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I. Introduction

Solar Cells, Inc. (SCI) was founded in 1987 to manufacture photovoltaic panels for use by electric utilities and to install solar generating fields. SCI has signed a contract with Toledo Edison for the installation of a photovoltaic generating facility in Northwestern Ohio to be connected to the Toledo Edison grid. The size of the field is to be determined by SCI and can be up to 5MW. A $500,000 grant has been obtained from the State of Ohio which is to be used to help pay for the Balance of Systems components of this generating field.

The original SCI plan was to install a continuous manufacturing line to produce thin film amorphous silicon (aSi) PV modules, and some initial steps were taken to implement this plan. The details of the manufacturing process to produce these aSi modules are given in Section II.

Evaluation of the manufacturing process continued as the initial stages of the project were undertaken to produce the manufacturing line. Further study confirmed the decision to use an automated continuous manufacturing line. We are more convinced than ever that this is the best way to obtain the high throughput and low cost required to penetrate the utility market. However, further internal study coupled with developments elsewhere caused us to reconsider our choice of material (amorphous silicon) and deposition technique (plasma enhanced chemical vapor deposition). The relatively low efficiency and poor stability of aSi were troubling, as was the low deposition rate possible with PECVD. In late 1990, we put our project on hold and undertook an intensive investigation of the advantages and limitations of various materials and deposition processes with emphasis on high throughput and low cost.

We have concluded that CdTe is a better choice than aSi for low cost PV modules. We expect to achieve higher efficiency and better stability with CdTe. Another advantage of thin film CdTe is that it allows a choice of deposition technique, since 10% efficient cells have been produced by a variety of deposition methods. This allows us to choose a deposition technique according to its compatibility with a high throughput, reliable, low cost continuous manufacturing line.

After a thorough evaluation of different CdTe deposition processes from the standpoint of a high throughput continuous PV manufacturing line, we have decided to focus on Close Spaced Sublimation (CSS). We are presently developing the technology to produce 60 cm x 120 cm CdTe PV modules using CSS. Because of the demonstrated high deposition rate possible with CSS (4 microns/

min), a continuous PV manufacturing line based on this process can have a very large throughput (hundreds of megawatts per year). This in turn leads to dramatic reductions in capital, labor and overhead cost per unit. Another potential advantage of CSS is that because of the high substrate temperature used in deposition (around 600° C) the possibility arises of tempering the glass substrate immediately after the semiconducting material is deposited as an integral part of the PV manufacturing process. This can lead to later system cost savings by eliminating the need to laminate the PV module to tempered glass to obtain the strength required to withstand strong winds and hail in field installations. Details are given in Section III of the changes in our approach and the reasons for these changes. A description is also given of the manufacturing process for CdTe modules using CSS as we now envision it.

Many challenges remain before a high throughput manufacturing line is obtained. Section IV describes problems which must be solved before the manufacturing line can become a reality. In Section V a detailed program is described for dealing with the issues discussed in Section IV. The general approach is to proceed from the present developmental stage to a 5 MW semi-automated continuous manufacturing line in early 1993 and then to a 300 MW fully automated continuous production line in early 1995.

II. Description of Manufacturing Process

This section gives a description of the amorphous silicon PV manufacturing process as originally planned by SCI. This process description is given primarily for purposes of comparison, since the decision has now been made to change to thin film CdTe modules using CSS. Some aspects of the original plan are maintained; in particular the concept of an automated continuous production line is preserved.

Generally speaking, it is more difficult to achieve a continuous manufacturing process than a batch process. However, once a continuous process has been achieved and brought to high efficiency, it has several advantages over a batch process. One advantage is low labor cost per panel. In a continuous production line the PV modules are moved from one step to the next in the process automatically by conveyer belts or robotic feeders. No operators are needed to keep the modules moving. Some operators are needed to monitor the process and make equipment adjustments, but the number of operators required is less than that for a batch process with equivalent capacity.

Another advantage of a continuous line is that the throughput (number of modules produced per unit time) can be very large. We have found it straightforward to design a 15 MW line for deposition of aSi modules using PECVD. As will be seen in Section III with CdTe deposited by CSS, a continuous line in the range of hundreds of megawatts is feasible. High throughput translates to large reductions in capital, labor and overhead cost per unit.

Cross contamination is reduced in a continuous line compared to a batch process since different materials are deposited at different locations in the line that are isolated from each other. When the process has been optimized a continuous line gives good reproducibility, high quality, high yield, and a good way to fine-tune production parameters.

The following is a list of production processes and related equipment for the originally planned SCI continuous aSi line using PECVD. As previously indicated the decision has now been made to change to CdTe. The process changes resulting from this material change are covered later in Section III.

1) Purchase tin oxide coated glass.

   Certain suppliers of flat glass have recently added the capability of depositing transparent conducting oxide films on the glass as it exits the float line. We have tested some of this tin oxide coated glass and it appears to be suitable for PV devices. It is difficult to see how any other process for depositing a transparent conducting film on glass could be as low cost as this process. TCO coated glass is available with sheet resistance in the range 10-20 ohms/square. This coated glass is available in sizes much larger than the 60 cm x 120 cm substrates we plan to use. If for any reason it is not feasible or economically advantageous to use this TCO coated glass, we have the capability to design and build equipment suitable for continuous in-line coating of glass substrates with TCO for PV modules. Through our close association with Glasstech, Inc., we have already designed and built a TCO furnace using atmospheric pressure CVD for use in a 3MW continuous aSi PV module manufacturing line. (Harold McMaster, Chairman of the Board of Solar Cells, Inc., is also co-founder and Chairman of Glasstech, Inc.)

2) Cut and edge glass.
This can be done by the glass supplier or by us as part of the production line.

3) Screen print silver grid and bus bars.
We have purchased a Cugher Model G-2S automated screen printer with capability of printing sizes up to 60 cm x 120 cm.

4) Cure ink and temper glass.
This is done in a modification of a standard Glasstech tempering furnace. As mentioned above, there is a close association with Glasstech, Inc., because Harold McMaster, Chairman of the Board of Solar Cells, Inc., is also Chairman and co-founder of Glasstech, Inc. Glasstech is the world's largest supplier of equipment for tempering and bending glass for the automotive and architectural industries.

5) Laser scribe tin oxide for cell isolation.
We have purchased a U.S. Laser 4034-D Scribing System which uses a Nd YAG laser to produce light at 1064 nm and 532 nm to scribe lines on a 60 cm x 120 cm substrate at rates up to 10 inches per second.

6) Chemical wash and rinse.

7) Thin film aSi deposition and sputtering of back metal electrode.
This is a continuous, in line amorphous silicon plasma enhanced chemical vapor deposition system (PECVD). It consists of a series of 11 vacuum chambers, each approximately 9 feet long, 5 feet wide, and 1 foot deep. Each chamber is fully isolated with slit valves which open to transport substrates between chambers and close to eliminate cross contamination. The system automatically transports substrates up to 120 cm x 240 cm. There is a P deposition chamber for depositing p doped aSi by exposing the moving substrate to an RF discharge in a Silane/Diborane gas mixture. The p layer

is typically 300 Å thick. The intrinsic aSi layer is deposited in the I deposition chamber by exposing the moving substrate to an RF discharge in pure Silane. For the best electronic properties of the intrinsic aSi layer, the deposition rate must be less than about 5 Å/sec. Typically the i layer is about 3000 Å thick and is deposited at 3 Å/sec. Since the deposition time for the i layer is in the range 15-20 minutes this is normally the rate limiting step in a continuous line. In a nominal 10 MW line, five 9 ft. long I deposition chambers are required for a substrate transport speed of 2 feet/minute. The n doped aSi layer is deposited in the N deposition chamber by exposing the moving substrate to an RF discharge in a Silane/Phosphene mixture. The n layer is typically 500 Å thick. The P, I and N deposition chambers are separated by isolation chambers to prevent cross-contamination. A sputtering chamber is used to deposit the back metal electrode. The remaining chambers are either load locks or isolation chambers which are used to eliminate contamination in the process.

8) Back metal patterning.

An additional thin layer of aSi is deposited over the back metal electrode. This aSi is laser scribed and the back metal is chemically etched in the scribed area. An alternative patterning technique is to use photolithography followed by chemical etching.

9) Module test.

A custom test station measures the performance of each module.

10) Attach leads.

Wire leads are attached to bus bars by means of soldering or ultrasonic welding.

11) Encapsulation.

Encapsulation is accomplished by laminating to a second glass sheet with a polymer between the two pieces of glass. This method is known to be effective in providing protection against the elements in outdoor use. A second method to be pursued later is to spray on a UV curable coating and cure the coating by passing the substrate under a UV lamp system. The UV cured coating is expected to be lower cost than laminating, but it remains to be proven that it can provide adequate protection in outdoor use.

The process steps described above refer to the original aSi line as planned by SCI. The plan was to accomplish this in two stages: an initial prototype manufacturing line of about 1 MW capacity and a later fully automated continuous line of about 10 MW capacity. The throughput of the manufacturing line is limited by the PECVD deposition process. As explained earlier, the decision has now been made to use CdTe instead of aSi and CSS instead of PECVD. This leads to much greater throughput and lower cost, as will be discussed in the following section.

III. Changes in Process to Increase Throughput and Reduce Cost

In this section we describe changes made from the original plan as described in Section II, the reasons for the changes and the benefits of these changes. We also present a process description as we now plan to implement it.

The primary change is in the material for the thin film PV modules. We plan to use CdTe rather than aSi. There are several factors involved in this decision. Efficiency of a single junction CdTe device is better than aSi. Stability has been shown to be better for CdTe. An important factor is that CdTe is much less sensitive to the method of deposition than aSi. For aSi it is necessary to use PECVD to obtain reasonable efficiency. For CdTe many different deposition techniques have been used successfully. Cells with efficiency greater than 9% have been produced by electrodeposition, spraying from a slurry, close spaced sublimation, MOCVD, screen printing, vacuum evaporation, molecular beam epitaxy and laser induced deposition. This lack of sensitivity to deposition technique has a strong influence on the ease of making the transition from the laboratory to a manufacturing line. For aSi the problem of getting to a low cost manufacturing line is that of taking the one process that is known to work, PECVD, and scaling it up to a manufacturing line with as high a reliability and as low a cost as possible. For CdTe the problem is different. Since many deposition techniques can be used, it is possible to start at the manufacturing end and to evaluate the deposition techniques from the standpoint of compatibility with a reliable low cost manufacturing line. This makes it much easier to actually achieve a low cost reliable manufacturing process.

