Subcontractor Report

January 2004 • NREL/SR-520-35177

Specific PVMaT R&D in CdTe Product Manufacturing

Final Subcontract Report
March 2003

J. Bohland, A. McMaster, S. Henson, and J. Hanak
First Solar, LLC
Perrysburg, Ohio

National Renewable Energy Laboratory

1617 Cole Boulevard
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NREL Technical Monitor: R.L. Mitchell
Prepared under Subcontract No. ZAX-8-17647-06

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John Bohland	Principal Investigator Phase I
Alan McMaster	Principal Investigator Phase II and III
Sam Henson	Principal Investigator Final
Dr Joseph Hanak	Consultant

Contributors: John Bohland, Eugene Bykov, Chris Flores, Frank Borgeson, Wayne Monie, Ken Smigielski, Chris Zarecki, Mike Ross, Jim Poddany, Dr. Joseph Hanak, Product Search, Inc, Matt Flis, Todd Dapkus, Steve Cox, Verlin Champion, Gary Faykosh, Mike McArthur, Tom Dunn, Larry Crosser Peter Meyers

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Contact Information

Technology:
First Solar, LLC - Technology Center
12900 Eckel Junction Rd
Perrysburg, OH 43551 Suite 69
Phone: (419) 872-7661
www.firstsolar.com

Applications:
First Solar, LLC - Applications
4050 E. Cotton Center Blvd, Bldg 6 Suite 68
Phoenix, AZ 85040
Phone:(602) 414-9300
www.firstsolar.com/

Engineering and Production:
First Solar, LLC – Operations
28101 Cedar Park Blvd.
Perrysburg, OH 43551
Phone: (419) 662-8500
www.firstsolar.com/

Abstract

Results of a 3+ year subcontract are presented. The research was conducted under Phase 5A2 of the subcontract entitled "Specific PVMaT R&D in CdTe Product Manufacturing". The three areas of effort in the subcontract were 1) manufacturing line improvements, 2) product readiness, and 3) environmental, safety, and health programs. The subcontract consisted of three phases, approximately 1 year each.

Phase I included the development, design and implementation of a high-throughput, low-cost lamination process. This goal was achieved using the support of key experts such as Automation and Robotics Research Institute (ARRI) to identify appropriate lamination equipment vendors, and material handling. Product designs were reviewed by Arizona State University Photovoltaic Testing Laboratory and Underwriters Laboratory. Modifications to the module designs were implemented in order to meet future testing requirements. A complete review of the Environmental, Health and Safety programs was conducted along with training by the Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA).

Work conducted during Phase II included the implementation of an improved potting procedure for the wiring junction. The design of the equipment focused on high throughput low cost operations. First Solar engaged industrial experts and vendors such as ARRI in the development, design and testing of alternative potting solutions which were directly scalable to 60 modules per hour with potential of exceeding that capacity with nominal upgrades. First Solar began the development of an improved scribing technique and design of associated equipment. A review of the process identified, throughput, labor, and equipment drawbacks. First Solar formulated an improved process through adaptation of state-of-the-art techniques and automation. This task resulted in the development of a high-throughput, low-cost scribing system increasing throughput by a factor of two; reducing downtime by a factor of three; and reducing equipment capital requirements by at least a factor of two. Product readiness efforts during Phase II included the initial testing of modules at Arizona State University Photovoltaic testing laboratory (PTL) and a review of design features such as: 1) junction box instead of pigtails; 2) sizes other than 60cm x 120cm; 3) alternative voltage; 4) alternate encapsulation materials or processes; and 5) other product changes influenced by market demand. Refinements were made to the EHS programs through the involvement of industry experts such as OSHA and On-Site Consultation of the Ohio Bureau of Employer Services. First Solar initiated improvements through a series of training and educational seminars for its employees affected by the targeted issues. Altogether over thirty different activities have been conducted in the EHS program over the period of the Phase II project. Among these activities were: development and implementation of fifteen EHS-related plans and programs; obtaining permits; generating reports to municipal and state agencies; conducting inspections; environmental sampling of R&D and production equipment and facilities for hazardous substances; installation and monitoring of EHS equipment; and periodic evaluation of employees for baseline cadmium.

During Phase III , First Solar made significant progress in three areas: Manufacturing Readiness, Product Performance and Environmental, Health and Safety (EH&S). First Solar's accomplishments in laser scribing significantly exceeded the stated goals. Innovations implemented during Phase III include increasing the scribing speed from 70

mm/s to 1700 – 3000 mm/s; achieving a throughput rate of 60 modules/hr for the three laser systems built for each of three scribes; decreasing the cost per system by a factor of two; decreasing significantly the kerf and spacing of the scribe lines, thereby increasing the active module area; increasing the laser life by a factor of 10 up to 10,000 hours and completely automating the scribing station, including loading, unloading, scribing, and focusing. These innovations were made possible by adopting a new type of high frequency, low-pulse-width laser, galvanometer-driven laser beam system, and numerous advanced, automated, equipment features. Because of the greater than one order of magnitude increase in the throughput and laser life, a factor of two decrease in equipment cost, and complete automation, a major impact on lowering the cost of the PV product is anticipated.

