DATA REQUIRED FOR ANALYSIS   DATE EVALUATED: 3/27/91

Name of Scenario Being Evaluated: SCENARIO 2 C Piece Processing

Yield per Roll Produced (# of modules	2400
Average Watts per Module:	5
Tax Rate:	0.35
Interest Rate:	0.10
Labor Rate per/hr for line supervisor	17.00

Station Input Data Name	Number	Deprcble First Cost	Non-Depr First Cosc	Salvage (@5 Yrs)	Number Operators @ Station	Effective Operator Rate per Hr	Cost of Material/Module When it reaches Station
Metalization	1	154000	120000	32500	0.000	0.00	0.80
a-Si Deposition	1	220000	120000	50000	0.500	15.00	1.00
ZnO Deposition	1	81000	80000	10000	0.500	15.00	1.25
Sheeter	1	20000	12500	2000	0.333	9.50	1.35
Punch	1	15000	12500	1500	0.333	9.50	1.35
Laser	1	108000	120000	25000	1.000	9.50	1.35
Screen Printer	1	46000	40000	8000	1.000	9.50	1.35
Bus Bar Attachment	1	30000	12500	10000	0.333	9.50	1.50
Encapsulator	2	3000	12500	0	1.000	9.50	1.55
							1.65 @end

Station Input Data Name	Number	Scheduled Hours Operating	Direct Labor* Cost per Hr	Power Cost per Hr	Maint/Repair Cost per Occur
Metalization	1	900	0.000	1.80	0
a-Si Deposition	1	8736	7.500	1.80	0
ZnO Deposition	1	8736	7.500	0.30	0
Sheeter	1	4368	3.164	0.08	0
Punch	1	4368	3.164	0.08	0
Laser	1	4368	9.500	1.80	0
Screen Printer	1	4368	9.500	0.30	0
Bus Bar Attachment	1	4368	3.164	0.08	0
Encapsulator	2	8736	9.500	0.08	0

* Does not include line supervisor

DIRECT PRODUCTION COST PER MODULE — Evaluation for: SCENARIO 2 C Piece Processing

Assumptions:

Tax Rate:	0.35
Interest Rate:	0.10

Annual Production (# rolls) :	72
Yield per Roll Produced (# of modules) :	2400
Average Watts per Module:	5

************************* Direct Production Cost ************************

Annual Cost to Implement and Operate Line :	$	520694
Annual WIP Cost (approximate figure):		10544
Annual Line Supervision Cost (some overhead):		96533
Total Annual Production Cost:	$	627770
Total Production Cost per Roll:	$	8719
Production Cost per Module:	$	3.633

************************** Direct Material Cost ************************

2 Mil Polyimide Substrate

Material Cost	$/Module
Material -- no encaps:	1.550
Material indoor encaps:	1.650
Material outdoor encaps:	2.550

1 Mil Polyimide Substrate

Material Cost per Module	$/Module
Material -- no encaps:	1.150
Material indoor encaps:	1.250
Material outdoor encaps:	2.150

NOTE: This calculation assumes 100% yield per roll. No scrap material charges are included.

**** Direct Production and Material Cost *****

PRODUCTION & MATERIAL COSTS	2 MIL SUBSTRATE		1 MIL SUBSTRATE	
	$/Module	$/Watt	$/Module	$/Watt
Production Cost Alone (no material):	3.633	0.727	3.633	0.727
Cost with NO Encapsulation:	5.183	1.037	4.783	0.957
Cost with INDOOR Encpsulation:	5.283	1.057	4.883	0.977
Cost with OUTDOOR Encapsulation:	6.183	1.237	5.783	1.157

6.28

RESULTS FROM SIMULATION

Annual Production (# of Rolls): 72

Station	Maint. # Occur per Yr	Average # Rolls in Queue for Station	Average Station Use per Year 100% = 1	Average Station Use while Scheduled
Metalization	0.00	0.22	0.07	0.07
a-Si Deposition	0.00	2.45	0.88	0.88
ZnO Deposition	0.00	0.06	0.89	0.89
Sheeter	0.00	0.02	0.14	0.28
Punch	0.00	0.01	0.10	0.20
Laser	0.00	0.08	0.40	0.80
Screen Printer	0.00	0.08	0.29	0.58
Bus Bar Attachment	0.00	0.04	0.10	0.20
Encapsulator	0.00	0.00	1.45	1.45

Average Operator Utilization:

Assignment	Average Number of Operators Busy/YR	Number of Operators Assigned	Average Utilization
Deposition Operators*	1.02	1.000	1.02
Sheeter, Punch & Bus Bar	0.21	0.999	0.21
Laser Station	0.40	1.000	0.40
Printing Station	0.29	1.000	0.29
Encapsulation Station	0.44	1.000	0.44
Total	2.360	4.999	0.472

* Line Supervisor primarily operates deposition equipment

DIRECT PRODUCTION COST -- COST TO INSTALL AND OPERATE THE LINE

STATION DATA: Name	Number Machines @ Station	AEC Including Op Cost* per Station	1st Yr Op Cost* (Pre-tax) per Station	ECONOMIC INPUT DATA: Deprcble First Cost	Non-Deprc First Cost	Salvage (@5 Yrs)
Metalization	1	59312	1620	154000	120000	32500
a-Si Deposition	1	126959	81245	220000	120000	50000
ZnO Deposition	1	84295	68141	81000	80000	10000
Sheeter	1	17059	14168	20000	12500	2000
Punch	1	16139	14168	15000	12500	1500
Laser	1	85136	49358	108000	120000	25000
Screen Printer	1	49116	42806	46000	40000	8000
Bus Bar Attachment	1	18153	14168	30000	12500	10000
Encapsulator	2	64525	84390	3000	12500	0
* Total for Line:	------>	520694 *	370063	677000	530000	139000

* Cost of Line Supervisor is not included
The after-tax 1st year Cost is 96533

ANNUAL MACHINE OPERATING PARAMETERS INPUT

MACHINE DATA: Station Name	Number Machines @ Station	Scheduled Operating Hrs per Yr per Mchn	Labor Cost per Hr per Mchn	Power Cost per Hr per Mchn	Number Maintnc per Yr per Mchn	Cost per Mntnc per Mchn
Metalization	1	900	0.00	1.80	0	0
a-Si Deposition	1	8736	7.50	1.80	0	0
ZnO Deposition	1	8736	7.50	0.30	0	0
Sheeter	1	4368	3.16	0.08	0	0
Punch	1	4368	3.16	0.08	0	0
Laser	1	4368	9.50	1.80	0	0
Screen Printer	1	4368	9.50	0.30	0	0
Bus Bar Attachment	1	4368	3.16	0.08	0	0
Encapsulator	2	8736	4.75	0.08	0	0

Annual Equivalent Cost for Priming and Metalization Station

First Cost: 274000
Salvage: 32500
Operating Cost: 1620

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	274000					
1		23100	1620		8652	-7032
2		33880	1701		12453	-10752
3		32340	1786		11944	-10158
4		32340	1875		11975	-10100
5		32340	1969	32500	633	-31164
		154000				

Present Value of After-Tax Cash Flow:	-49160
First Cost of Equipment:	274000
Total Present Value of Equipment:	224840
Annual Equivalent Cost to Install and Operate (5yr):	59312

Annual Equivalent Cost for a-Si Deposition Station

First Cost: 340000
Salvage: 50000
Operating Cost: 81245

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	340000					
1		33000	81245		39986	41259
2		48400	85307		46797	38510
3		46200	89572		47520	42052
4		46200	94051		49088	44963
5		46200	98754	50000	33234	15520
		220000				

Present Value of After-Tax Cash Flow:	141276
First Cost of Equipment:	340000
Total Present Value of Equipment:	481276
Annual Equivalent Cost to Install and Operate (5yr):	126959

Annual Equivalent Cost for ZnO (top contact coating) Deposition Station

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First Cost: 161000
Salvage: 10000
Operating Cost: 68141

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	161000					
1		12150	68141		28102	40039
2		17820	71548		31279	40269

3		17010	75125		32247	42878
4		17010	78881		33562	45319
5		17010	82826	10000	31442	41383
		81000				

Present Value of After-Tax Cash Flow: 158544
First Cost of Equipment: 161000
Total Present Value of Operating Station: 319544

Annual Equivalent Cost to Install and Operate (5yr): 84295

Annual Equivalent Cost for Sheet Cutting Station

First Cost: 32500
Salvage: 2000
Operating Cost: 14168

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	32500					
1		3000	14168		6009	8159
2		4400	14876		6747	8129
3		4200	15620		6937	8683
4		4200	16401		7210	9191
5		4200	17221	2000	6797	8424
		20000				

Present Value of After-Tax Cash Flow: 32167
First Cost of Equipment: 32500
Total Present Value of Operating Station: 64667

Annual Equivalent Cost to Install and Operate (5yr): 17059

Annual Equivalent Cost for Sheet Punching Station

First Cost: 27500
Salvage: 1500
Operating Cost: 14168

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	27500					
1		2250	14168		5746	8421
2		3300	14876		6362	8514
3		3150	15620		6569	9050
4		3150	16401		6843	9558
5		3150	17221	1500	6605	9116
		15000				