In considering the relative advantages and limitations of aSi and CdTe, we also considered double and triple junction aSi devices, which should be feasible in a continuous production line. Our analysis showed that, even though increased efficiency and stability are possible with double and triple junction aSi modules, increased material costs partially nullify these benefits. We were led to the conclusion that a single junction CdTe module would have a lower cost per Watt than a triple junction aSi module and would be easier to achieve.

Ultimately the preference for CdTe rests on cost. We have performed many cost analyses for PV manufacturing lines and installed PV systems. The results of these analyses depend on the assumptions that go into them, and since not all assumptions are based on experience, there is some uncertainty regarding the results. However, we have consistently found that, other things being equal, CdTe modules are lower cost than aSi modules.

An example of the results of a cost comparison between CdTe and aSi is given in Table I (Page 8). This shows the direct ma-

TABLE I

Direct materials Cost for Nominal 10 MW Production Line
($/Watt)

Production Year	aSi (Single)	aSi (Triple)	CdTe (Single)
1	$1.39	$1.87	$1.14
2	.88	1.21	.69
3	.77	.94	.54
4	.68	.80	.47
5	.63	.72	.42
6	.63	.69	.39

terials cost for three different continuous production lines of approximately the same size, capacity and capital cost. The direct materials cost is shown for each of the first six years of production for the three cases. It is clear that there is a substantial cost advantage for CdTe. The cost per Watt goes down with each year because of assumed improvements in uptime and yield. Details of this cost analysis are given in the Appendix which shows detailed drawings of each line, capital cost by item, assumptions regarding yield, uptime and efficiency, and an itemized breakdown of cost of materials, utilities, maintenance and panelization.

The advantages and limitations of different CdTe deposition techniques have been evaluated from the standpoint of a continuous, high-throughput, thin film, large area PV module production line. On the basis of this evaluation, the decision has been made to focus on close spaced sublimation (CSS). One of the main advantages of CSS is that it is capable of very high deposition rates. Small laboratory devices with efficiency greater than 10% have been produced by three separate research groups using CSS with deposition rates on the order of 4 microns/min. This high deposition rate can lead to a very high throughput continuous PV manufacturing line (300-500 MW), which in turn leads to dramatic reductions in capital, labor, and overhead cost per unit.

The throughput of a continuous manufacturing line is determined by the slowest step in the process. In continuous PV manufacturing lines that have been built so far, the limiting factor has been the deposition of the semi-conducting material. For p-i-n amorphous silicon PV modules the rate limiting step is in the deposition of the i layer aSi.

For an example of the effect of increased deposition rate on throughput, consider a comparison of two continuous lines: One that makes aSi modules using PECVD and another that makes CdTe modules using CSS.

A typical deposition rate for high quality aSi is 3-5 Å/sec. If we assume a deposition rate of 5 Å/sec and an i layer thickness of 5000 Å, it takes 16.6 minutes to deposit this i layer. In a continuous line a reasonable choice of parameters would be a substrate conveyer speed of 2 feet/min for a deposition length of 33 ft. The throughput could be increased by going faster, but this would require greater deposition length which means more hardware, lower reliability and higher capital cost for the line. If this line is producing 2 ft. x 4 ft. modules, the rate of production will be one module per minute (assuming modules travel in the 2 ft. direction with zero spacing). If we assume peak output power of 6 Watts/ft^2 this gives 48 Watts/module or 2880 Watts/hour. For a 6000 hour year (3 shifts), this gives 17.2 MW. If we degrade this by a factor of .7 for yield we have a 12.1 MW line.

For CSS deposition of CdTe a typical deposition rate is 4 microns/min or 667 Å/sec. If the CdTe layer is 1 micron thick, the deposition time is 15 sec. In a continuous line a reasonable choice of parameters would be a conveyer speed of 64 ft/min for a deposition length of 16 ft. This is roughly half the length of the deposition chambers for the aSi example. For 2 ft. x 4 ft modules the production rate is now 32 modules per minute. On the same assumptions as above (6 Watts/ft^2) we now have a 380 MW line.

If the capital cost of the deposition hardware in the two cases is comparable and the number of operators required to run this part of the line is comparable, it is clear that the cost per Watt of capital and labor is down by more than a factor of 10 in the CdTe case. Clearly this is an oversimplification since we are only considering one step in the process and are ignoring complicating factors. Nevertheless, two conclusions are clear:

1) The cost of the deposition process for CdTe can be much less than that for aSi.

2) Since the deposition of the semi-conducting material is no longer the rate limiting step, it now becomes reasonable to focus attention on other steps in the process (e.g., patterning) to remove bottlenecks to very high throughput (hundreds of megawatts/year).

Another advantage of CSS deposition of CdTe is that it should be possible to temper the glass substrate as an integral part of the PV manufacturing process. Glass is tempered by using forced air flow to rapidly cool it from a temperature of about 620°C to a temperature less than 300°C. For glass thickness 1/4" or less the cooling time is normally less than 10 seconds. This tempering process leaves compression layers on both surfaces of the glass, which greatly increases its strength. CSS works best at a temperature of about 600°C for the glass substrate. This is close to the temperature required to temper the glass (600°-620°C). Thus it should be possible to temper the glass by quickly quenching the glass immediately after deposition of the semi-conducting material. This still remains to be demonstrated, but if it can be done as part of the PV manufacturing process it offers the possibility of further cost reduction by eliminating the need to laminate the PV module to tempered glass to obtain the strength required to withstand strong winds and hail in field installations. There are technical challenges in handling 600°C glass at high speed in a continuous production line, but similar challenges are handled routinely in glass tempering lines. As mentioned earlier, Glasstech, Inc., is the leading company in the world in designing and building tempering furnaces, and there is a close association between Solar Cells, Inc., and Glasstech, Inc.

Section II gave a description of the manufacturing process as originally planned for aSi. With the change to CdTe the semiconductor material deposition step will be changed to the following:

7a) Thin film CdS, CdTe and ZnTe deposition.

This is a continuous, in-line deposition system. Glass substrates are fed into a first chamber where they are heated to approximately 600°C. In subsequent chambers they pass over high temperature sources of CdS, CdTe and ZnTe. The substrates are then tempered by rapid cooling by forced flow of gas.

The other process steps as given in Section II remain the same except that since the semi-conducting material deposition is now so much faster with CSS, emphasis is placed on examining the other steps in the process to make them compatible with a very high throughput line. One of the objectives of the cost reduction program described later in Section V is to make whatever improvements are required in other steps in the process to make them compatible with a very high throughput line. It should be noted that these improvements will have value for other high throughput production lines even if the deposition process is different.

The long range potential benefits of the changes described in this section are very high production rates (hundreds of megawatts per year) and very low cost (less than $1.00 per Watt), both of which are required to enter the utility market.

This low cost potential is illustrated in Table II (page 12) which compares the cost of manufacturing modules in a mature production facility under four different sets of assumptions:

10 MW single junction aSi line	-	$1.20/Watt
10 MW triple junction aSi line	-	$1.11/Watt
10 MW single junction CdTe line	-	$0.74/Watt
200 MW single junction CdTe line	-	$0.42/Watt

TABLE II

Cost Comparison for Mature Production Line

Cost per Watt

	aSi (Single) 10 MW	aSi (Triple) 10 MW	CdTe (Single) 10 MW	CdTe (Single) 200 MW
Direct Material Cost	$0.63	$0.69	$0.39	$0.30
Utilities	.02	.02	.02	.01
Maintenance	.01	.01	.00	.00
Panelization	.10	.07	.06	.05
Amortization of Capital (10 years)	.11	.10	.06	.02
Direct Labor with Benefits	.08	.05	.05	.01
Factory Overhead	.18	.12	.11	.02
General Administrative	.07	.05	.05	.01
Total Panel Cost	$1.20	$1.11	$0.74	$0.42

IV. Problems Requiring Solution

In this section a number of problems are described which must be overcome before a reliable high throughput manufacturing line to produce low cost modules can be obtained.

1) The CSS deposition process must be scaled up to large area modules. The CSS deposition process has been demonstrated only for small areas on the order of a few square centimeters. Before constructing a production line based on CSS, it must be proven that it is possible to obtain uniform deposition over areas on the order of 60 cm x 120 cm. There are many questions related to deposition parameters that must be resolved.

2) The CSS process must be adapted to large area substrates moving at rapid production speeds on the order of 1 ft./second. Since the glass substrates will be at a temperature on the order of 600°C they must be moved fairly rapidly to prevent deformation. The deposition rate is high enough to deposit 1 to 2 microns of CdTe on a substrate moving at 1 ft./sec. with a deposition chamber of reasonable length. However, there are many questions which must be answered relating to method of transporting substrates, materials for deposition chambers and source material boats, and optimum geometry to obtain uniform coatings of controlled thickness on large area substrates.

3) The question of tempering the glass substrate as an integral part of the PV manufacturing process must be resolved. The substrate temperature for CSS deposition is close to the proper temperature to which the glass must be heated for effective tempering, so this should be possible. However, this has never been done for any size substrate and this part of the process remains to be proven. Many questions must be answered relative to gas flow, geometry, substrate speed and time since deposition of semiconducting material. The effect of tempering on the semiconducting material and PV device properties must be understood.

4) The advantages and limitations of different device configurations must be explored and understood. The planned configuration is glass superstrate/TCO/CdS/CdTe/ZnTe/Back electrode/Encapsulation. Variations on this configuration must be explored from the standpoint of efficiency, adhesion, simplicity and sensitivity to changes in the process parameters.