Testing has been successfully completed and all required documentation has been submitted to UL. Final approval from UL to use the listed label has been granted. The impact of the UL listing has allowed First Solar to begin its production. The product has been made commercially available.

First Solar obtained IEC 61646 certification, for its modified Module. This certification validates the First Solar product and enables the product to be marketed internationally. Detailed testing results are included as appendix 1

EH&S capabilities were significantly advanced through implementation of detailed and comprehensive programs in each area - Environmental, Health and Safety, and a detailed plan was developed to obtain ISO 14000 certification. First Solar maintains a safe and healthy work place as well as an environmentally friendly manufacturing process and product.

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1. Introduction

This is the Final technical report for the Specific PVMaT R&D in CdTe Product Manufacturing subcontract awarded to Solar Cells, Inc. (SCI) in 1998. Just prior to Phase II of the PVMaT project, major changes occurred in the company's corporate structure. Beginning February 1, 1999 Solar Cell, Inc. (SCI) formed a joint venture partnership with True North Partners of Scottsdale, AZ. The new company was named First Solar, LLC. For brevity in this report, "First Solar" (or FS) is used to refer to all activities and accomplishments of SCI or First Solar, LLC. This event, resulted in an infusion of new financial resources and manpower toward the immediate start of construction of a new major manufacturing facility for photovoltaic modules, based on cadmium telluride. The site of the new plant is at Cedar Park Boulevard in Perrysburg, a suburb of Toledo, Ohio. The engineering plans for this facility were completed just prior to the formation of the joint venture. Equipment was originally designed to be capable of producing PV modules at a rate of 100 MW per year. A photo of the new First Solar PV module manufacturing facility appears in Figure 1. Because of the impending start of manufacturing activities scheduled for early 2000, the objectives were expanded as a result of continual reviews of the equipment and product design, to remove any potential bottlenecks in the overall manufacturing process.

Figure 1. A photograph of the new First Solar Facility PV module Manufacturing plant in Perrysburg, Ohio

2. Summary

Summary of Major Accomplishments for Subcontract ZAX-8-17647-06

Manufacturing Line Improvements

All task milestones were successfully complete. There were three specific areas of focus; Lamination, potting/junction wiring, and laser scribing.

A high through put lamination process was developed. Industry consultants including Automation and Robotic Research Institute (ARRI) and Product Search were engaged in the development of a lamination and potting process capable of producing 60 modules per hour. A low cost molded junction termination was developed and implemented. Automated inline simulator and wet hi-pot systems were developed and installed. Module performance data is obtained using this automated system.

Research was conducted using liquid polyester resin, rubber EPDM, and Trueseal corporations hot melt butyl compound, in addition to or as a replacement for the current Ethyl Vinyl Acetate (EVA) encapsulant material. Research was conducted on replacement materials for the current tempered back cover glass and several potential materials were identified for the next generation product. This effort will be continued in order to develop a lower cost, higher moisture barrier back cover layer for the CdTe module.

First Solar developed an improved high-throughput laser scribing system. The developed system is capable of scribing solar panels, measuring 120 cm x 60 cm, with a throughput of one per minute, at a reduced capital cost, improved reliability, improved scribe control and requiring the use of a single laser beam per each of three types of scribes.

The system developed is capable of achieving a 60-cm-long scribe line, having a minimum theoretical spot size of 70 microns. Scribe-to-scribe location is easily controlled. The scribing can reach speeds in excess of 3400 mm/sec, through the use of pulsed lasers having a high rep-rate. A key benefit of this system is the ability to use a correction factor in the software, which allows cell mapping and correcting the focus for uneven surfaces. In order to achieve speeds above 2000 mm/sec, scribing through the glass side of the solar panel, reported earlier [2], was pursued.

Green-light (532 nm) lasers are typically used for solar cell scribing in order to match the wavelength to the optical absorption of the material. In this project it was determined to use near-infrared (IR) lasers after developing the understanding that the CdTe absorption increases greatly with temperature for near-infrared (IR) wavelengths.

Considering the structure of the solar panels, from the sunny side, it consists of a soda-lime glass plate superstrate, coated with layers of TCO/CdS/CdTe/metal, encapsulated by a second plate of glass. The TCO signifies transparent conductive oxide. In the scribing sequence used at First Solar, each scribe removes a smaller amount of material compared to its predecessor, thus the top-most layers can be removed at low energies without damaging the inner layers. Scribe-1 removes all the layers on the glass; scribe-2 removes the CdS and CdTe, without ablating the TCO. Scribe-3 removes the metal layer, applied after scribe-2; the metal is removed chiefly by the high-pressure CdTe vapor formed at its interface by the beam reflected by the metal.