Present Value of After-Tax Cash Flow: 33681

First Cost of Equipment: 27500
Total Present Value of Operating Station: 61181

Annual Equivalent Cost to Install and Operate (5yr): 16139

Annual Equivalent Cost for Laser Scribing Station

First Cost: 228000
Salvage: 25000
Operating Cost: 49358

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	228000					
1		16200	49358		22945	26413
2		23760	51826		26455	25371
3		22680	54418		26984	27433
4		22680	57139		27936	29202
5		22680	59995	25000	20186	14809
		108000				

Present Value of After-Tax Cash Flow: 94731
First Cost of Equipment: 228000
Total Present Value of Operating Station: 322731

Annual Equivalent Cost to Install and Operate (5yr): 85136

Annual Equivalent Cost for Screen Printing Station

First Cost: 86000
Salvage: 8000
Operating Cost: 42806

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	86000					
1		6900	42806		17397	25409
2		10120	44947		19273	25673
3		9660	47194		19899	27295
4		9660	49554		20725	28829
5		9660	52031	8000	18792	25239
		46000				

Present Value of After-Tax Cash Flow: 100186
First Cost of Equipment: 86000
Total Present Value of Operating Station: 186186

Annual Equivalent Cost to Install and Operate (5yr): 49116

Annual Equivalent Cost for Bus Bar Attachment Station

First Cost: 42500
Salvage: 10000
Operating Cost: 14168

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	42500					
1		4500	14168		6534	7634
2		6600	14876		7517	7359
3		6300	15620		7672	7948
4		6300	16401		7945	8456
5		6300	17221	10000	4732	2489
		30000				

Present Value of After-Tax Cash Flow: 26314
First Cost of Equipment: 42500
Total Present Value of Operating Station: 68814

Annual Equivalent Cost to Install and Operate (5yr): 18153

Annual Equivalent Cost for Encapsulation Station

First Cost: 18500
Salvage: 0
Operating Cost: 84390

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	18500					
1		900	84390		29851	54538
2		1320	88609		31475	57134
3		1260	93040		33005	60035
4		1260	97692		34633	63059
5		1260	102576	0	36343	66234
		6000				

Present Value of After-Tax Cash Flow: 226099
First Cost of Equipment: 18500
Total Present Value of Operating Station: 244599

Annual Equivalent Cost to Install and Operate (5yr): 64525

WORK IN PROCESS COST — SCENARIO 2 C Piece Processing

Tax Rate:	0.35
Interest Rate:	0.10
Annual # Rolls:	72
Modules per Roll:	2400

Station Type	Total AEC Equip+Op Cost Per Station	Material Value Added @ Station per Module	Material Value Added @ Station per Roll	Allocation Of Station AEC per Roll	Cumualtive Value per Roll in Station Queue	Average Number Rolls in Station Queue	Average Annual WIP Cost per Station
(Beginning Web)		0.80	1920.00	0			
Metalization	59312	0.20	480.00	824	1920	0.220	422
a-Si Deposition	126959	0.25	600.00	1763	3224	2.450	7898
ZnO Deposition	84295	0.10	240.00	1171	5587	0.060	335
Sheeter	17059	0.00	0.00	237	6998	0.020	140
Punch	16139	0.00	0.00	224	7235	0.010	72
Laser	85136	0.00	0.00	1182	7459	0.080	597
Screen Printer	49116	0.15	360.00	682	8641	0.080	691
Bus Bar Attachment	18153	0.05	120.00	252	9684	0.040	387
Encapsulator	64525	0.10	240.00	896	10056	0.000	0
Total:	520694	1.65	3960.00	7232		2.960	10544

	WIP Burden
Line WIP Cost for Year:	10543.57
WIP Cost per roll produced:	146.44
WIP Cost per module:	0.061
Final Value Added per Roll:	11192

SCENARIO 3A

INPUT DATA REQUIRED FOR ANALYSIS   DATE EVALUATED: 3/27/91

Name of Scenario Being Evaluated: SCENARIO 3 A Roll-to-Roll with Etch
Yield per Roll Produced (# of modules   2400
Average Watts per Module: 5
Tax Rate: 0.35
Interest Rate: 0.10
Labor Rate per/hr for line supervisor   17.00

Station Input Data Name	Number	Deprcble First Cost	Non-Depr First Cost	Salvage (@5 Yrs)	Number Operators @ Station	Effective Operator Rate per Hr	Cost of Material/Module When it reaches Station
Metalization	1	154000	120000	32500	0.000	0.00	0.80
a-Si Deposition	1	220000	120000	50000	0.167	15.00	1.00
ZnO Deposition	1	81000	80000	10000	0.167	15.00	1.25
Sheeter	1	20000	12500	2000	0.000	9.50	1.35
Punch	0	15000	12500	1500	0.000	9.50	1.35
Laser	1	108000	120000	25000	0.333	15.00	1.35
Screen Printer	1	46000	40000	8000	0.333	15.00	1.35
Bus Bar Attachment	1	30000	12500	10000	0.000	9.50	1.50
Encapsulator	2	3000	12500	0	1.000	9.50	1.55
							1.65 @end

Station Input Data Name	Number	Scheduled Hours Operating	Direct Labor* Cost per Hr	Power Cost per Hr	Maint/Repair Cost per Occur
Metalization	1	900	0.000	1.80	0
a-Si Deposition	1	8736	2.505	1.80	0
ZnO Deposition	1	8736	2.505	0.30	0
Sheeter	1	8736	0.000	0.08	0
Punch	0	8736	0.000	0.08	0
Laser	1	8736	4.995	1.80	0
Screen Printer	1	8736	4.995	0.30	0
Bus Bar Attachment	1	8736	0.000	0.08	0
Encapsulator	2	8736	9.500	0.08	0

* Does not include line supervisor

DIRECT PRODUCTION COST PER MODULE — Evaluation for: SCENARIO 3 A Roll-to-Roll wit

Assumptions:

Tax Rate:	0.35
Interest Rate:	0.10

Annual Production (# rolls) :	72
Yield per Roll Produced (# of modules) :	2400
Average Watts per Module:	5

************************* Direct Production Cost *************************

Annual Cost to Implement and Operate Line :	$	436641
Annual WIP Cost (approximate figure):		9000
Annual Line Supervision Cost (some overhead):		96533
Total Annual Production Cost:	$	542174
Total Production Cost per Roll:	$	7530
Production Cost per Module:	$	3.138

************************** Direct Material Cost *************************

2 Mil Polyimide Substrate

Material Cost	$/Module
Material -- no encaps:	1.550
Material indoor encaps:	1.650
Material outdoor encaps:	2.550

1 Mil Polyimide Substrate

Material Cost per Module	$/Module
Material -- no encaps:	1.150
Material indoor encaps:	1.250
Material outdoor encaps:	2.150

NOTE: This calculation assumes 100% yield per roll. No scrap material charges are included.

**** Direct Production and Material Cost *****

PRODUCTION & MATERIAL COSTS	2 MIL SUBSTRATE		1 MIL SUBSTRATE	
	$/Module	$/Watt	$/Module	$/Watt
Production Cost Alone (no material):	3.138	0.628	3.138	0.628
Cost with NO Encapsulation:	4.688	0.938	4.288	0.858
Cost with INDOOR Encpsulation:	4.788	0.958	4.388	0.878
Cost with OUTDOOR Encapsulation:	5.688	1.138	5.288	1.058

RESULTS FROM SIMULATION

nnual Production (# of Rolls): 72

Station	Maint. # Occur per Yr	Average # Rolls in Queue for Station	Average Station Use per Year 100% = 1	Average Station Use while Scheduled
etalization	0.00	0.23	0.07	0.07
-Si Deposition	0.00	2.44	0.88	0.88
nO Deposition	0.00	0.00	0.91	0.91
heeter	0.00	0.00	0.02	0.02
unch	0.00	0.00	0.00	0.00
aser	0.00	0.02	0.40	0.40
creen Printer	0.00	0.00	0.43	0.43
us Bar Attachment	0.00	0.00	0.12	0.12
ncapsulator	0.00	0.00	1.58	1.58

verage Operator Utilization:

ssignment	Average Number of Operators Busy	Number of Operators Assigned	Average Utilization
eposition Operators*	1.17	0.334	3.50
Sheeter, Punch & Bus Bar	N/A	0.000	ERR
Laser Station	N/A	0.333	0.00
Printing Station	N/A	0.333	0.00
Encapsulation Station	0.62	1.000	0.62
Total	1.790	2.000	0.895