5) The details of the TCO layer must be resolved. The initial plan is to use glass coated with tin oxide at the exit of the float line. However, it remains to be proven that TCO deposited in this way leads to acceptable efficiency for large area modules made using CSS. TCO coatings are available in different thicknesses which give different combinations of sheet resistance and optical transmission. These must be evaluated to be able to choose the most cost effective thickness.

6) Patterning of 60 cm x 120 cm modules must be evaluated to identify a patterning method which gives good area utilization and is compatible with a very high throughput production line. Screen printing, laser scribing and photolithographic patterning are some of the options to be evaluated. Some non-conventional methods of patterning may be required to keep up with the high throughput.

7) All of the process steps in the continuous production line must be re-examined in light of a very high throughput. Process steps such as glass washing, substrate transportation, metallization, automatic test stations, encapsulation and accumulation systems must be reviewed and re-designed to make them compatible with high throughputs of several hundreds of megawatts per year.

8) A reliable, cost effective encapsulation method must be developed. It is known that laminating to a second glass plate works quite well and gives good protection in outdoor use. However, this method of encapsulation is unlikely to be the preferred long-term low cost method. Other methods such as uv cured sprayed on polymers must be evaluated.

9) One of the most important parts of a continuous PV manufacturing line is the control system which controls the process and allows the operators to interface with the process. A balance must be obtained between adequate control, flexibility, reliability and simplicity. There is no substitute for actual production experience with a computer control system to evaluate it and improve it.

10) An important element in the overall system is the way in which individual PV modules are combined into panels suitable for installation in a solar generating field. This panelization process will be part of the PV module manufacturing process to save labor in the field installation. Much remains to be learned about the most cost effective way to achieve panelization. Experience from actual field installations will be helpful in leading to improvements in panelization techniques.

11) PV modules must be tested under conditions which come close to actual conditions encountered in field installations. Experience with actual field installations will be helpful in supplementing these results obtained with environmental chambers.

12) In order to achieve low cost PV modules, it is necessary to have a high throughput, high yield, high uptime manufacturing line. To obtain high yield and high uptime, it is essential that appropriate quality assurance and process improvement procedures should be developed and implemented. Production personnel must be trained in the necessary skills such as statistical process control. To do this properly requires actual production experience.

13) It is necessary to develop a detailed health, safety and environmental program to protect the health and safety of the production personnel and to avoid polluting the environment. The details of this program will depend on the details of the production process.

V. Program to Solve Problems

In this section, we describe a program to solve the problems listed in Section IV and lead to the achievement of low cost PV modules. The program we envision has four major elements:

1.) Develop the equipment and processes necessary for a high throughput continuous manufacturing line for CSS deposition of 60cm x 120cm thin film CdTe modules. This development program is underway now and we expect it to continue for at least three years. Early emphasis is on scaling up and optimizing the process. Later work will be aimed at increasing module efficiency and improving process yield.

2.) Construct and operate a moderate capacity (approximately 5MW) semi-automated continuous PV manufacturing line for 60cm x 120cm CdTe modules. This allows us to prove and improve our processes in a production environment. Selling modules for utility use will provide feedback on product performance and provide the cash flow required to keep the program financially healthy. Our timetable calls for beginning construction of this line in April, 1992 and beginning production of PV modules in April, 1993.

3.) Install a solar generating field (up to 5MW) using the PV modules produced on the semi-automated continuous line. This provides realistic testing of the PV modules in outdoor use in a generating field tied to a utility grid. This step will provide valuable feedback on the suitability of product design. The panelization design will be tested from the overall system standpoint, including the labor required for field installation. It is expected that this initial field installation will lead to some modifications in PV module design and possibly panelization modifications to reduce overall installed system cost. We plan to start to install this solar generating field in April, 1993 and start to generate electrical power in October, 1993.

4.) Construct and operate a very high throughput continuous manufacturing line. The capacity of this line is still to be determined but is expected to be in the range of 200-500 megawatts. The CSS deposition process is capable of 500 megawatts; the actual capacity of the line will be determined by other steps in the process. This will be determined by examining the cost effectiveness of increasing the speeds of each step in the process to different values in the range of 100-500 megawatts. This will be one of the important results to come out of this program - an experimentally determined optimum throughput in the range of 100-500 MW. When this very high throughput fully automated continuous production line is achieved, the PV module cost is expected to be approximately $.50/Watt. Total installed system cost for a solar generating field using these modules is expected to be less than $1.50/Watt. Our time table calls for preliminary design work to begin on this line in April, 1993, construction of the line to begin in October, 1993 and production of PV modules to begin in January, 1995.

Specific tasks required to carry out this program are listed in Tables III, IV, and V (pages 18-20). Table III lists the tasks for the first year of the program. All of the effort in the first year is devoted to designing and constructing the 5MW Initial Production Line. Tables IV and V give similar lists of tasks for the second and third years of the program. The effort in the second year is divided between improving the productivity of the Initial Production Line, installing the solar generating field and preliminary design work on the High Throughput Production Line. The effort in the third year is devoted entirely to the High Throughput Production Line.

TABLE III

Tasks for First Year

1.) Perform tests required to define production tempering system and CdTe deposition system.

2.) Perform tests required to define production patterning and interconnection scheme.

3.) Design, order and install wash stations.

4.) Design, build, install and test substrate transport conveyers.

5.) Design, build, install, test and de-bug glass preheat system.

6.) Design, order, install, test and de-bug TCO patterning equipment.

7.) Design, build, install, test and de-bug equipment for deposition of CdS, CdTe and ZnTe.

8.) Design, build, install, test and de-bug quench/tempering system.

9.) Design, order, install, test and de-bug equipment for patterning semiconducting material.

10.) Design, build, install, test and de-bug equipment for automatic pinhole repair.

11.) Design, build, install, test and de-bug metallization system.

12.) Design, order, install, test and de-bug equipment for metallization patterning.

13.) Perform tests required to define production encapsulation system.

14.) Design, build, install, test and de-bug encapsulation equipment.

15.) Design, build, install, test and de-bug automatic test stations.

16.) Perform tests required to define panel framework and interconnects for production panelization system.

17.) Design, build, and install panelization station.

18.) Install electrical, mechanical, HVAC, DI water, chiller and drainage facilities for production line.

19.) Develop total Quality Assurance program.

20.) Develop health, safety and environmental program.

TABLE IV

Tasks for Second Year

1.) Run Initial Production Line in continuous mode to de-bug and improve process.

2.) Improve efficiency of production modules.

3.) Review design of all BOS components for solar field.

4.) Acquire and prepare land for solar field.

5.) Specify, order install and commission power conditioning unit for solar field.

6.) Install support structure for solar field.

7.) Install electrical wiring for solar field.

8.) Design high throughput patterning equipment for High Throughput Production Line (HTPL).

9.) Design panelization system for HTPL.

10.) Design substrate transportation system for HTPL.

11.) Design substrate cleaning systems for HTPL.

12.) Design glass pre-heat furnace for HTPL.

12.) Design deposition system for CdS, CdTe, and ZnTe for HTPL.

14.) Design quench station for HTPL.

15.) Design metallization system for HTPL.

16.) Design encapsulation system for HTPL.

17.) Design automatic module test stations for HTPL.

18.) Design accumulator systems for HTPL.

19.) Design control system for HTPL.

20.) Set up preliminary Quality program for HTPL.

21.) Set up preliminary health, safety and environmental program for HTPL.

Table V

Tasks for Third Year

1) Acquire building for High Throughput Production Line (HTPL) and prepare electrical, mechanical, HVAC and other facilities.

2) Order, install and de-bug glass unloading system for HTPL.

3) Build, install, test and de-bug glass transportation system for HTPL.

4) Install and de-bug substrate cleaning stations for HTPL.

5) Order, install, test and de-bug patterning equipment for HTPL.

6) Build, install, test and de-bug glass pre-heat furnace for HTPL.

7) Build, install, test and de-bug deposition system for CdS, CdTe and ZnTe for HTPL.

8) Build, install, test and de-bug quench station for HTPL.

9) Build, install, test and de-bug metallization system for HTPL.

10) Build, install, test and de-bug encapsulation equipment for HTPL.

11) Build, install, test and de-bug automatic module test stations for HTPL.

12) Build and install panelization station for HTPL.

13) Build, install, test and de-bug accumulator systems for HTPL.

14) Complete design, build, install, test and de-bug computer control system for HTPL.

15) Train personnel to operate HTPL.

16) Set up and implement total quality program for HTPL.

17) Set up and implement health, safety and environmental program for HTPL.

18) De-bug HTPL in continuous mode.

19) Identify production problems and bottlenecks.

20) Improve productivity to acceptable level.

VI. SUMMARY

A development/manufacturing program is described for achieving PV modules at a cost less than \$.50/Watt and solar generating fields at a total installed system cost of less than \$1.50/Watt. The basic approach is to construct a fully automated continuous production line based on close spaced sublimation (CSS) deposition of CdTe to produce 60cm x 120cm thin film PV modules. The high deposition rate possible with CSS opens up the possibility of obtaining very high throughput in the range of hundreds of megawatts per year. This leads to dramatic reductions in the capital, labor and overhead cost per unit.

The program includes a development phase, and initial production line of about 5MW/year capacity, a 5MW solar generating field and a high throughput production line with capacity in the range of hundreds of megawatts per year. The high substrate temperature used in CSS (600° C) allows the possibility of tempering the glass substrate as an integral part of the PV manufacturing process. This leads to further system cost savings by eliminating the need to laminate the PV module to tempered glass to obtain the strength required to withstand strong winds and hail in field installations.

The high deposition rate possible with CSS means that the deposition of the semiconducting material is no longer the rate limiting step in a continuous PV manufacturing line. This shifts the emphasis to improving the other process steps (glass washing, substrate transportation, metallization, patterning, automatic test stations, encapsulation) to make them compatible with high throughputs of several hundreds of megawatts per year. These improvements have value for other high throughput production lines even if the deposition process is different.