Improvements with the improved scribing system include: (1) Reduced capital cost - the cost of high-speed improved laser system is about 65% less than that of a conventional system, with four nozzles; (2) reduced and lower-cost maintenance, which reduces down-time by a factor of ten; (3) greatly enhanced location accuracy of subsequent scribes through the use of fiducials, coupled with automated correction for panel growth/ shrinkage caused by temperature variations as well as panel rotation; (4) substantially reduced kerf widths and scribe spacing, whereby the active area of the panel is increased; (5) IR lasers deliver about twice the power of frequency-doubled green lasers and have life expectancy of up to 10,000 hours, 14 times greater than green lasers, and lower cost; and (6) increased production throughput by a factor of four.

Product Readiness

R&D activities were conducted to facilitate UL and IEC certification. These efforts included: (a) heat strengthening of glass to avoid breakage; (b) elimination of failures in the cord plate junction through the use RTV silicone potting material (c) relocation of the hole in the cover glass from 10 cm to 25 cm off the edge of the glass, thereby lowering the tensile stresses in the laminated module an average of 500 PSI; and (d) screening of alternative encapsulants to EVA to improve electrical insulation during damp-heat testing.

At the start of Phase III First Solar PV modules received “recognition” from the Underwriter Laboratories, which allowed the modules to be used on listed mounting systems.

During April 2001, and September 2002 modules were resubmitted to the Arizona Testing Laboratory with a c-channel and d-channel mounting system respectively. HF-10 and static load testing were successful and First Solar received authorization to use the UL Listed mark on its FS-50c and FS50d modules. These are complete modules with mounting attachments secured to the backside. The c, and d, designations indicate the style of mounting with the c denoting aluminum c-channel rails, and the d denoting aluminum d-channel rails.

In October 2002, nine standard production modules were submitted for testing to the Photovoltaic Testing Laboratory (PTL) at the Arizona State University, in accordance with the IEC standards. First Solar modules have completed the certification testing in accordance with IEC 61646 and have obtained international certification.

Environmental, Safety, and Health Program

EH&S capabilities were significantly advanced through implementation of detailed and comprehensive programs in each area - Environmental, Health and Safety, and a detailed plan was developed to obtain ISO 14000 certification. Over thirty specific tasks were completed during this subcontract period. Among these tasks were: development and implementation of a personal protective equipment program, means of Egress plan, first aid/blood born pathogens training, electrical lockout/tag out training, light/noise/ ventilation evaluations, generation of reports to municipal and state agencies; equipment safety inspections; environmental sampling of R&D and production equipment and facilities for hazardous substances; installation and monitoring of EHS equipment; and periodic evaluation of employees for baseline cadmium. First Solar maintains a safe and healthy work place as well as an environmentally friendly manufacturing process and product. First Solar is continuing on plan to obtain ISO 14000 (or equivalent) certification.

3. Report Overview

This subcontract consisted of three separate phases. During each phase there were specific tasks relating to: Manufacturing Line Improvements, Product Readiness, and Environmental, Health and Safety Programs. These tasks were sequentially numbered and milestones were assigned for each task.

Phase I
- Task 1 Manufacturing Line Improvements
- Task 2 Product Readiness
- Task 3 Environmental, Health and Safety Programs

Phase II
- Task 4 Manufacturing Line Improvements
- Task 5 Product Readiness
- Task 6 Environmental, Health and Safety Programs

Phase III
- Task 7 Manufacturing Line Improvements
- Task 8 Product Readiness
- Task 9 Environmental, Health and Safety Programs

In order to follow the efforts of this development subcontract, the report has been organized by the three Phases. An overview of the tasks is listed followed by the milestones and results for each milestone.

4. Phase I Task Overview

Task 1 Manufacturing Line Improvements - Lamination

The specific objective of this task for Phase I was to develop, design and implement a high-throughput, low-cost lamination process with throughputs increased from 18 units/hour to at least 30 units/hour, labor costs reduced by 50% and equipment capital requirements lowered by a factor of four. This goal was to be achieved using the support of key experts such as Automation and Robotics Research Institute (ARRI) to identify appropriate lamination equipment vendors, material handling solutions and establish parameters for its integration on the First Solar production line. Besides demonstrating laminator throughput of 30 modules/hour, improved lamination preparation techniques including EVA cutting and application, bus bar application, and back glass handling and application were included in this work.

Task 2 Product Readiness

The specific objective of this task was to qualify First Solar's current module design according to protocols of IEEE 1262 and UL 1703 and achieve certification from Powermark Corporation; a worldwide recognized PV module certification for product durability and performance.

Note: During Phase III the certification requirements were revised to include IEC 61646 and UL 1703 only. IEEE 1262 was no longer in effect at the end of the project. In addition, references to IEC 1215 should also be considered as requiring IEC 61646. IEC 61646 was developed specifically for Thin-film Photovoltaic modules, where IEC 1215 was intended only for Crystalline Silicon photovoltaic modules.