* Line Supervisor primarily operates deposition equipment

DIRECT PRODUCTION COST -- COST TO INSTALL AND OPERATE THE LINE

STATION DATA: Name	Number Machines @ Station	AEC Including Op Cost* per Station	1st Yr Op Cost* (Pre-tax) per Station	ECONOMIC INPUT DATA: Deprcble First Cost	Non-Deprc First Cost	Salvage (@5 Yrs)
Metalization	1	59312	1620	154000	120000	32500
a-Si Deposition	1	95904	37608	220000	120000	50000
ZnO Deposition	1	53239	24504	81000	80000	10000
Sheeter	1	7473	699	20000	12500	2000
Punch	0	3795	699	15000	12500	1500
Laser	1	92255	59361	108000	120000	25000
Screen Printer	1	51571	46257	46000	40000	8000
Bus Bar Attachment	1	8567	699	30000	12500	10000
Encapsulator	2	64525	84390	3000	12500	0
* Total for Line:	------>	436641 *	255838	677000	530000	139000

* Cost of Line Supervisor is not included
The after-tax 1st year Cost is 96533

ANNUAL MACHINE OPERATING PARAMETERS INPUT

MACHINE DATA: Station Name	Number Machines @ Station	Scheduled Operating Hrs per Yr per Mchn	Labor Cost per Hr per Mchn	Power Cost per Hr per Mchn	Number Maintnc per Yr per Mchn	Cost per Mntnc per Mchn
Metalization	1	900	0.00	1.80	0	0
a-Si Deposition	1	8736	2.51	1.80	0	0
ZnO Deposition	1	8736	2.51	0.30	0	0
Sheeter	1	8736	0.00	0.08	0	0
Punch	0	8736	0.00	0.08	0	0
Laser	1	8736	5.00	1.80	0	0
Screen Printer	1	8736	5.00	0.30	0	0
Bus Bar Attachment	1	8736	0.00	0.08	0	0
Encapsulator	2	8736	4.75	0.08	0	0

Annual Equivalent Cost for Priming and Metalization Station

First Cost: 274000
Salvage: 32500
Operating Cost: 1620

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	274000					
1		23100	1620		8652	-7032
2		33880	1701		12453	-10752
3		32340	1786		11944	-10158
4		32340	1875		11975	-10100
5		32340	1969	32500	633	-31164
		154000				

Present Value of After-Tax Cash Flow:	-49160
First Cost of Equipment:	274000
Total Present Value of Equipment:	224840

Annual Equivalent Cost to Install and Operate (5yr): 59312

Annual Equivalent Cost for a-Si Deposition Station

First Cost: 340000
Salvage: 50000
Operating Cost: 37608

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	340000					
1		33000	37608		24713	12896
2		48400	39489		30761	8728
3		46200	41463		30682	10781
4		46200	43537		31408	12129
5		46200	45713	50000	14670	-18956
		220000				

Present Value of After-Tax Cash Flow:	23550
First Cost of Equipment:	340000
Total Present Value of Equipment:	363550

Annual Equivalent Cost to Install and Operate (5yr): 95904

Annual Equivalent Cost for ZnO (top contact coating) Deposition Station

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First Cost: 161000
Salvage: 10000
Operating Cost: 24504

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	161000					
1		12150	24504		12829	11675
2		17820	25730		15242	10487

3		17010	27016		15409	11607
4		17010	28367		15882	12485
5		17010	29785	10000	12878	6907
		81000				

Present Value of After-Tax Cash Flow:	40818
First Cost of Equipment:	161000
Total Present Value of Operating Station:	201818
Annual Equivalent Cost to Install and Operate (5yr):	53239

Annual Equivalent Cost for Sheet Cutting Station

First Cost: 32500
Salvage: 2000
Operating Cost: 699

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	32500					
1		3000	699		1295	-596
2		4400	734		1797	-1063
3		4200	771		1740	-969
4		4200	809		1753	-944
5		4200	849	2000	1067	-2218
		20000				

Present Value of After-Tax Cash Flow:	-4170
First Cost of Equipment:	32500
Total Present Value of Operating Station:	28330
Annual Equivalent Cost to Install and Operate (5yr):	7473

Annual Equivalent Cost for Sheet Punching Station

First Cost: 12500
Salvage: 0
Operating Cost: 699

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	12500					
1		0	699		245	454
2		0	734		257	477
3		0	771		270	501
4		0	809		283	526
5		0	849	0	297	552
		0				

Present Value of After-Tax Cash Flow: 1885

First Cost of Equipment:	12500
Total Present Value of Operating Station:	14385
Annual Equivalent Cost to Install and Operate (5yr):	3795

Annual Equivalent Cost for Laser Scribing Station

First Cost:	228000
Salvage:	25000
Operating Cost:	59361

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	228000					
1		16200	59361		26446	32915
2		23760	62329		30131	32198
3		22680	65446		30844	34602
4		22680	68718		31989	36729
5		22680	72154	25000	24442	22712
		108000				

Present Value of After-Tax Cash Flow:	121718
First Cost of Equipment:	228000
Total Present Value of Operating Station:	349718
Annual Equivalent Cost to Install and Operate (5yr):	92255

Annual Equivalent Cost for Screen Printing Station

First Cost:	86000
Salvage:	8000
Operating Cost:	46257

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	86000					
1		6900	46257		18605	27652
2		10120	48570		20541	28023
3		9660	50998		21230	29768
4		9660	53548		22123	31425
5		9660	56226	8000	20260	27966
		46000				

Present Value of After-Tax Cash Flow:	109496
First Cost of Equipment:	86000
Total Present Value of Operating Station:	195496
Annual Equivalent Cost to Install and Operate (5yr):	51571

Annual Equivalent Cost for Bus Bar Attachment Station

First Cost: 42500
Salvage: 10000
Operating Cost: 699

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	42500					
1		4500	699		1820	-1121
2		6600	734		2567	-1833
3		6300	771		2475	-1704
4		6300	809		2488	-1679
5		6300	849	10000	-998	-8153
		30000				

Present Value of After-Tax Cash Flow: -10023
First Cost of Equipment: 42500
Total Present Value of Operating Station: 32477

Annual Equivalent Cost to Install and Operate (5yr): 8567

Annual Equivalent Cost for Encapsulation Station

First Cost: 18500
Salvage: 0
Operating Cost: 84390

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	18500					
1		900	84390		29851	54538
2		1320	88609		31475	57134
3		1260	93040		33005	60035
4		1260	97692		34633	63059
5		1260	102576	0	36343	66234
		6000				

Present Value of After-Tax Cash Flow: 226099
First Cost of Equipment: 18500
Total Present Value of Operating Station: 244599

Annual Equivalent Cost to Install and Operate (5yr): 64525

SCENARIO 3B

INPUT DATA REQUIRED FOR ANALYSIS   DATE EVALUATED: 3/27/91

Name of Scenario Being Evaluated: SCENARIO 3 B Roll-to-Roll with Etch

Yield per Roll Produced (# of modules 2400

Average Watts per Module: 5

Tax Rate: 0.35

Interest Rate: 0.10

Labor Rate per/hr for line supervisor 17.00

Station Input Data Name	Number	Deprcble First Cost	Non-Depr First Cost	Salvage (25 Yrs)	Number Operators @ Station	Effective Operator Rate per Hr	Cost of Material/Module When it reaches Station
Metalization	1	154000	120000	32500	0.000	0.00	0.80
a-Si Deposition	1	220000	120000	50000	0.167	15.00	1.00
ZnO Deposition	1	81000	80000	10000	0.167	15.00	1.25
Sheeter	1	20000	12500	2000	0.000	9.50	1.35
Punch	0	15000	12500	1500	0.000	9.50	1.35
Laser	1	108000	120000	25000	0.466	15.00	1.35
Screen Printer	1	46000	40000	8000	0.466	15.00	1.35
Bus Bar Attachment	1	30000	12500	10000	0.000	9.50	1.50
Encapsulator	2	3000	12500	0	1.000	9.50	1.55
							1.65 @end

Station Input Data Name	Number	Scheduled Hours Operating	Direct Labor* Cost per Hr	Power Cost per Hr	Maint/Repair Cost per Occur
Metalization	1	900	0.000	1.80	0
a-Si Deposition	1	8736	2.505	1.80	0
ZnO Deposition	1	8736	2.505	0.30	0
Sheeter	1	6240	0.000	0.08	0
Punch	0	6240	0.000	0.08	0
Laser	1	6240	6.990	1.80	0
Screen Printer	1	6240	6.990	0.30	0
Bus Bar Attachment	1	6240	0.000	0.08	0
Encapsulator	2	8736	9.500	0.08	0

* Does not include line supervisor

DIRECT PRODUCTION COST PER MODULE   Evaluation for: SCENARIO 3 B Roll-to-Roll wit

Assumptions:
Tax Rate: 0.35
Interest Rate: 0.10

Annual Production (# rolls) : 72
Yield per Roll Produced (# of modules) : 2400
Average Watts per Module: 5

************************* Direct Production Cost *************************

Annual Cost to Implement and Operate Line :	$	432458
Annual WIP Cost (approximate figure):		9000
Annual Line Supervision Cost (some overhead):		96533
Total Annual Production Cost:	$	537990
Total Production Cost per Roll:	$	7472
Production Cost per Module:	$	3.113

************************** Direct Material Cost *************************

2 Mil Polyimide Substrate		1 Mil Polyimide Substrate	
Material Cost	$/Module	Material Cost per Module	$/Module
Material -- no encaps:	1.550	Material -- no encaps:	1.150
Material indoor encaps:	1.650	Material indoor encaps:	1.250
Material outdoor encaps:	2.550	Material outdoor encaps:	2.150

NOTE: This calculation assumes 100% yield per roll. No scrap material charges are included.