VII. Appendix

This appendix gives details of a cost analysis of three different continuous PV module production lines; one for single junction aSi, one for triple junction aSi, and one for single junction CdTe. Some of the results of this analysis were summarized in Tables I and II. For each case a drawing is shown of the configuration of the continuous production line. Tables of itemized capital cost are given for each piece of equipment in each of the three lines. The numbers in the capital equipment lists correspond to the numbers in the drawings of the lines. Assumptions are shown for average module efficiency, yield and uptime for each of the first six years of production on each line. Assumptions are shown for direct, factory and administrative labor. Projections are given for square feet produced and Watts produced in each year. Two products are considered: 2 ft. x 4 ft. flat utility modules and curved PV car roof modules. The assumed mix of these two products is given for each year. Each of the three lines is nominally a 10 MW line but changes with time in efficiency, yield, uptime and product mix result in a capacity of less than 10 MW in the first year and greater than 10MW in later years. Results are shown for detailed breakdown of materials and other costs for each line for each of the six years.

aSi Single Junction

aSi Single Junction

Projections and Assumptions

Time from decision to begin to first module: 15 months

Time from decision to begin to acceptance tests: 18 months

Projections for efficiency, yield and uptime:

Year	Efficiency	Yield	Uptime
1	5.0%	60%	50%
2	6.0%	80%	65%
3	6.5%	85%	75%
4	7.0%	89%	78%
5	7.5%	90%	80%
6	7.5%	90%	80%

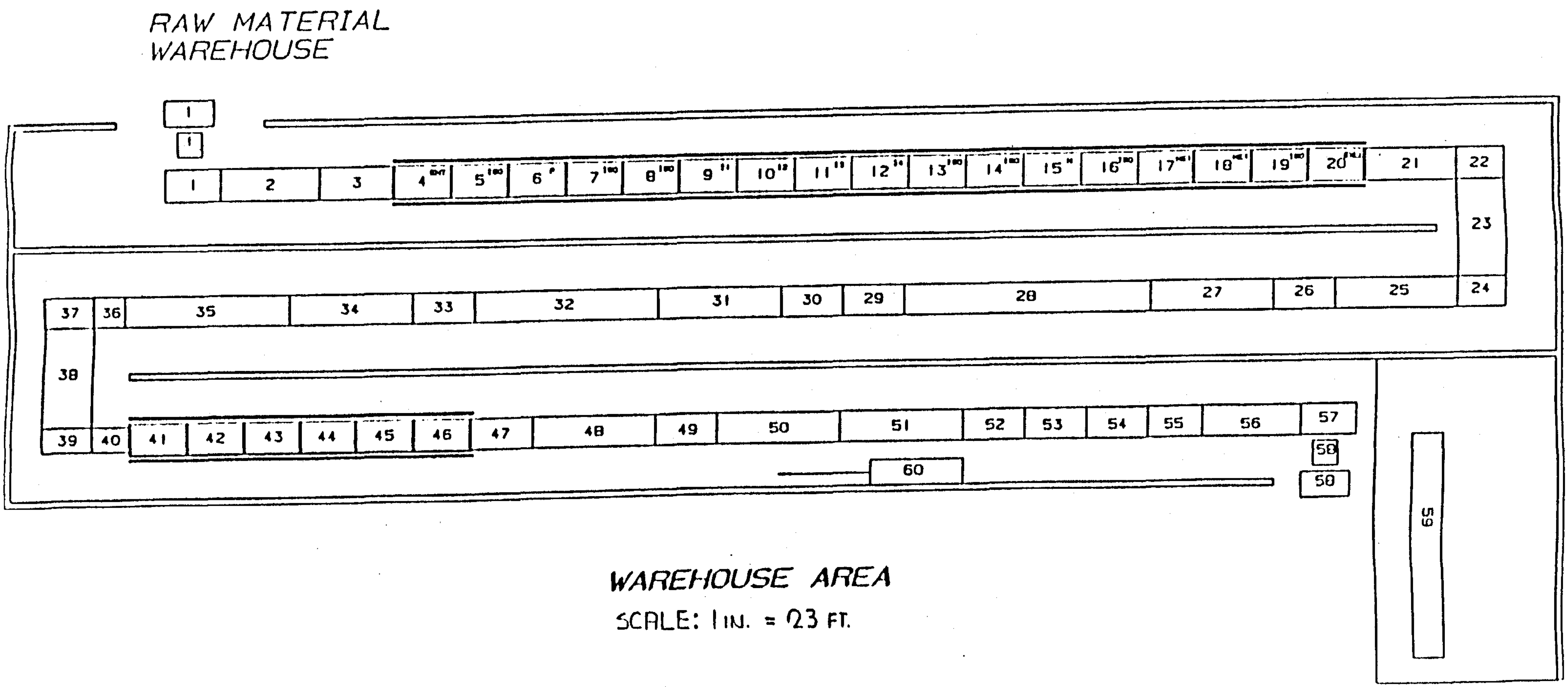
Projections for number of units produced, square feet produced, and Watts produced:

	Car Roof Modules			Utility Modules (2'x4')			Total		
Year	Units	Sq.Ft.	Power (MW)	Units	Sq.Ft.	Power (MW)	Units	Sq.Ft.	Power (MW)
1	0	0	0	128,880	1,031,040	4.79	128,880	1,031,040	4.79
2	0	0	0	223,392	1,787,136	9.97	223,392	1,787,136	9.97
3	20,000	82,000	0.50	253,870	2,030,960	12.30	235,870	2,112,960	12.80
4	50,000	205,000	1.33	248,228	1,985,824	12.90	298,228	2,190,824	14.20
5	100,000	410,000	2.86	209,312	1,674,496	11.70	309,312	2,084,496	14.60
6	100,000	410,000	2.86	209,312	1,674,496	11.70	309,312	2,084,496	14.60

Projections for Labor:

Year	Direct Labor	Factory Labor	Admin. Labor
1	36	19	11
2	36	19	11
3	36	19	11
4	36	19	11
5	36	19	11
6	36	19	11

PHASE II LINE LAYOUT PROPOSED
a:Si SINGLE JUNCTION



SCALE: 1 IN. = 23 FT.

SCI PHASE II
EQUIPMENT COST ESTIMATE
AMORPHOUS SILICON PROCESS
SINGLE JUNCTION

Description	Cost to Purchase New
1) Robotic load station	120,000
2) Washer	150,000
3) Preheat/entrance conveyor	100,000
4) - 20) Pin line:	
Vacuum Chambers	
Stainless	185,130
Fittings	43,350
Heaters	18,700
Support Frame	19,040
Machining	399,500
Assembly	17,000
Transport	
Stainless	32,164
Bearings	28,220
Coating	4,080
Belts	4,250
Machining	129,200
Assembly	11,900
RF Electrodes	
Stainless	6,006
Fittings	4,800
Machining	18,000
Slit Valves	296,800
Pumps/Valves/Piping	821,403
RF Power	173,000
DC Power	170,000
Cathodes	228,000
Metallization Targets	8,000
21) Test	60,000
22) Square turn	15,000
23) Cool/Glass bank	60,000
24) Square turn	15,000
25) Photoresist spray	200,000
26) Expose	250,000
27) Develop/rinse	110,000
28) Triple etch/rinse/dry	508,000
29) Test	60,000
30) Expose	250,000
31) Develop/rinse	110,000
32) Double etch/rinse/dry	353,000
33) Expose	250,000
34) Develop/rinse/dry	110,000
35) Reflow bake	100,000
36) Spacer conveyor	10,000
37) Square turn	15,000
38) Conveyor/Glass bank	60,000
39) Square turn	15,000

40) Entrance conveyor	10,000
41) - 46) Metallization line:	
Vacuum Chambers	
Stainless	65,340
Fittings	15,300
Heaters	6,600
Support Frame	6,720
Machining	141,000
Assembly	6,000
Transport	
Stainless	11,352
Bearings	9,960
Coating	1,440
Belts	1,500
Machining	45,600
Assembly	4,200
Slit Valves	84,800
Pumps/Valves/Piping	297,797
DC Power	170,000
Cathodes	228,000
Metallization Targets	8,000
47) Exit conveyor	10,000
48) Photoresist spray	200,000
49) Expose	250,000
50) Develop/rinse	110,000
51) Single etch/rinse/dry	170,000
52) UV Expose	60,000
53) Photoresist strip	110,000
54) Test station	100,000
55) Connect external leads	50,000
56) Encapsulant	150,000
57) Exit conveyor	10,000
58) Robot unload station	120,000
59) Laminating equipment	200,000
60) Carrier return/clean	150,000
Control Hardware/Software	702,000
Gas handling	1,500,000
Glass handling	100,000
Environment test chamber	45,000
Lab test equipment	120,000
U.P.S.	100,000
Spare parts	500,000
Carriers	50,000
Labor (installation & design)	1,500,000
Total	$12,960,152

Building and Related Cost

	Estimated Cost
1) Building	1,600,000
2) Safety equipment	30,000
3) Phone systems	10,000
4) Fire alarm system	10,000
5) Clean rooms	360,000
6) HVAC	375,000
7) Machine shop	80,000
8) Tow motors	50,000
9) Utilities	180,000
10) Office equipment	20,000
11) Chemical Treatment	250,000
12) Gas outdoor storage house	20,000
13) DI water system	230,000
14) Compressed air	40,000
Total	$3,255,000