Task 3 Environmental, Health and Safety Programs

The specific objective of this task was to continue and improve First Solar's environmental, health and safety programs initiated during its PVMaT Phase 2B subcontract. An internal review of current programs was to be conducted and, using the assistance of industry experts, their status relative to industry best practices assessed.

4.1. Phase I Results for Task 1, 2, and 3 Milestones

4.1.1. Task 1 Milestones---Manufacturing Line Improvements

m-1.1.1	Initiate development program by interviewing key supplies and experts such as STR, Inc., ARRI, and automotive glass manufacturers	(Task 1)
m-1.1.2	Complete process specification for high throughput laminator	(Task 1)
m-1.2.1	Complete design specification for high throughput laminator	(Task 1)
m-1.3.1	Begin debug of high-throughput laminator	(Task 1)
m-1.4.1	Complete prove-in of high throughput laminator at a rate of thirty modules per hour	(Task 1)
m-1.4.2	Complete report on lamination rates, yields, and reductions in labor and equipment costs	(Task 1)
m-1.4.3	Complete the Phase I portion of the effort under Task 1	(Task 1)

Milestone Description

m-1.1.1	Initiate lamination development program by interviewing key suppliers and experts such as STR, Inc., ARRI, and automotive glass manufacturers

This milestone was completed successfully. Though the PV industry on the whole has adopted the one atmosphere, bag style vacuum laminator, high throughput applications such as automobile windshield glass manufacturers have always used *autoclaves* for mass production of laminated glass. First Solar, based on outside and inside expertise and experience, abandoned the home-built bag style vacuum laminator and purchased an autoclave for high volume, low cost lamination of CdTe thin-film PV modules. Additionally, after some delay due to negotiating intellectual property rights, a contract was signed with Automation Robotics and Research Institute to address lamination preparation process improvements aiming to align module assembly tasks time and labor with the improvements anticipated by using the autoclave instead of the bag laminator.

Milestone Description

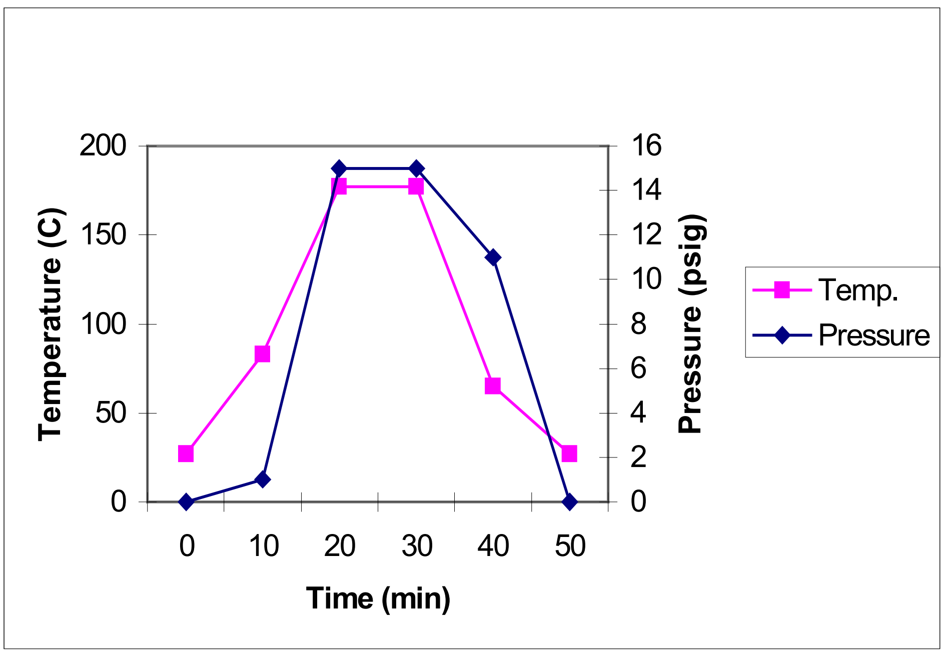
m-1.1.2	Complete process specification for high throughput laminator

This milestone was completed successfully. A series of manufacturing experiments were undertaken using the same materials and assembly lay-up procedure as used for the abandoned vacuum press style laminator. Embedded thermocouples were used to monitor temperature of the laminate interlayer (EVA) for comparison to Springborn (EVA manufacturer) recommendations. Pressure was tracked using the on-board chart recorder of the autoclave.

Ultimately, a lamination process cycle as described below was developed. The total cycle time for a batch of up to 24 module units is 45 minutes, resulting in the targeted hourly throughput rate of up to 30 units per hour.

This cycle resulted in surprisingly good "gel content" results, a measure of EVA polymerization. Chart 1 shows the typical gel content for EVA as reported by Springborn for vacuum press laminators compared to the gel content achieved by the First Solar Autoclave. A higher gel content result indicates a higher degree of polymerization; implying improved EVA polymer adhesion and stability. Another improvement resulting from the superior performance of the autoclave is the lack of entrapped air bubbles in the EVA laminate film. Previously, all modules laminated in the vacuum press laminator had small air bubbles trapped particularly in the edge deleted (bonding) area of the unit; these are absent from autoclave laminated modules.