**** Direct Production and Material Cost *****

PRODUCTION & MATERIAL COSTS	2 MIL SUBSTRATE		1 MIL SUBSTRATE	
	$/Module	$/Watt	$/Module	$/Watt
Production Cost Alone (no material):	3.113	0.623	3.113	0.623
Cost with NO Encapsulation:	4.663	0.933	4.263	0.853
Cost with INDOOR Encpsulation:	4.763	0.953	4.363	0.873
Cost with OUTDOOR Encapsulation:	5.663	1.133	5.263	1.053

RESULTS FROM SIMULATION

Annual Production (# of Rolls): 72

Station	Maint. # Occur per Yr	Average # Rolls in Queue for Station	Average Station Use per Year 100% = 1	Average Station Use while Scheduled
Metalization	0.00	0.22	0.07	0.07
a-Si Deposition	0.00	2.43	0.88	0.88
ZnO Deposition	0.00	0.10	0.90	0.90
Sheeter	0.00	0.00	0.02	0.03
Punch	0.00	0.00	0.00	0.00
Laser	0.00	0.02	0.40	0.56
Screen Printer	0.00	0.00	0.44	0.62
Bus Bar Attachment	0.00	0.01	0.12	0.17
Encapsulator	0.00	0.00	1.58	1.58

Average Operator Utilization:

Assignment	Average Number of Operators Busy	Number of Operators Assigned	Average Utilization
Deposition Operators*	1.17	0.334	3.50
Sheeter, Punch & Bus Bar	N/A	0.000	ERR
Laser Station	N/A	0.466	0.00
Printing Station	N/A	0.466	0.00
Encapsulation Station	0.62	1.000	0.62
Total	1.790	2.266	0.790

* Line Supervisor primarily operates deposition equipment

DIRECT PRODUCTION COST -- COST TO INSTALL AND OPERATE THE LINE

STATION DATA: Name	Number Machines @ Station	AEC Including Op Cost* per Station	1st Yr Op Cost* (Pre-tax) per Station	ECONOMIC INPUT DATA: Deprcble First Cost	Non-Deprc First Cost	Salvage (@5 Yrs)
Metalization	1	59312	1620	154000	120000	32500
a-Si Deposition	1	95904	37608	220000	120000	50000
ZnO Deposition	1	53239	24504	81000	80000	10000
Sheeter	1	7331	499	20000	12500	2000
Punch	0	3653	499	15000	12500	1500
Laser	1	89044	54850	108000	120000	25000
Screen Printer	1	51025	45490	46000	40000	8000
Bus Bar Attachment	1	8425	499	30000	12500	10000
Encapsulator	2	64525	84390	3000	12500	0
* Total for Line: ------>		432458 *	249960	677000	530000	139000

* Cost of Line Supervisor is not included

The after-tax 1st year Cost is 96533

ANNUAL MACHINE OPERATING PARAMETERS INPUT

MACHINE DATA: Station Name	Number Machines @ Station	Scheduled Operating Hrs per Yr per Mchn	Labor Cost per Hr per Mchn	Power Cost per Hr per Mchn	Number Maintnc per Yr per Mchn	Cost per Mntnc per Mchn
Metalization	1	900	0.00	1.80	0	0
a-Si Deposition	1	8736	2.51	1.80	0	0
ZnO Deposition	1	8736	2.51	0.30	0	0
Sheeter	1	6240	0.00	0.08	0	0
Punch	0	6240	0.00	0.08	0	0
Laser	1	6240	6.99	1.80	0	0
Screen Printer	1	6240	6.99	0.30	0	0
Bus Bar Attachment	1	6240	0.00	0.08	0	0
Encapsulator	2	8736	4.75	0.08	0	0

Annual Equivalent Cost for Priming and Metalization Station

First Cost:	274000
Salvage:	32500
Operating Cost:	1620

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	274000					
1		23100	1620		8652	-[illegible]032
2		33880	1701		12453	-10752
3		32340	1786		11944	-10158
4		32340	1875		11975	-10100
5		32340	1969	32500	633	-31164
		154000				

Present Value of After-Tax Cash Flow: -49160
First Cost of Equipment: 274000
Total Present Value of Equipment: 224840

Annual Equivalent Cost to Install and Operate (5yr): 59312

Annual Equivalent Cost for a-Si Deposition Station

First Cost: 340000
Salvage: 50000
Operating Cost: 37608

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	340000					
1		33000	37608		24713	12896
2		48400	39489		30761	8728
3		46200	41463		30682	10781
4		46200	43537		31408	12129
5		46200	45713	50000	14670	-18956
		220000				

Present Value of After-Tax Cash Flow: 23550
First Cost of Equipment: 340000
Total Present Value of Equipment: 363550

Annual Equivalent Cost to Install and Operate (5yr): 95904

Annual Equivalent Cost for ZnO (top contact coating) Deposition Station

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First Cost: 161000
Salvage: 10000
Operating Cost: 24504

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	161000					
1		12150	24504		12829	11675
2		17820	25730		15242	10487

3		17010	27016		15409	11607
4		17010	28367		15882	12485
5		17010	29785	10000	12878	6907
		81000				

Present Value of After-Tax Cash Flow:	40818
First Cost of Equipment:	161000
Total Present Value of Operating Station:	201818
Annual Equivalent Cost to Install and Operate (5yr):	53239

Annual Equivalent Cost for Sheet Cutting Station

First Cost: 32500
Salvage: 2000
Operating Cost: 499

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	32500					
1		3000	499		1225	-726
2		4400	524		1723	-1199
3		4200	550		1663	-1112
4		4200	578		1672	-1094
5		4200	607	2000	982	-2376
		20000				

Present Value of After-Tax Cash Flow:	-4709
First Cost of Equipment:	32500
Total Present Value of Operating Station:	27791
Annual Equivalent Cost to Install and Operate (5yr):	7331

Annual Equivalent Cost for Sheet Punching Station

First Cost: 12500
Salvage: 0
Operating Cost: 499

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	12500					
1		0	499		175	324
2		0	524		183	341
3		0	550		193	358
4		0	578		202	376
5		0	607	0	212	394
		0				

Present Value of After-Tax Cash Flow: 1347

First Cost of Equipment: 12500
Total Present Value of Operating Station: 13847

Annual Equivalent Cost to Install and Operate (5yr): 3653

Annual Equivalent Cost for Laser Scribing Station

First Cost: 228000
Salvage: 25000
Operating Cost: 54850

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	228000					
1		16200	54850		24867	29982
2		23760	57592		28473	29119
3		22680	60472		29103	31369
4		22680	63495		30161	33334
5		22680	66670	25000	22523	19148
		108000				

Present Value of After-Tax Cash Flow: 109546
First Cost of Equipment: 228000
Total Present Value of Operating Station: 337546

Annual Equivalent Cost to Install and Operate (5yr): 89044

Annual Equivalent Cost for Screen Printing Station

First Cost: 86000
Salvage: 8000
Operating Cost: 45490

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	86000					
1		6900	45490		18336	27153
2		10120	47764		20259	27505
3		9660	50152		20934	29218
4		9660	52660		21812	30848
5		9660	55293	8000	19934	27359
		46000				

Present Value of After-Tax Cash Flow: 107425
First Cost of Equipment: 86000
Total Present Value of Operating Station: 193425

Annual Equivalent Cost to Install and Operate (5yr): 51025

Annual Equivalent Cost for Bus Bar Attachment Station

First Cost: 42500
Salvage: 10000
Operating Cost: 499

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	42500					
1		4500	499		1750	-1251
2		6600	524		2493	-1969
3		6300	550		2398	-1847
4		6300	578		2407	-1829
5		6300	607	10000	-1083	-8311
		30000				

Present Value of After-Tax Cash Flow:	-10562
First Cost of Equipment:	42500
Total Present Value of Operating Station:	31938
Annual Equivalent Cost to Install and Operate (5yr):	8425

Annual Equivalent Cost for Encapsulation Station

First Cost: 18500
Salvage: 0
Operating Cost: 84390

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	18500					
1		900	84390		29851	54538
2		1320	88609		31475	57134
3		1260	93040		33005	60035
4		1260	97692		34633	63059
5		1260	102576	0	36343	66234
		6000				

Present Value of After-Tax Cash Flow:	226099
First Cost of Equipment:	18500
Total Present Value of Operating Station:	244599
Annual Equivalent Cost to Install and Operate (5yr):	64525

SCENARIO 4A

INPUT DATA REQUIRED FOR ANALYSIS   DATE EVALUATED: 3/27/91

Name of Scenario Being Evaluated: SCENARIO 4 A PIECE PROCESSING
Yield per Roll Produced (# of modules 2400
Average Watts per Module: 5
Tax Rate: 0.35
Interest Rate: 0.10
Labor Rate per/hr for line supervisor 17.00