SCI Phase II Amorphous Silicon Single Junction	Grand Total	$16,215,152

SCI PHASE II

PRODUCTION COST ESTIMATE

AMORPHOUS SILICON - SINGLE JUNCTION

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
AVE UPTIME	50%	65%	75%	78%	80%	80%
AVE YIELD	60%	80%	85%	89%	90%	90%
	\$/ft^2	\$/ft^2	\$/ft^2	\$/ft^2	\$/ft^2	\$/ft^2
MATERIALS:						
3/16" 20 ohm GLASS	\$2.133	\$1.600	\$1.506	\$1.438	\$1.422	\$1.422
GLASS CUT/TEMPER	\$1.000	\$0.750	\$0.706	\$0.674	\$0.667	\$0.667
WASHING DETERGENT	\$0.001	\$0.001	\$0.001	\$0.001	\$0.001	\$0.001
PROCESS GASES:						
SILANE	\$0.932	\$0.699	\$0.658	\$0.628	\$0.621	\$0.621
TRIMETHYLBORON	\$0.081	\$0.061	\$0.057	\$0.055	\$0.054	\$0.054
PHOSPHINE	\$0.095	\$0.071	\$0.067	\$0.064	\$0.063	\$0.063
METHANE	\$0.008	\$0.006	\$0.006	\$0.006	\$0.005	\$0.005
ARGON	\$0.030	\$0.022	\$0.021	\$0.020	\$0.020	\$0.020
H2/He	\$0.002	\$0.002	\$0.001	\$0.001	\$0.001	\$0.001
NITROGEN	\$0.020	\$0.015	\$0.014	\$0.013	\$0.013	\$0.013
SF6	\$0.010	\$0.008	\$0.007	\$0.007	\$0.007	\$0.007
SPUTTERING TARGETS	\$0.633	\$0.475	\$0.447	\$0.427	\$0.422	\$0.422
PHOTORESIST	\$0.707	\$0.530	\$0.499	\$0.477	\$0.471	\$0.471
DEVELOPER	\$0.286	\$0.215	\$0.202	\$0.193	\$0.191	\$0.191
ETCHANTS	\$0.060	\$0.045	\$0.042	\$0.041	\$0.040	\$0.040
ARTWORK	\$0.023	\$0.017	\$0.016	\$0.016	\$0.016	\$0.016
UV ENCAPSULANTS	\$0.220	\$0.165	\$0.155	\$0.148	\$0.146	\$0.146
PACKAGING	\$0.225	\$0.225	\$0.225	\$0.225	\$0.225	\$0.225
SUBTOTAL	\$6.47	\$4.91	\$4.63	\$4.43	\$4.39	\$4.39
UTILITIES:						
ELECTRICITY	\$0.197	\$0.148	\$0.139	\$0.133	\$0.132	\$0.132
GAS HEATING	\$0.005	\$0.004	\$0.004	\$0.004	\$0.004	\$0.004
WATER	\$0.053	\$0.040	\$0.038	\$0.036	\$0.036	\$0.036
SUBTOTAL	\$0.26	\$0.19	\$0.18	\$0.17	\$0.17	\$0.17
MAINTENANCE:						
PUMP REBUILD:	\$0.021	\$0.016	\$0.015	\$0.014	\$0.014	\$0.014
PUMP OIL	\$0.028	\$0.021	\$0.020	\$0.019	\$0.018	\$0.018
FILTERS	\$0.010	\$0.007	\$0.007	\$0.007	\$0.006	\$0.006
SUBTOTAL	\$0.06	\$0.04	\$0.04	\$0.04	\$0.04	\$0.04
BEFORE PANELIZATION	\$6.78	\$5.14	\$4.85	\$4.64	\$4.60	\$4.60
PANELIZATION:						
STEEL FRAMING	\$0.693	\$0.520	\$0.490	\$0.468	\$0.462	\$0.462
WIRE	\$0.089	\$0.067	\$0.063	\$0.060	\$0.059	\$0.059
CONNECTORS	\$0.077	\$0.058	\$0.054	\$0.052	\$0.051	\$0.051
RUBBER CHANNEL	\$0.145	\$0.109	\$0.103	\$0.098	\$0.097	\$0.097
DIODES	\$0.057	\$0.043	\$0.041	\$0.039	\$0.038	\$0.038
SUBTOTAL	\$1.06	\$0.80	\$0.75	\$0.72	\$0.71	\$0.71
TOTAL	\$7.84	\$5.94	\$5.60	\$5.36	\$5.31	\$5.31

SCI PHASE II
PRODUCTION COST ESTIMATE
AMORPHOUS SILICON - SINGLE JUNCTION

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
AVE UPTIME	50%	65%	75%	78%	80%	80%
AVE YIELD	60%	80%	85%	89%	90%	90%
AVE EFFICIENCY	5.0%	6.0%	6.5%	7.0%	7.5%	7.5%
	$/WATT	$/WATT	$/WATT	$/WATT	$/WATT	$/WATT
MATERIALS:						
3/16" 20 ohm GLASS	$0.459	$0.287	$0.249	$0.221	$0.204	$0.204
GLASS CUT/TEMPER	$0.215	$0.135	$0.117	$0.104	$0.096	$0.096
WASHING DETERGENT	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
PROCESS GASES:						
SILANE	$0.201	$0.125	$0.109	$0.097	$0.089	$0.089
TRIMETHYLBORON	$0.017	$0.011	$0.009	$0.008	$0.008	$0.008
PHOSPHINE	$0.020	$0.013	$0.011	$0.010	$0.009	$0.009
METHANE	$0.002	$0.001	$0.001	$0.001	$0.001	$0.001
ARGON	$0.006	$0.004	$0.003	$0.003	$0.003	$0.003
H2/He	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
NITROGEN	$0.004	$0.003	$0.002	$0.002	$0.002	$0.002
SF6	$0.002	$0.001	$0.001	$0.001	$0.001	$0.001
SPUTTERING TARGETS	$0.136	$0.085	$0.074	$0.066	$0.061	$0.061
PHOTORESIST	$0.152	$0.095	$0.083	$0.073	$0.068	$0.068
DEVELOPER	$0.062	$0.038	$0.033	$0.030	$0.027	$0.027
ETCHANTS	$0.013	$0.008	$0.007	$0.006	$0.006	$0.006
ARTWORK	$0.005	$0.003	$0.003	$0.002	$0.002	$0.002
UV ENCAPSULANTS	$0.047	$0.030	$0.026	$0.023	$0.021	$0.021
PACKAGING	$0.048	$0.040	$0.037	$0.035	$0.032	$0.032
SUBTOTAL	$1.39	$0.88	$0.77	$0.68	$0.63	$0.63
UTILITIES:						
ELECTRICITY	$0.042	$0.027	$0.023	$0.020	$0.019	$0.019
GAS HEATING	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001
WATER	$0.011	$0.007	$0.006	$0.006	$0.005	$0.005
SUBTOTAL	$0.06	$0.03	$0.03	$0.03	$0.02	$0.02
MAINTENANCE:						
PUMP REBUILD:	$0.005	$0.003	$0.002	$0.002	$0.002	$0.002
PUMP OIL	$0.006	$0.004	$0.003	$0.003	$0.003	$0.003
FILTERS	$0.002	$0.001	$0.001	$0.001	$0.001	$0.001
SUBTOTAL	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
BEFORE PANELIZATION	$1.46	$0.92	$0.80	$0.71	$0.66	$0.66
PANELIZATION:						
STEEL FRAMING	$0.149	$0.093	$0.081	$0.072	$0.066	$0.066
WIRE	$0.019	$0.012	$0.010	$0.009	$0.009	$0.009
CONNECTORS	$0.017	$0.010	$0.009	$0.008	$0.007	$0.007
RUBBER CHANNEL	$0.031	$0.020	$0.017	$0.015	$0.014	$0.014
DIODES	$0.012	$0.008	$0.007	$0.006	$0.005	$0.005
SUBTOTAL	$0.23	$0.14	$0.12	$0.11	$0.10	$0.10
TOTAL	$1.69	$1.06	$0.92	$0.82	$0.76	$0.76

aSi Triple Junction

aSi Triple Junction

Projections and Assumptions

Time from decision to begin to first module: 18 months

Time from decision to begin to acceptance tests: 24 months

Projections for efficiency, yield and uptime:

Year	Efficiency	Yield	Uptime
1	6.0%	60%	50%
2	7.0%	80%	65%
3	8.5%	85%	75%
4	9.0%	89%	78%
5	10.5%	90%	80%
6	11.5%	90%	80%

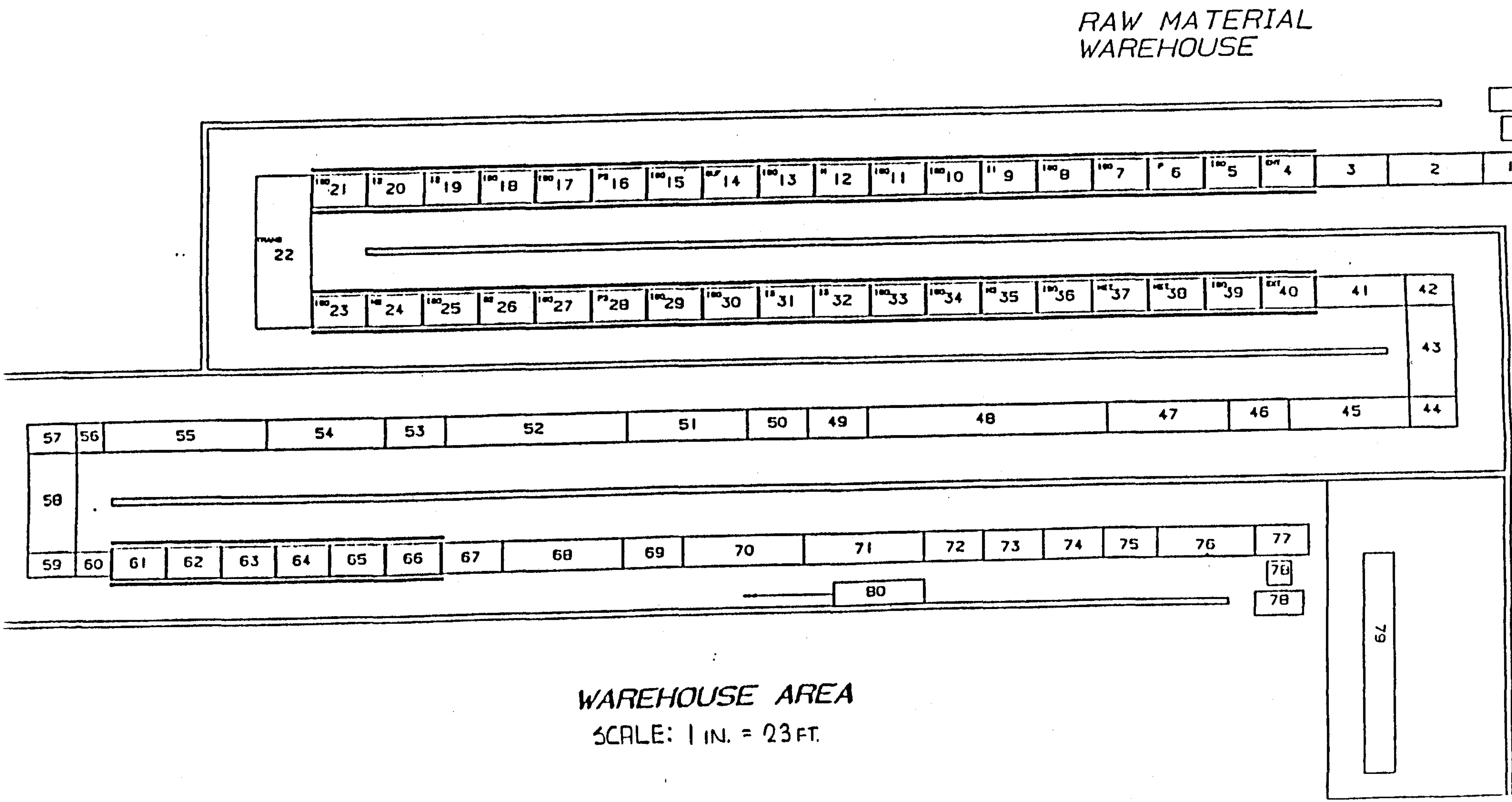
Projections for number of units produced, square feet produced, and Watts produced:

	Car Roof Modules			Utility Modules (2'x4')			Total		
Year	Units	Sq.Ft.	Power (MW)	Units	Sq.Ft.	Power (MW)	Units	Sq.Ft.	Power (MW)
1	0	0	0	128,880	1,031,040	5.75	128,880	1,031,040	5.75
2	0	0	0	223,392	1,787,136	11.60	223,392	1,787,136	11.60
3	20,000	82,000	0.65	253,870	2,030,960	16.00	235,870	2,112,960	16.70
4	50,000	205,000	1.81	248,228	1,985,824	17.50	298,228	2,190,824	19.30
5	100,000	410,000	4.00	209,312	1,674,496	16.30	309,312	2,084,496	20.30
6	100,000	410,000	4.18	209,312	1,674,496	17.10	309,312	2,084,496	21.30

Projections for Labor:

Year	Direct Labor	Factory Labor	Admin. Labor
1	42	19	11
2	42	19	11
3	42	19	11
4	42	19	11
5	42	19	11
6	42	19	11

PHASE II LINE LAYOUT PROPOSED
a:Si TRIPLE JUNCTION



WAREHOUSE AREA

SCALE: 1 IN. = 23 FT.

SCI PHASE II
EQUIPMENT COST ESTIMATE
AMORPHOUS SILICON PROCESS
TRIPLE JUNCTION

Description	Cost to Purchase New
1) Robotic load station	120,000
2) Washer	150,000
3) Preheat/entrance conveyor	100,000
4) - 40) Pin line:	
Vacuum Chambers	
Stainless	392,040
Fittings	91,800
Heaters	39,600
Support Frame	40,320
Machining	846,000
Assembly	36,000
Transport	
Stainless	68,112
Bearings	59,760
Coating	8,640
Belts	9,000
Machining	273,600
Assembly	25,200
RF	
Stainless	13,013
Fittings	10,400
Machining	39,000
Transfer Chamber	185,000
Slit Valves	742,000
Pumps/Valves/Piping	1,561,971
RF Power	195,000
DC Power	255,000
Cathodes	342,000
Metallization Targets	28,000
41) Test	60,000
42) Square turn	15,000
43) Cool/Glass bank	60,000
44) Square turn	15,000
45) Photoresist spray	200,000
46) Expose	250,000
47) Develop/rinse	110,000
48) Triple etch/rinse/dry	508,000
49) Test	60,000
50) Expose	250,000
51) Develop/rinse	110,000
52) Double etch/rinse/dry	353,000
53) Expose	250,000
54) Develop/rinse/dry	110,000
55) Reflow bake	100,000
56) Spacer conveyor	10,000
57) Square turn	15,000
58) Conveyor/Glass bank	60,000
59) Square turn	15,000

60) Entrance conveyor	10,000
61) - 66) Metallization line:	
Vacuum Chambers	
Stainless	65,340
Fittings	15,300
Heaters	6,600
Support Frame	6,720
Machining	141,000
Assembly	6,000
Transport	
Stainless	11,352
Bearings	9,960
Coating	1,440
Belts	1,500
Machining	45,600
Assembly	4,200
Slit Valves	84,800
Pumps/Valves/Piping	297,797
DC Power	170,000
Cathodes	228,000
Metallization Targets	8,000
67) Exit conveyor	10,000
68) Photoresist spray	200,000
69) Expose	250,000
70) Develop/rinse	110,000
71) Single etch/rinse/dry	170,000
72) UV Expose	120,000
73) Photoresist Strip	110,000
74) Test station	100,000
75) Connect external leads	50,000
76) Encapsulant	150,000
77) Exit conveyor	10,000
78) Robot unload station	120,000
79) Laminating equipment	200,000
80) Carrier return/clean	85,000
Control Hardware/Software	1,180,000
Gas handling	2,360,000
Glass handling	100,000
Environment test chamber	45,000
Lab test equipment	120,000
U.P.S.	100,000
Spare parts	500,000
Carriers	50,000
Labor (installation & design)	2,000,000
Total	$17,436,065

Building and Related Cost

		Estimated Cost
1)	Building	1,600,000
2)	Safety equipment	30,000
3)	Phone systems	10,000
4)	Fire alarm system	10,000
5)	Clean rooms	360,000
6)	HVAC	597,000
7)	Machine shop	80,000
8)	Tow motors	50,000
9)	Utilities	180,000
10)	Office equipment	20,000
11)	Chemical Treatment	250,000
12)	Gas outdoor storage house	20,000
13)	DI water system	230,000
14)	Compressed air	40,000
	Total	$3,477,000

SCI Phase II
Amorphous Silicon Grand Total $20,913,065
Triple Junction

SCI PHASE II
PRODUCTION COST ESTIMATE
AMORPHOUS SILICON - TRIPLE JUNCTION

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
AVE UPTIME	50%	65%	75%	78%	80%	80%
AVE YIELD	60%	80%	85%	89%	90%	90%
	\$/ft^2	\$/ft^2	\$/ft^2	\$/ft^2	\$/ft^2	\$/ft^2
MATERIALS:						
3/16" 20 ohm GLASS	\$2.133	\$1.600	\$1.506	\$1.438	\$1.422	\$1.422
GLASS CUT/TEMPER	\$1.000	\$0.750	\$0.706	\$0.674	\$0.667	\$0.667
WASHING DETERGENT	\$0.001	\$0.001	\$0.001	\$0.001	\$0.001	\$0.001
PROCESS GASES:						
SILANE	\$1.556	\$1.167	\$1.098	\$1.049	\$1.037	\$1.037
TRIMETHYLBORON	\$0.243	\$0.182	\$0.172	\$0.164	\$0.162	\$0.162
PHOSPHINE	\$0.283	\$0.212	\$0.200	\$0.191	\$0.189	\$0.189
GERMANE	\$2.879	\$2.159	\$2.032	\$1.941	\$1.919	\$1.919
METHANE	\$0.040	\$0.030	\$0.028	\$0.027	\$0.027	\$0.027
ARGON	\$0.059	\$0.044	\$0.042	\$0.040	\$0.039	\$0.039
H2/He	\$0.006	\$0.005	\$0.004	\$0.004	\$0.004	\$0.004
NITROGEN	\$0.034	\$0.025	\$0.024	\$0.023	\$0.023	\$0.023
SF6	\$0.019	\$0.014	\$0.013	\$0.013	\$0.013	\$0.013
SPUTTERING TARGETS	\$0.633	\$0.475	\$0.447	\$0.427	\$0.422	\$0.422
PHOTORESIST	\$0.707	\$0.530	\$0.499	\$0.477	\$0.471	\$0.471
DEVELOPER	\$0.286	\$0.215	\$0.202	\$0.193	\$0.191	\$0.191
ETCHANTS	\$0.060	\$0.045	\$0.042	\$0.041	\$0.040	\$0.040
ARTWORK	\$0.023	\$0.017	\$0.016	\$0.016	\$0.016	\$0.016
UV ENCAPSULANTS	\$0.220	\$0.165	\$0.155	\$0.148	\$0.146	\$0.146
PACKAGING	\$0.225	\$0.225	\$0.225	\$0.225	\$0.225	\$0.225
SUBTOTAL	\$10.41	\$7.86	\$7.41	\$7.09	\$7.01	\$7.01
UTILITIES:						
ELECTRICITY	\$0.267	\$0.200	\$0.188	\$0.180	\$0.178	\$0.178
GAS HEATING	\$0.005	\$0.004	\$0.004	\$0.004	\$0.004	\$0.004
WATER	\$0.053	\$0.040	\$0.038	\$0.036	\$0.036	\$0.036
SUBTOTAL	\$0.33	\$0.24	\$0.23	\$0.22	\$0.22	\$0.22
MAINTENANCE:						
PUMP REBUILD:	\$0.044	\$0.033	\$0.031	\$0.030	\$0.029	\$0.029
PUMP OIL	\$0.033	\$0.024	\$0.023	\$0.022	\$0.022	\$0.022
FILTERS	\$0.010	\$0.007	\$0.007	\$0.007	\$0.006	\$0.006
SUBTOTAL	\$0.09	\$0.06	\$0.06	\$0.06	\$0.06	\$0.06
BEFORE PANELIZATION	\$10.82	\$8.17	\$7.70	\$7.37	\$7.29	\$7.29
PANELIZATION:						
STEEL FRAMING	\$0.693	\$0.520	\$0.490	\$0.468	\$0.462	\$0.462
WIRE	\$0.089	\$0.067	\$0.063	\$0.060	\$0.059	\$0.059
CONNECTORS	\$0.077	\$0.058	\$0.054	\$0.052	\$0.051	\$0.051
RUBBER CHANNEL	\$0.145	\$0.109	\$0.103	\$0.098	\$0.097	\$0.097
DIODES	\$0.057	\$0.043	\$0.041	\$0.039	\$0.038	\$0.038
SUBTOTAL	\$1.06	\$0.80	\$0.75	\$0.72	\$0.71	\$0.71
TOTAL	\$11.88	\$8.97	\$8.45	\$8.09	\$8.00	\$8.00