Chart 1:
Autoclave Operating Conditions



Milestone	**Description**
m-1.2.1	Complete design specifications for the high throughput laminator

This milestone was completed successfully. Figures 2 and 3 show the high throughput laminator design as proposed and as installed.

Figure 2: High-throughput laminator as proposed

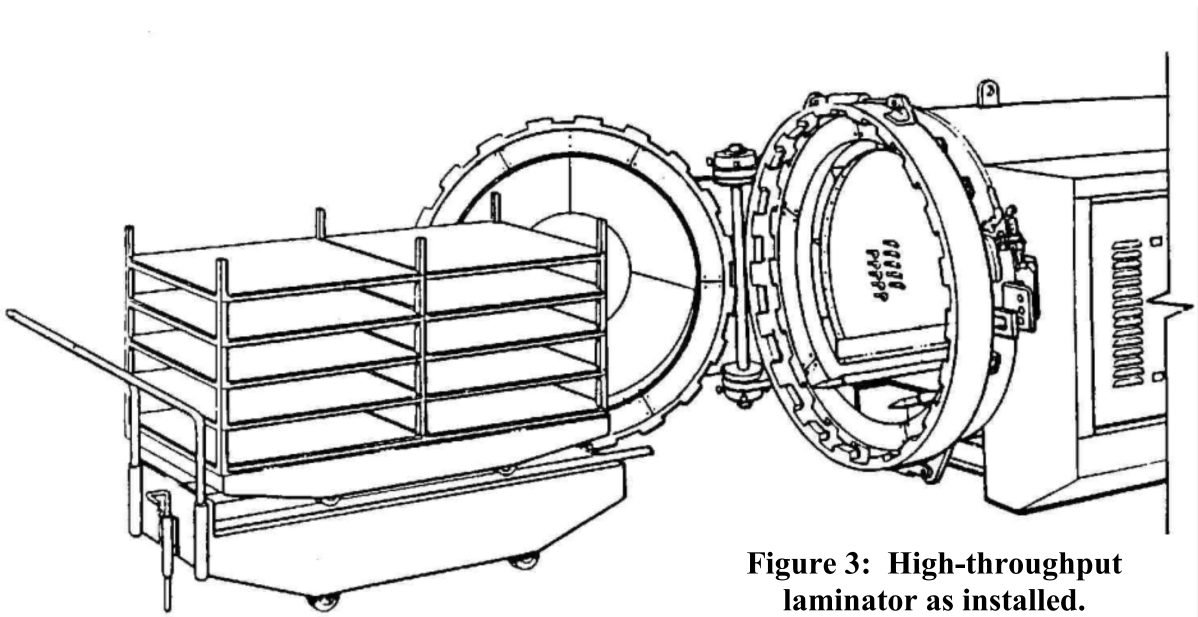


Figure 3: High-throughput laminator as installed.

Additional sub-tasks to develop high-throughput, labor reducing, material saving lamination preparation equipment were submitted by ARRI and approved and initiated by First Solar. As pointed out in the Overview, this equipment is necessary to maintain productivity in the module assembly stage of the lamination operation equivalent to the high-throughput autoclave laminator.

These subtasks were defined as:

- ⇨ "As-is" analysis of the final module assembly process
- ⇨ Process and material handling vendor search
- ⇨ "To-be" concept designs for final module assembly
- ⇨ Simulation model development
- ⇨ Process development
- ⇨ Material handling development
- ⇨ Quarterly reviews
- ⇨ Integration and test
- ⇨ System set-up, testing and training

Milestone Description

m-1.3.1	Begin de-bug of high-throughput laminator

This milestone was completed successfully. There were two significant problems encountered when production module lamination using the autoclave began. First, since the autoclave process cycle requires a total pressure of about 2 atmospheres (~ 1.5 atmosphere from the initial air removal step when the module is placed in a plastic de-airing bag and another applied atmosphere from the autoclave for bubble-free laminations), yield fall-off from breakage *increased* compared to the old vacuum press style laminator. Second, direct material costs *increased* compared to the old laminator because a host of materials to contain the assembled module under vacuum were needed for initial de-airing including release film, woven breather material, tape and the plastic vacuum bag. To clarify this point, the autoclave process is not a pressure process only. Initial de-airing of the module assembly must occur before pressure is applied to remove entrained air; flexible, elastomeric vacuum rings and nip rollers are alternative de-airing processes.

Clearly, though the laminator throughput objective of 30 units/hour was met, increased yield fall-off and direct materials costs were not acceptable.