Station Input Data Name	Number	Deprcble First Cost	Non-Depr First Cost	Salvage (@5 Yrs)	Number Operators @ Station	Effective Operator Rate per Hr	Cost of Material/Module When it reaches Station
Metalization	1	154000	120000	32500	0.000	0.00	0.80
a-Si Deposition	1	220000	120000	50000	0.500	15.00	1.00
ZnO Deposition	1	81000	80000	10000	0.500	15.00	1.25
Sheeter	1	20000	12500	2000	0.000	9.50	1.35
Punch	1	55000	12500	1500	0.000	9.50	1.35
Laser	1	148000	120000	25000	0.000	9.50	1.35
Screen Printer	1	86000	40000	8000	0.000	9.50	1.35
Bus Bar Attachment	1	70000	12500	10000	0.000	9.50	1.50
Encapsulator	2	3000	12500	0	1.000	9.50	1.55
							1.65 @end

Station Input Data Name	Number	Scheduled Hours Operating	Direct Labor* Cost per Hr	Power Cost per Hr	Maint/Repair Cost per Occur
Metalization	1	900	0.000	1.80	0
a-Si Deposition	1	8736	7.500	1.80	0
ZnO Deposition	1	8736	7.500	0.30	0
Sheeter	1	8736	0.000	0.08	0
Punch	1	8736	0.000	0.08	0
Laser	1	8736	0.000	1.80	0
Screen Printer	1	8736	0.000	0.30	0
Bus Bar Attachment	1	8736	0.000	0.08	0
Encapsulator	2	8736	9.500	0.08	0

* Does not include line supervisor

DIRECT PRODUCTION COST PER MODULE — Evaluation for: SCENARIO 4 A PIECE PROCESSING

Assumptions:

Tax Rate:	0.35
Interest Rate:	0.10

Annual Production (# rolls) :	73
Yield per Roll Produced (# of modules) :	2400
Average Watts per Module:	5

************************* Direct Production Cost *************************

Annual Cost to Implement and Operate Line :	$	470531
Annual WIP Cost (approximate figure):		9000
Annual Line Supervision Cost (some overhead):		96533
Total Annual Production Cost:	$	576064
Total Production Cost per Roll:	$	7891
Production Cost per Module:	$	3.288

************************* Direct Material Cost *************************

2 Mil Polyimide Substrate

Material Cost	$/Module
Material -- no encaps:	1.550
Material indoor encaps:	1.650
Material outdoor encaps:	2.550

1 Mil Polyimide Substrate

Material Cost per Module	$/Module
Material -- no encaps:	1.150
Material indoor encaps:	1.250
Material outdoor encaps:	2.150

NOTE: This calculation assumes 100% yield per roll. No scrap material charges are included.

**** Direct Production and Material Cost *****

PRODUCTION & MATERIAL COSTS	2 MIL SUBSTRATE		1 MIL SUBSTRATE	
	$/Module	$/Watt	$/Module	$/Watt
Production Cost Alone (no material):	3.288	0.658	3.288	0.658
Cost with NO Encapsulation:	4.838	0.968	4.438	0.888
Cost with INDOOR Encpsulation:	4.938	0.988	4.538	0.908
Cost with OUTDOOR Encapsulation:	5.838	1.168	5.438	1.088

RESULTS FROM SIMULATION SCENARIO 4 A PIECE PROCESSING

Annual Production (# of Rolls): 73

Station	Maint. # Occur per Yr	Average # Rolls in Queue for Station	Average Station Use per Year 100% = 1	Average Station Use while Scheduled
Metalization	0.00	0.19	0.06	0.06
a-Si Deposition	0.00	2.49	0.88	0.88
ZnO Deposition	0.00	0.06	0.89	0.89
Sheeter	0.00	0.00	0.05	0.05
Punch	0.00	0.00	0.13	0.13
Laser	0.00	0.00	0.41	0.41
Screen Printer	0.00	0.00	0.38	0.38
Bus Bar Attachment	0.00	0.00	0.13	0.13
Encapsulator	0.00	0.00	1.45	1.45

Average Operator Utilization:

Assignment	Average Number of Operators Busy/YR	Number of Operators Assigned	Average Utilization
Deposition Operators*	0.32	1.000	0.32
Sheeter, Punch & Bus Bar	0.00	0.000	ERR
Laser Station	0.00	0.000	ERR
Printing Station	0.00	0.000	ERR
Encapsulation Station	0.44	1.000	0.44
Total	0.760	2.000	0.380

* Line Supervisor primarily operates deposition equipment

DIRECT PRODUCTION COST -- COST TO INSTALL AND OPERATE THE LINE

STATION DATA: Name	Number Machines @ Station	AEC Including Op Cost* per Station	1st Yr Op Cost* (Pre-tax) per Station	ECONOMIC INPUT DATA: Deprcble First Cost	Non-Deprc First Cost	Salvage (@5 Yrs)
Metalization	1	59312	1620	154000	120000	32500
a-Si Deposition	1	126959	81245	220000	120000	50000
ZnO Deposition	1	84295	68141	81000	80000	10000
Sheeter	1	7473	699	20000	12500	2000
Punch	1	14337	699	55000	12500	1500
Laser	1	68982	15725	148000	120000	25000
Screen Printer	1	28298	2621	86000	40000	8000
Bus Bar Attachment	1	16350	699	70000	12500	10000
Encapsulator	2	64525	84390	3000	12500	0
* Total for Line:	------>	470531 *	255838	837000	530000	139000

* Cost of Line Supervisor is not included

The after-tax 1st year Cost is 96533

ANNUAL MACHINE OPERATING PARAMETERS INPUT

MACHINE DATA: Station Name	Number Machines @ Station	Scheduled Operating Hrs per Yr per Mchn	Labor Cost per Hr per Mchn	Power Cost per Hr per Mchn	Number Maintnc per Yr per Mchn	Cost per Mntnc per Mchn
Metalization	1	900	0.00	1.80	0	0
a-Si Deposition	1	8736	7.50	1.80	0	0
ZnO Deposition	1	8736	7.50	0.30	0	0
Sheeter	1	8736	0.00	0.08	0	0
Punch	1	8736	0.00	0.08	0	0
Laser	1	8736	0.00	1.80	0	0
Screen Printer	1	8736	0.00	0.30	0	0
Bus Bar Attachment	1	8736	0.00	0.08	0	0
Encapsulator	2	8736	4.75	0.08	0	0

Annual Equivalent Cost for Priming and Metalization Station

First Cost: 274000

Salvage: 32500

Operating Cost: 1620

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	274000					
1		23100	1620		8652	-7032
2		33880	1701		12453	-10752
3		32340	1786		11944	-10158
4		32340	1875		11975	-10100
5		32340	1969	32500	633	-31164
		154000				

Present Value of After-Tax Cash Flow:	-49160
First Cost of Equipment:	274000
Total Present Value of Equipment:	224840

Annual Equivalent Cost to Install and Operate (5yr): 59312

Annual Equivalent Cost for a-Si Deposition Station

First Cost:	340000
Salvage:	50000
Operating Cost:	81245

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	340000					
1		33000	81245		39986	41259
2		48400	85307		46797	38510
3		46200	89572		47520	42052
4		46200	94051		49088	44963
5		46200	98754	50000	33234	15520
		220000				

Present Value of After-Tax Cash Flow:	141276
First Cost of Equipment:	340000
Total Present Value of Equipment:	481276

Annual Equivalent Cost to Install and Operate (5yr): 126959

Annual Equivalent Cost for ZnO (top contact coating) Deposition Station

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First Cost:	161000
Salvage:	10000
Operating Cost:	68141

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	161000					
1		12150	68141		28102	40039
2		17820	71548		31279	40269

3		17010	75125		32247	42878
4		17010	78881		33562	45319
5		17010	82826	10000	31442	41383
		81000				

Present Value of After-Tax Cash Flow: 158544

First Cost of Equipment: 161000

Total Present Value of Operating Station: 319544

Annual Equivalent Cost to Install and Operate (5yr): 84295

Annual Equivalent Cost for Sheet Cutting Station

First Cost: 32500

Salvage: 2000

Operating Cost: 699

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	32500					
1		3000	699		1295	-596
2		4400	734		1797	-1063
3		4200	771		1740	-969
4		4200	809		1753	-944
5		4200	849	2000	1067	-2218
		20000				

Present Value of After-Tax Cash Flow: -4170

First Cost of Equipment: 32500

Total Present Value of Operating Station: 28330

Annual Equivalent Cost to Install and Operate (5yr): 7473

Annual Equivalent Cost for Sheet Punching Station

First Cost: 67500

Salvage: 1500

Operating Cost: 699

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	67500					
1		8250	699		3132	-2433
2		12100	734		4492	-3758
3		11550	771		4312	-3542
4		11550	809		4326	-3517
5		11550	849	1500	3815	-4465
		55000				

Present Value of After-Tax Cash Flow: -13153

First Cost of Equipment: 67500
Total Present Value of Operating Station: 54347

Annual Equivalent Cost to Install and Operate (5yr): 14337

Annual Equivalent Cost for Laser Scribing Station

First Cost: 268000
Salvage: 25000
Operating Cost: 15725

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	268000					
1		22200	15725		13274	2451
2		32560	16511		17175	-664
3		31080	17337		16946	391
4		31080	18203		17249	954
5		31080	19114	25000	8818	-14704
		148000				