SCI PHASE II
PRODUCTION COST ESTIMATE
AMORPHOUS SILICON - TRIPLE JUNCTION

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
AVE UPTIME	50%	65%	75%	78%	80%	80%
AVE YIELD	60%	80%	85%	89%	90%	90%
AVE EFFICIENCY	6.0%	7.0%	8.5%	9.5%	10.5%	11.0%
	$/WATT	$/WATT	$/WATT	$/WATT	$/WATT	$/WATT
MATERIALS:						
3/16" 20 ohm GLASS	$0.383	$0.246	$0.191	$0.163	$0.146	$0.139
GLASS CUT/TEMPER	$0.179	$0.115	$0.089	$0.076	$0.068	$0.065
WASHING DETERGENT	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
PROCESS GASES:						
SILANE	$0.279	$0.179	$0.139	$0.119	$0.106	$0.102
TRIMETHYLBORON	$0.044	$0.028	$0.022	$0.019	$0.017	$0.016
PHOSPHINE	$0.051	$0.033	$0.025	$0.022	$0.019	$0.018
GERMANE	$0.516	$0.332	$0.257	$0.220	$0.197	$0.188
METHANE	$0.007	$0.005	$0.004	$0.003	$0.003	$0.003
ARGON	$0.011	$0.007	$0.005	$0.005	$0.004	$0.004
H2/He	$0.001	$0.001	$0.001	$0.000	$0.000	$0.000
NITROGEN	$0.006	$0.004	$0.003	$0.003	$0.002	$0.002
SF6	$0.003	$0.002	$0.002	$0.001	$0.001	$0.001
SPUTTERING TARGETS	$0.114	$0.073	$0.057	$0.048	$0.043	$0.041
PHOTORESIST	$0.127	$0.082	$0.063	$0.054	$0.048	$0.046
DEVELOPER	$0.051	$0.033	$0.026	$0.022	$0.020	$0.019
ETCHANTS	$0.011	$0.007	$0.005	$0.005	$0.004	$0.004
ARTWORK	$0.004	$0.003	$0.002	$0.002	$0.002	$0.002
UV ENCAPSULANTS	$0.039	$0.025	$0.020	$0.017	$0.015	$0.014
PACKAGING	$0.040	$0.035	$0.028	$0.025	$0.023	$0.022
SUBTOTAL	$1.87	$1.21	$0.94	$0.80	$0.72	$0.69
UTILITIES:						
ELECTRICITY	$0.048	$0.031	$0.024	$0.020	$0.018	$0.017
GAS HEATING	$0.001	$0.001	$0.000	$0.000	$0.000	$0.000
WATER	$0.010	$0.006	$0.005	$0.004	$0.004	$0.003
SUBTOTAL	$0.06	$0.04	$0.03	$0.02	$0.02	$0.02
MAINTENANCE:						
PUMP REBUILD:	$0.008	$0.005	$0.004	$0.003	$0.003	$0.003
PUMP OIL	$0.006	$0.004	$0.003	$0.002	$0.002	$0.002
FILTERS	$0.002	$0.001	$0.001	$0.001	$0.001	$0.001
SUBTOTAL	$0.02	$0.01	$0.01	$0.01	$0.01	$0.01
BEFORE PANELIZATION	$1.94	$1.26	$0.98	$0.83	$0.75	$0.71
PANELIZATION:						
STEEL FRAMING	$0.124	$0.080	$0.062	$0.053	$0.047	$0.045
WIRE	$0.016	$0.010	$0.008	$0.007	$0.006	$0.006
CONNECTORS	$0.014	$0.009	$0.007	$0.006	$0.005	$0.005
RUBBER CHANNEL	$0.026	$0.017	$0.013	$0.011	$0.010	$0.009
DIODES	$0.010	$0.007	$0.005	$0.004	$0.004	$0.004
SUBTOTAL	$0.19	$0.12	$0.09	$0.08	$0.07	$0.07
TOTAL	$2.13	$1.38	$1.07	$0.91	$0.82	$0.78

CdTe Single Junction

CdTe Single Junction

Projections and Assumptions

Time from decision to begin to first module: 15 months

Time from decision to begin to acceptance tests: 18 months

Projections for efficiency, yield and uptime:

Year	Efficiency	Yield	Uptime
1	6.0%	60%	50%
2	7.5%	80%	65%
3	9.0%	85%	75%
4	10.0%	89%	78%
5	11.0%	90%	80%
6	12.0%	90%	80%

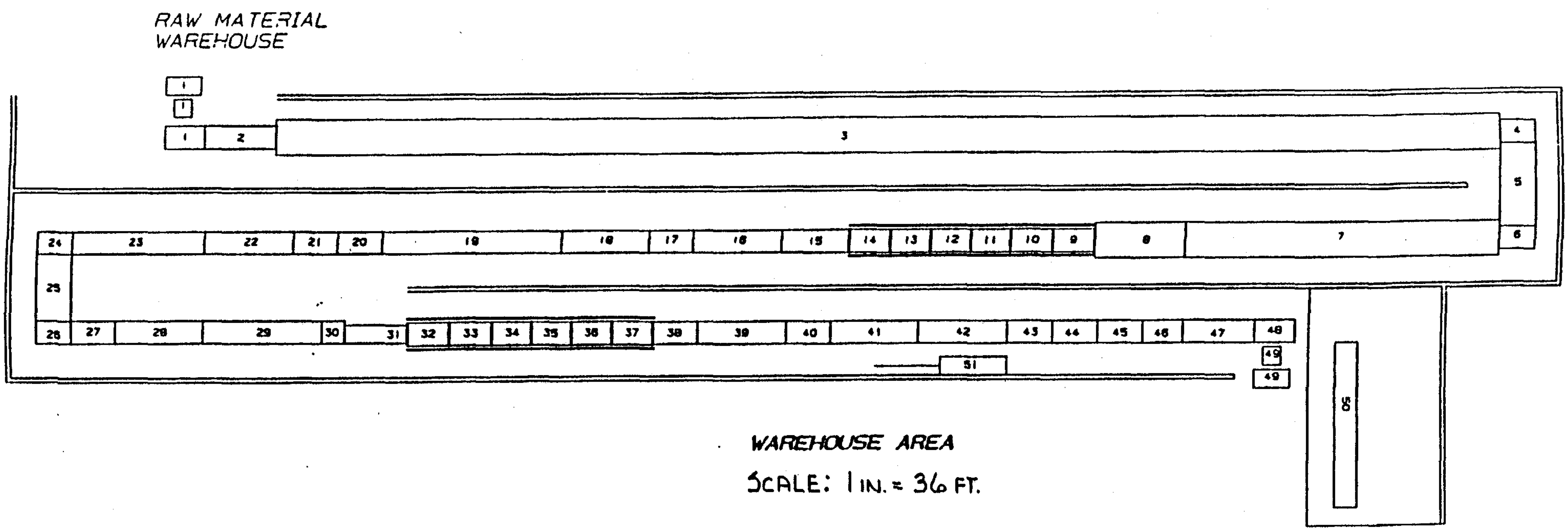
Projections for number of units produced, square feet produced, and Watts produced:

	Car Roof Modules			Utility Modules (2'x4')			Total		
Year	Units	Sq.Ft.	Power (MW)	Units	Sq.Ft.	Power (MW)	Units	Sq.Ft.	Power (MW)
1	0	0	0	128,880	1,031,040	5.75	128,880	1,031,040	5.75
2	0	0	0	223,392	1,787,136	12.50	223,392	1,787,136	12.50
3	20,000	82,000	0.69	253,870	2,030,960	17.00	235,870	2,112,960	17.70
4	50,000	205,000	1.90	248,228	1,985,824	18.40	298,228	2,190,824	20.30
5	100,000	410,000	4.18	209,312	1,674,496	17.10	309,312	2,084,496	21.30
6	100,000	410,000	4.59	209,312	1,674,496	18.80	309,312	2,084,496	23.40

Projections for Labor:

Year	Direct Labor	Factory Labor	Admin. Labor
1	36	19	11
2	36	19	11
3	36	19	11
4	36	19	11
5	36	19	11
6	36	19	11

PHASE II LINE LAYOUT PROPOSED
CADMIUM TELLURIDE



SCALE: 1 IN. = 36 FT.