Consultation with Springborn yielded the suggestion of trying a *textured*, rather than smoothly finished EVA. This simple material change, actually just a change of the laminate film surface, solved both the yield fall-off problem and the increased direct material costs problem at once. By switching from smooth to textured EVA, de-airing becomes much more efficient. Because more air is removed earlier in the autoclave cycle, the pressure applied during the pressure part of the cycle can be reduced. The process was modified to reduce the applied autoclave pressure from 1.5 to 1 atmosphere (15 PSI) using textured EVA laminate film. This, along with a slight modification to the bus-bar ribbon connection (to reduce the total thickness at the end bus bar) essentially eliminated yield fall-off from breakage. Addendum II shows the results of a controlled experiment to document yield fall-off improvement.

Again, because de-airing is more efficient using textured EVA, this allowed adopting a re-usable, silicon elastomer vacuum ring to effectively de-air the module assembly. When the rings were tried without the textured EVA, incomplete de-airing occurred and bubbles remained after lamination. In conjunction with a back-glass bus bar exit hole sealing technique such as using either an epoxy pre-potting or simply a silicon suction cup, textured EVA allowed the elimination of all the described disposable direct materials. This cost reduction reduced direct material costs by nearly $10 per unit, a substantial percentage decrease of total direct costs.

Work continued this quarter by ARRI on the lamination assembly automation equipment. Several options with various degrees of automation were studied.

Milestone Description

m-1.4.1	Complete prove-in of high-throughput laminator at a rate of thirty modules per hour.

This milestone was completed successfully. Fixtured for 24 modules (rather than the ten slot fixture that came with the autoclave), and a cycle time of 45 minutes, a laminator throughput of 30 modules/hour is achieved. Additionally, the autoclave installed and evaluated by First Solar is comparatively small. Autoclaves are available in sizes that allow lamination of First Solar's 60cm x 120cm modules on the scale of *hundreds* of units per cycle.

Milestone Description

m-1.4.2	Complete report on lamination rates, yields, and reductions in labor and equipment costs.

This milestone was completed successfully. The throughput rate was concluded and reported on in milestone m-1.4.1 above. The cycle time per unit for the vacuum press laminator was about 20 minutes; that has been reduced to a per unit cycle time of 2 minutes, or a full order of magnitude, using an autoclave fixtured for 24 units and a 45 minute cycle time.

A larger scale yield investigation is planned but a preliminary study documented as Addendum II shows a yield fall-off improvement from 10% before implementing the textured EVA and elastomeric vacuum ring system to a negligible level after implementing it.

Since one person was required to operate the bag laminator and one person is required to operate the autoclave (actually the autoclave operator can leave the machine unattended during the lamination cycle), a labor savings comparison is straightforward. If the 20 minute cycle time for the bag laminator is one labor unit, and the autoclave can produce the equivalent of 10 units in 20 minutes, an order of magnitude reduction in labor has been achieved (90% labor reduction). This is significantly *better* than the stated 50% labor reduction in the Task 1 goal.

Last, the capital equipment objective for this task was a factor of four reduction. A leading supplier reports a state-of-the-art bag laminator costs $285,000. McGill autoclave reports a 5' x 10' autoclave, fixtured for twenty-four 60cm x 120cm modules costs roughly the same ($250,000). For the same amount of capital, throughput increases 10 times, resulting in a *ten* times reduction in unit related capital costs. This is better than the factor of four objective.

Milestone Description

m-1.4.3	Complete the Phase I portion of the effort under Task I.

This milestone is complete. Complimentary work is underway by ARRI to complete the module assembly automation equipment that will allow the 30 module/hour throughput target required to support the autoclave laminator. Several recent ARRI status reports are attached as Addendum III showing the progress for automation equipment design and testing. The semi-automated prototype lamination preparation station will be completed by ARRI in June and First Solar will demonstrate the 30-unit/hour throughput, scaleable to 60 unit/hour at that time.

4.1.2. Task 2 Milestones Product Readiness

m-1.1.3	Initiate contact with module testing laboratory and complete preliminary module design review	(Task 2)
m-1.2.2	Complete preliminary testing of modules	(Task 2)
m-1.2.3	Establish qualification testing schedule	(Task 2)
m-1.3.2	Initiate qualification testing on First Solar's standard module	(Task 2)
m-1.4.4	Complete qualification testing on First Solar's standard module for IEEE 1262, IEC 1215, and UL 1703	(Task 2)
m-1.4.5	Complete the Phase I portion of the effort under Task 2	(Task 2)

Milestone Description

m-1.1.3	Initiate contact with module testing laboratory and complete preliminary module design review.

This milestone was completed successfully. The Arizona State University Photovoltaic Testing Laboratory was contacted and chosen as the module testing laboratory. The ASU lab is nationally and internationally recognized as a reliable PV testing facility. Certification is provided through PowerMark Corporation. European equivalence is provided through simultaneous testing to IEC 1646 protocols.

Preliminary module design review was also completed. The First Solar "SPN-7" modules designated for testing were unchanged from previous designs except that the front substrate was changed from 5mm to 3mm thickness (for weight and cost savings).