Present Value of After-Tax Cash Flow: -6505
First Cost of Equipment: 268000
Total Present Value of Operating Station: 261495

Annual Equivalent Cost to Install and Operate (5yr): 68982

Annual Equivalent Cost for Screen Printing Station

First Cost: 126000
Salvage: 8000
Operating Cost: 2621

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	126000					
1		12900	2621		5432	-2811
2		18920	2752		7585	-4833
3		18060	2889		7332	-4443
4		18060	3034		7383	-4349
5		18060	3186	8000	4636	-9450
		86000				

Present Value of After-Tax Cash Flow: -18727
First Cost of Equipment: 126000
Total Present Value of Operating Station: 107273

Annual Equivalent Cost to Install and Operate (5yr): 28298

Annual Equivalent Cost for Bus Bar Attachment Station

First Cost: 82500
Salvage: 10000
Operating Cost: 699

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	82500					
1		10500	699		3920	-3221
2		15400	734		5647	-4913
3		14700	771		5415	-4644
4		14700	809		5428	-4619
5		14700	849	10000	1942	-11093
		70000				

Present Value of After-Tax Cash Flow:	-20520
First Cost of Equipment:	82500
Total Present Value of Operating Station:	61980
Annual Equivalent Cost to Install and Operate (5yr):	16350

Annual Equivalent Cost for Encapsulation Station

First Cost: 18500
Salvage: 0
Operating Cost: 84390

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	18500					
1		900	84390		29851	54538
2		1320	88609		31475	57134
3		1260	93040		33005	60035
4		1260	97692		34633	63059
5		1260	102576	0	36343	66234
		6000				

Present Value of After-Tax Cash Flow:	226099
First Cost of Equipment:	18500
Total Present Value of Operating Station:	244599
Annual Equivalent Cost to Install and Operate (5yr):	64525

SCENARIO 4B

INPUT DATA REQUIRED FOR ANALYSIS   DATE EVALUATED: 3/27/91

Name of Scenario Being Evaluated: SCENARIO 4 B PIECE PROCESSING
Yield per Roll Produced (# of modules 2400
Average Watts per Module: 5
Tax Rate: 0.35
Interest Rate: 0.10
Labor Rate per/hr for line supervisor 17.00

Station Input Data Name	Number	Deprcble First Cost	Non-Depr First Cost	Salvage (@5 Yrs)	Number Operators @ Station	Effective Operator Rate per Hr	Cost of Material/Module When it reaches Station
Metalization	1	154000	120000	32500	0.000	0.00	0.80
a-Si Deposition	1	220000	120000	50000	0.500	15.00	1.00
ZnO Deposition	1	81000	80000	10000	0.500	15.00	1.25
Sheeter	1	20000	12500	2000	0.000	9.50	1.35
Punch	1	55000	12500	1500	0.000	9.50	1.35
Laser	1	148000	120000	25000	0.000	9.50	1.35
Screen Printer	1	86000	40000	8000	0.000	9.50	1.35
Bus Bar Attachment	1	70000	12500	10000	0.000	9.50	1.50
Encapsulator	2	3000	12500	0	1.000	9.50	1.55
							1.65 @end

Station Input Data Name	Number	Scheduled Hours Operating	Direct Labor* Cost per Hr	Power Cost per Hr	Maint/Repair Cost per Occur
Metalization	1	900	0.000	1.80	0
a-Si Deposition	1	8736	7.500	1.80	0
ZnO Deposition	1	8736	7.500	0.30	0
Sheeter	1	4368	0.000	0.08	0
Punch	1	4368	0.000	0.08	0
Laser	1	4368	0.000	1.80	0
Screen Printer	1	4368	0.000	0.30	0
Bus Bar Attachment	1	4368	0.000	0.08	0
Encapsulator	2	8736	9.500	0.08	0

* Does not include line supervisor

DIRECT PRODUCTION COST PER MODULE — Evaluation for: SCENARIO 4 B PIECE PROCESSING

Assumptions:

Tax Rate:	0.35
Interest Rate:	0.10

Annual Production (# rolls) :	57
Yield per Roll Produced (# of modules) :	2400
Average Watts per Module:	5

************************* Direct Production Cost *************************

Annual Cost to Implement and Operate Line :	$	463257
Annual WIP Cost (approximate figure):		9000
Annual Line Supervision Cost (some overhead):		96533
Total Annual Production Cost:	$	568790
Total Production Cost per Roll:	$	9979
Production Cost per Module:	$	4.158

************************** Direct Material Cost *************************

2 Mil Polyimide Substrate

Material Cost	$/Module
Material -- no encaps:	1.550
Material indoor encaps:	1.650
Material outdoor encaps:	2.550

1 Mil Polyimide Substrate

Material Cost per Module	$/Module
Material -- no encaps:	1.150
Material indoor encaps:	1.250
Material outdoor encaps:	2.150

NOTE: This calculation assumes 100% yield per roll. No scrap material charges are included.

**** Direct Production and Material Cost *****

PRODUCTION & MATERIAL COSTS	2 MIL SUBSTRATE		1 MIL SUBSTRATE	
	$/Module	$/Watt	$/Module	$/Watt
Production Cost Alone (no material):	4.158	0.832	4.158	0.832
Cost with NO Encapsulation:	5.708	1.142	5.308	1.062
Cost with INDOOR Encpsulation:	5.808	1.162	5.408	1.082
Cost with OUTDOOR Encapsulation:	6.708	1.342	6.308	1.262

RESULTS FROM SIMULATION SCENARIO 4 B PIECE PROCESSING

Annual Production (# of Rolls): 57

Station	Maint. # Occur per Yr	Average # Rolls in Queue for Station	Average Station Use per Year 100% = 1	Average Station Use while Scheduled
Metalization	0.00	1.51	0.21	0.21
a-Si Deposition	0.00	3.03	0.91	0.91
ZnO Deposition	0.00	0.08	0.94	0.94
Sheeter	0.00	0.00	0.05	0.10
Punch	0.00	0.00	0.10	0.20
Laser	0.00	0.00	0.54	1.08
Screen Printer	0.00	0.00	0.31	0.62
Bus Bar Attachment	0.00	0.00	0.10	0.20
Encapsulator	0.00	0.00	1.11	1.11

Average Operator Utilization:

Assignment	Average Number of Operators Busy/YR	Number of Operators Assigned	Average Utilization
Deposition Operators*	1.01	1.000	1.01
Sheeter, Punch & Bus Bar	0.00	0.000	ERR
Laser Station	0.00	0.000	ERR
Printing Station	0.00	0.000	ERR
Encapsulation Station	0.33	1.000	0.33
Total	1.340	2.000	0.670

* Line Supervisor primarily operates deposition equipment

DIRECT PRODUCTION COST -- COST TO INSTALL AND OPERATE THE LINE

STATION DATA: Name	Number Machines @ Station	AEC Including Op Cost* per Station	1st Yr Op Cost* (Pre-tax) per Station	ECONOMIC INPUT DATA: Deprcble First Cost	Non-Deprc First Cost	Salvage (@5 Yrs)
Metalization	1	59312	1620	154000	120000	32500
a-Si Deposition	1	126959	81245	220000	120000	50000
ZnO Deposition	1	84295	68141	81000	80000	10000
Sheeter	1	7225	349	20000	12500	2000
Punch	1	14088	349	55000	12500	1500
Laser	1	63386	7862	148000	120000	25000
Screen Printer	1	27366	1310	86000	40000	8000
Bus Bar Attachment	1	16101	349	70000	12500	10000
Encapsulator	2	64525	84390	3000	12500	0
* Total for Line: ------>		463257 *	245616	837000	530000	139000

* Cost of Line Supervisor is not included

The after-tax 1st year Cost is 96533

ANNUAL MACHINE OPERATING PARAMETERS INPUT

MACHINE DATA: Station Name	Number Machines @ Station	Scheduled Operating Hrs per Yr per Mchn	Labor Cost per Hr per Mchn	Power Cost per Hr per Mchn	Number Maintnc per Yr per Mchn	Cost per Mntnc per Mchn
Metalization	1	900	0.00	1.80	0	0
a-Si Deposition	1	8736	7.50	1.80	0	0
ZnO Deposition	1	8736	7.50	0.30	0	0
Sheeter	1	4368	0.00	0.08	0	0
Punch	1	4368	0.00	0.08	0	0
Laser	1	4368	0.00	1.80	0	0
Screen Printer	1	4368	0.00	0.30	0	0
Bus Bar Attachment	1	4368	0.00	0.08	0	0
Encapsulator	2	8736	4.75	0.08	0	0

Annual Equivalent Cost for Priming and Metalization Station

First Cost:	274000
Salvage:	32500
Operating Cost:	1620

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	274000					
1		23100	1620		8652	-7032
2		33880	1701		12453	-10752
3		32340	1786		11944	-10158
4		32340	1875		11975	-10100
5		32340	1969	32500	633	-31164
		154000				