SCI PHASE II
EQUIPMENT COST ESTIMATE
CADMIUM TELLURIDE PROCESS
SINGLE JUNCTION

Description	Cost to Purchase New
1) Robotic load station	120,000
2) Washer	150,000
3) CdS & CdTE Pyrolytic Spray	1,500,000
4) Square turn	15,000
5) Cool/Glass Bank	60,000
6) Square turn	15,000
7) Heat Treatment Furnace	850,000
8) Graphite Spray System	30,000
9) - 14) Metallization Line:	
Vacuum Chambers	
Stainless	65,340
Fittings	15,300
Heaters	6,600
Support Frame	6,720
Machining	141,000
Assembly	6,000
Transport	
Stainless	11,352
Bearings	9,960
Coating	1,440
Belts	1,500
Machining	45,600
Assembly	4,200
Slit Valves	84,800
Pumps/valves/piping	297,797
DC Power	170,000
Cathodes	228,000
Metallization Targets	8,000
15) Exit conveyor	10,000
16) Photoresist spray	200,000
17) Expose	250,000
18) Develop/rinse	110,000
19) Triple etch/rinse/dry	508,000
20) Test	60,000
21) Expose	250,000
22) Develop/rinse	110,000
23) Double etch/rinse/dry	353,000
24) Square turn	15,000
25) Conveyor/Glass bank	60,000
26) Square turn	15,000
27) Expose	250,000
28) Develop/Rinse/Dry	110,000
29) Reflow bake	100,000
30) Spacer conveyor	10,000
31) Entrance conveyor	10,000

32) - 37) Metallization line:	
Vacuum Chambers	
Stainless	65,340
Fittings	15,300
Heaters	6,600
Support Frame	6,720
Machining	141,000
Assembly	6,000
Transport	
Stainless	11,352
Bearings	9,960
Coating	1,440
Belts	1,500
Machining	45,600
Assembly	4,200
Slit Valves	84,800
Pumps/valves/piping	297,797
DC Power	170,000
Cathodes	228,000
Metallization Targets	8,000
38) Exit conveyor	10,000
39) Photoresist spray	200,000
40) Expose	250,000
41) Develop/rinse	110,000
42) Single etch/rinse/dry	170,000
43) UV Expose	60,000
44) Photoresist Strip	110,000
45) Test station	100,000
46) Connect external leads	50,000
47) Encapsulant	150,000
48) Unload conveyor	10,000
49) Robot unload station	120,000
50) Laminating equipment	200,000
51) Carrier return/clean	150,000
Control Hardware/Software	432,000
Glass handling	100,000
Environment test chamber	45,000
Lab test equipment	120,000
U.P.S.	100,000
Spare parts	500,000
Carriers	50,000
Labor (installation & design)	1,500,000
Total	$11,905,218

Additional Cost not Included

		Estimated Cost
1)	Building	1,600,000
2)	Safety equipment	30,000
3)	Phone systems	10,000
4)	Fire alarm system	10,000
5)	Clean rooms	360,000
6)	HVAC	239,000
7)	Machine shop	80,000
8)	Tow motors	50,000
9)	Utilities	180,000
10)	Office equipment	20,000
11)	Chemical Treatment	350,000
	Total	$3,199,000

SCI Phase II
Cadmium Telluride Single Junction — Grand Total $15,104,218

SCI PHASE II
PRODUCTION COST ESTIMATE
CADMIUM TELLURIDE

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
AVE UPTIME	50%	65%	75%	78%	80%	80%
AVE YIELD	60%	80%	85%	89%	90%	90%
	\$/ft^2	\$/ft^2	\$/ft^2	\$/ft^2	\$/ft^2	\$/ft^2
MATERIALS:						
3/16" 20 ohm GLASS	\$2.133	\$1.600	\$1.506	\$1.438	\$1.422	\$1.422
GLASS CUT/TEMPER	\$1.000	\$0.750	\$0.706	\$0.674	\$0.667	\$0.667
WASHING DETERGENT	\$0.001	\$0.001	\$0.001	\$0.001	\$0.001	\$0.001
PROCESS MATERIAL:						
CdTe	\$0.567	\$0.425	\$0.400	\$0.382	\$0.378	\$0.378
OTHER	\$0.500	\$0.375	\$0.353	\$0.337	\$0.333	\$0.333
SPUTTERING TARGETS	\$0.633	\$0.475	\$0.447	\$0.427	\$0.422	\$0.422
PHOTORESIST	\$0.707	\$0.530	\$0.499	\$0.477	\$0.471	\$0.471
DEVELOPER	\$0.286	\$0.215	\$0.202	\$0.193	\$0.191	\$0.191
ETCHANTS	\$0.060	\$0.045	\$0.042	\$0.041	\$0.040	\$0.040
UV ENCAPSULANTS	\$0.220	\$0.165	\$0.155	\$0.148	\$0.146	\$0.146
ARTWORK	\$0.023	\$0.017	\$0.016	\$0.016	\$0.016	\$0.016
PACKAGING	\$0.225	\$0.225	\$0.225	\$0.225	\$0.225	\$0.225
SUBTOTAL	\$6.36	\$4.82	\$4.55	\$4.36	\$4.31	\$4.31
UTILITIES:						
ELECTRICITY	\$0.267	\$0.200	\$0.188	\$0.180	\$0.178	\$0.178
GAS HEATING	\$0.005	\$0.004	\$0.004	\$0.004	\$0.004	\$0.004
WATER	\$0.053	\$0.040	\$0.038	\$0.036	\$0.036	\$0.036
SUBTOTAL	\$0.33	\$0.24	\$0.23	\$0.22	\$0.22	\$0.22
MAINTENANCE:						
PUMP REBUILD	\$0.007	\$0.005	\$0.005	\$0.005	\$0.005	\$0.005
PUMP OIL	\$0.005	\$0.004	\$0.004	\$0.004	\$0.004	\$0.004
FILTERS	\$0.010	\$0.007	\$0.007	\$0.007	\$0.006	\$0.006
SUBTOTAL	\$0.02	\$0.02	\$0.02	\$0.01	\$0.01	\$0.01
BEFORE PANELIZATION	\$6.70	\$5.08	\$4.80	\$4.59	\$4.54	\$4.54
PANELIZATION:						
STEEL FRAMING	\$0.693	\$0.520	\$0.490	\$0.468	\$0.462	\$0.462
WIRE	\$0.089	\$0.067	\$0.063	\$0.060	\$0.059	\$0.059
CONNECTORS	\$0.077	\$0.058	\$0.054	\$0.052	\$0.051	\$0.051
RUBBER CHANNEL	\$0.145	\$0.109	\$0.103	\$0.098	\$0.097	\$0.097
DIODES	\$0.057	\$0.043	\$0.041	\$0.039	\$0.038	\$0.038
SUBTOTAL	\$1.06	\$0.80	\$0.75	\$0.72	\$0.71	\$0.71
TOTAL	\$7.76	\$5.88	\$5.55	\$5.31	\$5.25	\$5.25

SCI PHASE II
PRODUCTION COST ESTIMATE
CADMIUM TELLURIDE

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
AVE UPTIME	50%	65%	75%	78%	80%	80%
AVE YIELD	60%	80%	85%	89%	90%	90%
AVE EFFICIENCY	6.0%	7.5%	9.0%	10.0%	11.0%	12.0%
	$/WATT	$/WATT	$/WATT	$/WATT	$/WATT	$/WATT
MATERIALS:						
3/16" 20 ohm GLASS	$0.383	$0.230	$0.180	$0.155	$0.139	$0.128
GLASS CUT/TEMPER	$0.179	$0.108	$0.084	$0.073	$0.065	$0.060
WASHING DETERGENT	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
PROCESS GASES:						
CdTe	$0.102	$0.061	$0.048	$0.041	$0.037	$0.034
OTHER	$0.090	$0.054	$0.042	$0.036	$0.033	$0.030
SPUTTERING TARGETS	$0.114	$0.068	$0.053	$0.046	$0.041	$0.038
PHOTORESIST	$0.127	$0.076	$0.060	$0.051	$0.046	$0.042
DEVELOPER	$0.051	$0.031	$0.024	$0.021	$0.019	$0.017
ETCHANTS	$0.011	$0.006	$0.005	$0.004	$0.004	$0.004
UV ENCAPSULANTS	$0.039	$0.024	$0.019	$0.016	$0.014	$0.013
ARTWORK	$0.004	$0.003	$0.002	$0.002	$0.002	$0.001
PACKAGING	$0.040	$0.032	$0.027	$0.024	$0.022	$0.020
SUBTOTAL	$1.14	$0.69	$0.54	$0.47	$0.42	$0.39
UTILITIES:						
ELECTRICITY	$0.048	$0.029	$0.023	$0.019	$0.017	$0.016
GAS HEATING	$0.001	$0.001	$0.000	$0.000	$0.000	$0.000
WATER	$0.010	$0.006	$0.005	$0.004	$0.003	$0.003
SUBTOTAL	$0.06	$0.04	$0.03	$0.02	$0.02	$0.02
MAINTENANCE:						
PUMP REBUILD	$0.001	$0.001	$0.001	$0.001	$0.000	$0.000
PUMP OIL	$0.001	$0.001	$0.000	$0.000	$0.000	$0.000
FILTERS	$0.002	$0.001	$0.001	$0.001	$0.001	$0.001
SUBTOTAL	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
BEFORE PANELIZATION	$1.20	$0.73	$0.57	$0.49	$0.44	$0.41
PANELIZATION:						
STEEL FRAMING	$0.124	$0.075	$0.059	$0.050	$0.045	$0.041
WIRE	$0.016	$0.010	$0.008	$0.006	$0.006	$0.005
CONNECTORS	$0.014	$0.008	$0.007	$0.006	$0.005	$0.005
RUBBER CHANNEL	$0.026	$0.016	$0.012	$0.011	$0.009	$0.009
DIODES	$0.010	$0.006	$0.005	$0.004	$0.004	$0.003
SUBTOTAL	$0.19	$0.11	$0.09	$0.08	$0.07	$0.06
TOTAL	$1.39	$0.84	$0.66	$0.57	$0.51	$0.47

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16. Abstract (Limit: 200 words)

A development/manufacturing program is described for achieving photovoltaic modules at a cost less than $.50/Watt and solar generating fields at a total installed system cost of less than $1.50/Watt. The basic approach is to construct a fully automated continuous production line based on close spaced sublimation (CSS) deposition of CdTe to produce 60 cm x 120 cm thin-film PV modules. The high deposition rate possible with CSS opens up the possibility of obtaining very high throughput in the range of hundreds of megawatts per year. This leads to dramatic reductions in the capital, labor and overhead cost per unit. The program includes a development phase, an initial production line of about 5-MW/year capacity, a 5 MW solar generating field, and a high-throughput production line with a capacity in the range of hundreds of megawatts per year.

17. Document Analysis
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