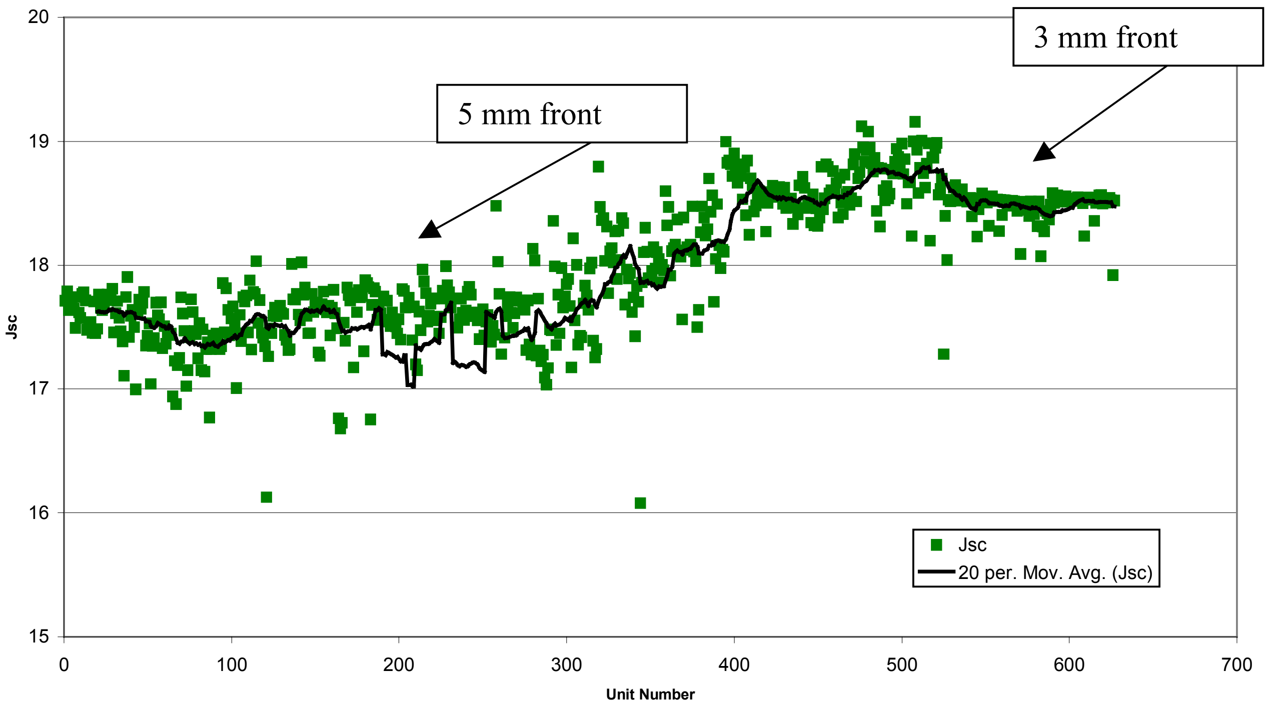
Milestone Description

m-1.2.2	Complete preliminary testing of modules.

This milestone was completed successfully. Modules made using the new 3mm thick glass substrate were manufactured, tested and approved for initial performance. By decreasing the front substrate thickness from 5 to 3mm, Jsc improved due to more usable photons reaching the semiconductor rather than being absorbed in the glass substrate.

Chart two shows a moving average trend line indicating the clear improvement in Jsc as the 3mm substrate glass was introduced. The improvement in Jsc paves the way for overall efficiency improvements for a given TCO front-contact resistivity.

Chart 2
Jsc Comparison - September 1 to December 10, 1998



Milestone **Description**

m-1.2.3	Establish Qualification Testing Schedule

This milestone was completed successfully. Twelve First Solar "SPN-7" modules were shipped to the Arizona State University Photovoltaic Testing Laboratory on August 25, 1998 and received by ASU in early September. A completion date of January 1, 1999 was predicted by ASU.

Milestone **Description**

m-1.3.2	Initiate qualification testing on First Solar's standard modules.

This milestone was completed successfully. Qualification testing was actually initiated ahead of schedule in the last quarter (4th quarter 1998).

Milestone **Description**

m-1.4.4	Complete qualification testing on First Solar's standard module for IEEE 1262 and UL 1703.

This milestone is complete. Qualification testing was completed in April and a final test report is awaited from the ASU Photovoltaic Testing Laboratory. First Solar's "SPN-7" has passed IEEE 1262 Sequence "A" testing (200 thermal cycles), Sequence "B" up to heat-humidity-freeze cycling, Sequence "C" up to damp heat testing and Sequence "F". The outcome of the damp heat test was initially unclear and delayed due to problems with a contaminated test chamber where the SPN-7 modules were first tested. A repeat test yielded a marginally below standard result (slightly more than allowable performance degradation). Testing under UL 1703 has not been completed under this task; it will be completed after IEEE1262 is passed.