Present Value of After-Tax Cash Flow:	-49160
First Cost of Equipment:	274000
Total Present Value of Equipment:	224840
Annual Equivalent Cost to Install and Operate (5yr):	59312

Annual Equivalent Cost for a-Si Deposition Station

First Cost:	340000
Salvage:	50000
Operating Cost:	81245

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	340000					
1		33000	81245		39986	41259
2		48400	85307		46797	38510
3		46200	89572		47520	42052
4		46200	94051		49088	44963
5		46200	98754	50000	33234	15520
		220000				

Present Value of After-Tax Cash Flow:	141276
First Cost of Equipment:	340000
Total Present Value of Equipment:	481276
Annual Equivalent Cost to Install and Operate (5yr):	126959

Annual Equivalent Cost for ZnO (top contact coating) Deposition Station

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First Cost:	161000
Salvage:	10000
Operating Cost:	68141

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	161000					
1		12150	68141		28102	40039
2		17820	71548		31279	40269

3		17010	75125		32247	42878
4		17010	78881		33562	45319
5		17010	82826	10000	31442	41383
		81000				

Present Value of After-Tax Cash Flow: 158544
First Cost of Equipment: 161000
Total Present Value of Operating Station: 319544

Annual Equivalent Cost to Install and Operate (5yr): 84295

Annual Equivalent Cost for Sheet Cutting Station

First Cost: 32500
Salvage: 2000
Operating Cost: 349

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	32500					
1		3000	349		1172	-823
2		4400	367		1668	-1302
3		4200	385		1605	-1220
4		4200	405		1612	-1207
5		4200	425	2000	919	-2494
		20000				

Present Value of After-Tax Cash Flow: -5113
First Cost of Equipment: 32500
Total Present Value of Operating Station: 27387

Annual Equivalent Cost to Install and Operate (5yr): 7225

Annual Equivalent Cost for Sheet Punching Station

First Cost: 67500
Salvage: 1500
Operating Cost: 349

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	67500					
1		8250	349		3010	-2660
2		12100	367		4363	-3997
3		11550	385		4177	-3792
4		11550	405		4184	-3780
5		11550	425	1500	3666	-4741
		55000				

Present Value of After-Tax Cash Flow: -14096

First Cost of Equipment: 67500
Total Present Value of Operating Station: 53404

Annual Equivalent Cost to Install and Operate (5yr): 14088

Annual Equivalent Cost for Laser Scribing Station

First Cost: 268000
Salvage: 25000
Operating Cost: 7862

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	268000					
1		22200	7862		10522	-2659
2		32560	8256		14285	-6030
3		31080	8668		13912	-5244
4		31080	9102		14064	-49[illegible]2
5		31080	9557	25000	5473	-20[illegible]16
		148000				

Present Value of After-Tax Cash Flow: -27717
First Cost of Equipment: 268000
Total Present Value of Operating Station: 240283

Annual Equivalent Cost to Install and Operate (5yr): 63386

Annual Equivalent Cost for Screen Printing Station

First Cost: 126000
Salvage: 8000
Operating Cost: 1310

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	126000					
1		12900	1310		4974	-3663
2		18920	1376		7104	-5728
3		18060	1445		6827	-5382
4		18060	1517		6852	-5335
5		18060	1593	8000	4078	-10486
		86000				

Present Value of After-Tax Cash Flow: -22262
First Cost of Equipment: 126000
Total Present Value of Operating Station: 103738

Annual Equivalent Cost to Install and Operate (5yr): 27366

Annual Equivalent Cost for Bus Bar Attachment Station

First Cost: 82500
Salvage: 10000
Operating Cost: 349

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	82500					
1		10500	349		3797	-3448
2		15400	367		5518	-5152
3		14700	385		5280	-4895
4		14700	405		5287	-4882
5		14700	425	10000	1794	-11369
		70000				

Present Value of After-Tax Cash Flow: -21463
First Cost of Equipment: 82500
Total Present Value of Operating Station: 61037

Annual Equivalent Cost to Install and Operate (5yr): 16101

Annual Equivalent Cost for Encapsulation Station

First Cost: 18500
Salvage: 0
Operating Cost: 84390

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	18500					
1		900	84390		29851	54538
2		1320	88609		31475	57134
3		1260	93040		33005	60035
4		1260	97692		34633	63059
5		1260	102576	0	36343	66234
		6000				

Present Value of After-Tax Cash Flow: 226099
First Cost of Equipment: 18500
Total Present Value of Operating Station: 244599

Annual Equivalent Cost to Install and Operate (5yr): 64525

SCENARIO 4C

INPUT DATA REQUIRED FOR ANALYSIS   DATE EVALUATED: 3/27/91

Name of Scenario Being Evaluated: SCENARIO 4 C PIECE PROCESSING
Yield per Roll Produced (# of modules 2400
Average Watts per Module: 5
Tax Rate: 0.35
Interest Rate: 0.10
Labor Rate per/hr for line supervisor 17.00

Station Input Data Name	Number	Deprcble First Cost	Non-Depr First Cost	Salvage (@5 Yrs)	Number Operators @ Station	Effective Operator Rate per Hr	Cost of Material/Module When it reaches Station
Metalization	1	154000	120000	32500	0.000	0.00	0.80
a-Si Deposition	1	220000	120000	50000	0.500	15.00	1.00
ZnO Deposition	1	81000	80000	10000	0.500	15.00	1.25
Sheeter	1	20000	12500	2000	0.000	9.50	1.35
Punch	1	55000	12500	1500	0.000	9.50	1.35
Laser	1	148000	120000	25000	0.000	9.50	1.35
Screen Printer	1	86000	40000	8000	0.000	9.50	1.35
Bus Bar Attachment	1	70000	12500	10000	0.000	9.50	1.50
Encapsulator	2	3000	12500	0	1.000	9.50	1.55
							1.65 @end

Station Input Data Name	Number	Scheduled Hours Operating	Direct Labor* Cost per Hr	Power Cost per Hr	Maint/Repair Cost per Occur
Metalization	1	900	0.000	1.80	0
a-Si Deposition	1	8736	7.500	1.80	0
ZnO Deposition	1	8736	7.500	0.30	0
Sheeter	1	6552	0.000	0.08	0
Punch	1	6552	0.000	0.08	0
Laser	1	6552	0.000	1.80	0
Screen Printer	1	6552	0.000	0.30	0
Bus Bar Attachment	1	6552	0.000	0.08	0
Encapsulator	2	8736	9.500	0.08	0

* Does not include line supervisor

DIRECT PRODUCTION COST PER MODULE — Evaluation for: SCENARIO 4 C PIECE PROCESSING

Assumptions:

Tax Rate:	0.35
Interest Rate:	0.10

Annual Production (# rolls) :	72
Yield per Roll Produced (# of modules) :	2400
Average Watts per Module:	5

**************************** Direct Production Cost ***************************

Annual Cost to Implement and Operate Line :	$	466894
Annual WIP Cost (approximate figure):		9000
Annual Line Supervision Cost (some overhead):		96533
Total Annual Production Cost:	$	572427
Total Production Cost per Roll:	$	7950
Production Cost per Module:	$	3.313

**************************** Direct Material Cost ***************************

2 Mil Polyimide Substrate

Material Cost	$/Module
Material -- no encaps:	1.550
Material indoor encaps:	1.650
Material outdoor encaps:	2.550

1 Mil Polyimide Substrate

Material Cost per Module	$/Module
Material -- no encaps:	1.150
Material indoor encaps:	1.250
Material outdoor encaps:	2.150

NOTE: This calculation assumes 100% yield per roll. No scrap material charges are included.

**** Direct Production and Material Cost *****

PRODUCTION & MATERIAL COSTS	2 MIL SUBSTRATE		1 MIL SUBSTRATE	
	$/Module	$/Watt	$/Module	$/Watt
Production Cost Alone (no material):	3.313	0.663	3.313	0.663
Cost with NO Encapsulation:	4.863	0.973	4.463	0.893
Cost with INDOOR Encpsulation:	4.963	0.993	4.563	0.913
Cost with OUTDOOR Encapsulation:	5.863	1.173	5.463	1.093

RESULTS FROM SIMULATION SCENARIO 4 C PIECE PROCESSING

Annual Production (# of Rolls): 72

Station	Maint. # Occur per Yr	Average # Rolls in Queue for Station	Average Station Use per Year 100% = 1	Average Station Use while Scheduled
Metalization	0.00	0.19	0.06	0.06
a-Si Deposition	0.00	2.51	0.88	0.88
ZnO Deposition	0.00	0.06	0.90	0.90
Sheeter	0.00	0.00	0.06	0.08
Punch	0.00	0.00	0.13	0.17
Laser	0.00	0.00	0.41	0.55
Screen Printer	0.00	0.00	0.40	0.53
Bus Bar Attachment	0.00	0.00	0.13	0.17
Encapsulator	0.00	0.00	1.44	1.44

Average Operator Utilization:

Assignment	Average Number of Operators Busy/YR	Number of Operators Assigned	Average Utilization
Deposition Operators*	0.41	1.000	0.41
Sheeter, Punch & Bus Bar	0.00	0.000	ERR
Laser Station	0.00	0.000	ERR
Printing Station	0.00	0.000	ERR
Encapsulation Station	0.43	1.000	0.43
Total	0.840	2.000	0.420

* Line Supervisor primarily operates deposition equipment

DIRECT PRODUCTION COST -- COST TO INSTALL AND OPERATE THE LINE

STATION DATA: Name	Number Machines @ Station	AEC Including Op Cost* per Station	1st Yr Op Cost* (Pre-tax) per Station	ECONOMIC INPUT DATA: Deprcble First Cost	Non-Deprc First Cost	Salvage (@5 Yrs)
Metalization	1	59312	1620	154000	120000	32500
a-Si Deposition	1	126959	81245	220000	120000	50000
ZnO Deposition	1	84295	68141	81000	80000	10000
Sheeter	1	7349	524	20000	12500	2000
Punch	1	14212	524	55000	12500	1500
Laser	1	66184	11794	148000	120000	25000
Screen Printer	1	27832	1966	86000	40000	8000
Bus Bar Attachment	1	16226	524	70000	12500	10000
Encapsulator	2	64525	84390	3000	12500	0
* Total for Line: ------>		466894 *	250727	837000	530000	139000

* Cost of Line Supervisor is not included

The after-tax 1st year Cost is 96533

ANNUAL MACHINE OPERATING PARAMETERS INPUT

MACHINE DATA: Station Name	Number Machines @ Station	Scheduled Operating Hrs per Yr per Mchn	Labor Cost per Hr per Mchn	Power Cost per Hr per Mchn	Number Maintnc per Yr per Mchn	Cost per Mntnc per Mchn
Metalization	1	900	0.00	1.80	0	0
a-Si Deposition	1	8736	7.50	1.80	0	0
ZnO Deposition	1	8736	7.50	0.30	0	0
Sheeter	1	6552	0.00	0.08	0	0
Punch	1	6552	0.00	0.08	0	0
Laser	1	6552	0.00	1.80	0	0
Screen Printer	1	6552	0.00	0.30	0	0
Bus Bar Attachment	1	6552	0.00	0.08	0	0
Encapsulator	2	8736	4.75	0.08	0	0

Annual Equivalent Cost for Priming and Metalization Station

First Cost:	274000
Salvage:	32500
Operating Cost:	1620

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	274000					
1		23100	1620		8652	-7032
2		33880	1701		12453	-10752
3		32340	1786		11944	-10158
4		32340	1875		11975	-10100
5		32340	1969	32500	633	-31164
		154000				

Present Value of After-Tax Cash Flow:	-49160
First Cost of Equipment:	274000
Total Present Value of Equipment:	224840
Annual Equivalent Cost to Install and Operate (5yr):	59312

Annual Equivalent Cost for a-Si Deposition Station

First Cost: 340000
Salvage: 50000
Operating Cost: 81245

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	340000					
1		33000	81245		39986	41259
2		48400	85307		46797	38510
3		46200	89572		47520	42052
4		46200	94051		49088	44963
5		46200	98754	50000	33234	15520
		220000				

Present Value of After-Tax Cash Flow:	141276
First Cost of Equipment:	340000
Total Present Value of Equipment:	481276
Annual Equivalent Cost to Install and Operate (5yr):	126959

Annual Equivalent Cost for ZnO (top contact coating) Deposition Station

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First Cost: 161000
Salvage: 10000
Operating Cost: 68141

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	161000					
1		12150	68141		28102	40039
2		17820	71548		31279	40269

3		17010	75125		32247	42878
4		17010	78881		33562	45319
5		17010	82826	10000	31442	41383
		81000				

Present Value of After-Tax Cash Flow:	158544
First Cost of Equipment:	161000
Total Present Value of Operating Station:	319544
Annual Equivalent Cost to Install and Operate (5yr):	84295

Annual Equivalent Cost for Sheet Cutting Station

First Cost: 32500
Salvage: 2000
Operating Cost: 524

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	32500					
1		3000	524		1233	-709
2		4400	550		1733	-1182
3		4200	578		1672	-1094
4		4200	607		1682	-1076
5		4200	637	2000	993	-2356
		20000				

Present Value of After-Tax Cash Flow:	-4642
First Cost of Equipment:	32500
Total Present Value of Operating Station:	27858
Annual Equivalent Cost to Install and Operate (5yr):	7349

Annual Equivalent Cost for Sheet Punching Station

First Cost: 67500
Salvage: 1500
Operating Cost: 524

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	67500					
1		8250	524		3071	-2547
2		12100	550		4428	-3877
3		11550	578		4245	-3667
4		11550	607		4255	-3648
5		11550	637	1500	3740	-4603
		55000				

Present Value of After-Tax Cash Flow:	-13625

First Cost of Equipment: 67500
Total Present Value of Operating Station: 53875

Annual Equivalent Cost to Install and Operate (5yr): 14212

Annual Equivalent Cost for Laser Scribing Station

First Cost: 268000
Salvage: 25000
Operating Cost: 11794

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	268000					
1		22200	11794		11898	-104
2		32560	12383		15730	-3347
3		31080	13002		15429	-2426
4		31080	13653		15656	-2004
5		31080	14335	25000	7145	-17810
		148000				

Present Value of After-Tax Cash Flow: -17111
First Cost of Equipment: 268000
Total Present Value of Operating Station: 250889

Annual Equivalent Cost to Install and Operate (5yr): 66184

Annual Equivalent Cost for Screen Printing Station

First Cost: 126000
Salvage: 8000
Operating Cost: 1966

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	126000					
1		12900	1966		5203	-3237
2		18920	2064		7344	-5280
3		18060	2167		7079	-4912
4		18060	2275		7117	-4842
5		18060	2389	8000	4357	-9968
		86000				

Present Value of After-Tax Cash Flow: -20494
First Cost of Equipment: 126000
Total Present Value of Operating Station: 105506

Annual Equivalent Cost to Install and Operate (5yr): 27832

Annual Equivalent Cost for Bus Bar Attachment Station

First Cost: 82500
Salvage: 10000
Operating Cost: 524

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	82500					
1		10500	524		3858	-3334
2		15400	550		5583	-5032
3		14700	578		5347	-4769
4		14700	607		5357	-4751
5		14700	637	10000	1868	-11231
		70000				

Present Value of After-Tax Cash Flow:	-20992
First Cost of Equipment:	82500
Total Present Value of Operating Station:	61508
Annual Equivalent Cost to Install and Operate (5yr):	16226

Annual Equivalent Cost for Encapsulation Station

First Cost: 18500
Salvage: 0
Operating Cost: 84390

End Year	First Cost	(ACRS) Deprec.	Annual Operating Expense	Salvage	Tax Savings	After-Tax Cash Flow
0	18500					
1		900	84390		29851	54538
2		1320	88609		31475	57134
3		1260	93040		33005	60035
4		1260	97692		34633	63059
5		1260	102576	0	36343	66234
		6000				

Present Value of After-Tax Cash Flow:	226099
First Cost of Equipment:	18500
Total Present Value of Operating Station:	244599
Annual Equivalent Cost to Install and Operate (5yr):	64525

Document Control Page	1. SERI Report No. NREL/TP-214-4488	2. NTIS Accession No. DE92001163	3. Recipient's Accession No.
4. Title and Subtitle Monolithic Amorphous Silicon Modules on Continuous Polymer Substrate			5. Publication Date March 1992 6.
7. Author(s) D.P. Grimmer			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Iowa Thin Film Technologies Suite 607, ISIS ISU Research Park Ames, Iowa 50010			10. Project/Task/Work Unit No. PV250101 11. Contract (C) or Grant (G) No. (C) XC-1-10057-18 (G)
12. Sponsoring Organization Name and Address National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393			13. Type of Report & Period Covered Technical Report 9 January 1991 - 14 April 1991 14.
15. Supplementary Notes NREL technical monitor: R. Mitchell			

16. Abstract (Limit: 200 words)

This report examines manufacturing monolithic amorphous silicon modules on a continuous polymer substrate. Module production costs can be reduced by increasing module performance, expanding production, and improving and modifying production processes. Material costs can be reduced by developing processes that use a 1-mil polyimide substrate and multilayers of low-cost material for the front encapsulant. Research to speed up a-Si and ZnO deposition rates is needed to improve throughputs. To keep throughput rates compatible with depositions, multibeam fiber optic delivery systems for laser scribing can be used. However, mechanical scribing systems promise even higher throughputs. Tandem cells and production experience can increase device efficiency and stability. Two alternative manufacturing processes are described: (1) wet etching and sheet handling and (2) wet etching and roll-to-roll fabrication.

17. Document Analysis

a. Descriptors

amorphous silicon ; manufacturing ; modules ; continuous polymer substrate ; solar cells ; photovoltaics

b. Identifiers/Open-Ended Terms

c. UC Categories

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18. Availability Statement	19. No. of Pages
National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	113 20. Price A06

Form No. 0069E (6-30-87)

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