Now, the task for Phase II becomes more involved because significant module encapsulation processes and product design changes will have to be made to ensure certification of IEEE 1262 on the next qualification attempt scheduled for Phase II of this work. The module potting system and moisture edge barrier will be the focus of this work, as well as understanding surface preparation techniques to maximize adhesion of the laminate material and consideration of alternative encapsulants.

Milestone Description

m-1.4.5	Complete the Phase I portion of the effort under Task 2.

This milestone is complete. Work is underway to modify materials, processes and product design to ensure passage of all IEEE 1262 and UL 1703 requirements in Phase II of this work.

4.1.3. Task 3 Milestones--- Environmental, Health and Safety Programs

m-1.1.4	Complete review and survey of current ES&H programs	(Task 3)
m-1.2.4	Develop plans for critical areas of ES&H improvement with the assistance of industry experts such as OSHA On-Site Consultation	(Task 3)
m-1.3.3	Initiate EH&S improvement projects	(Task 3)
m-1.4.6	Complete implementation of critical ES&H improvements	(Task 3)
m-1.4.7	Complete the Phase I portion of the effort under Task 3	(Task 3)

Milestone Description

m-1.1.4	Complete review and survey of current environmental, health and safety (EHS)programs.

This milestone was completed successfully. In addition to an in-house review of current EHS programs by the EHS manager, an EHS Technician support position was created and filled. This individual attended two comprehensive seminars related to EPA (Environmental Protection Agency) and OSHA (Occupational and Health Administration) compliance in order to gain information and plan for improvement during the second quarter of this task.

The review included not only compliance related programs but a review of internal safety rules and procedures as well as industrial ventilation equipment and related engineering controls for worker exposure to cadmium compounds and volatile organic hydrocarbons (VOC's).

Milestone Description

m-1.2.4	Develop plans for critical areas of EHS improvement with the assistance of industry experts such as OSHA On-Site Consultation.

This milestone was completed successfully. Though OSHA On-Site Consultation services was not used, the EHS Manager and EHS Technician, using information from the Internet and recent EHS workshops, created a comprehensive EHS improvement process plan. The EHS improvement planning process was broken down separately for all three environmental, health and safety elements into strictly compliance program development and best management practices and activities. To save repetition, the EHS plan and First Solar's record of completing the plan (according to milestone m-1.4.6) are attached as Addendum I.

Milestone Description

m-1.3.3	Initiate EHS improvement projects

This milestone was completed successfully. Similar to milestone m-1.3.2, EHS improvement projects were actually initiated ahead of schedule in the second quarter (refer to Addendum I for the project schedule).

Milestone Description

m-1.4.6	Complete implementation of critical EHS improvements.

This milestone has been completed successfully. The EHS improvement program improvement process has followed the schedule outlined in Addendum I. Results are indicated there.

Safety and health highlights include the improvement of local ventilation controls for cadmium in the edge deletion, laser and cadmium chloride application processes, the implementation of a comprehensive lockout-tag out program in conjunction with electrical safety training, first aid, blood borne pathogens and CPR training, material handling and fork truck training and a revised respirator training program.

Complete facility mass balance emissions calculations were done to demonstrate compliance with environmental regulations and requirements.

First Solar's current lost workday rate is **13.3** and lost workday case rate is **8.3** for the Phase I project period (May 1998 through April 1999). This corresponds to **32** for lost workdays and **6.8** for lost workday cases in the electronics-manufacturing sector for the last year data is available (1996). This shows that, while First Solar experienced an 18% higher accident rate than the electronics-manufacturing sector for the period, the severity was 140% *lower*. Improvements will be achieved as safety awareness training becomes more routine.

Milestone Description

m-1.4.7	Complete the Phase I portion of the effort under Task 3.

As noted above, this milestone has been successfully completed.

5. Phase II Task Overview

Task 4 Manufacturing Line Improvements – Laser Scribing and Potting

First Solar, LLC (First Solar) shall develop and implement an improved potting procedure and design associated equipment. First Solar shall conduct a thorough review and analysis of the current process to identify throughput, labor, and equipment drawbacks. First Solar shall formulate an improved process through adaptation of well-proven glass manufacturing methods and automation. First Solar shall engage industrial experts and vendors such as the ARRI as needed in the development, design and testing of alternative potting solutions which are directly scalable to 60 modules per hour with potential of exceeding that capacity with nominal upgrades. First Solar shall complete off-line development of the individual potting processes such as diode connection, mold positioning, and urethane injection. First Solar shall carry out the prototyping of material handling steps for the potting process such as: handling large sheets of glass in and out of buffers; feeding glass in and out of the potting work station; flash tests; and parts-feeding. First Solar shall test a prototype potting station to demonstrate the improvement elements and provide functional information for the high-throughput design. First Solar shall complete testing of the improved high-throughput potting system, including process and material handling components, on its module production line. The task is expected to result in high-throughput, low-cost potting by increasing throughput per potting line by a factor of at least four; reducing labor costs by at least a factor of ten; and increasing overall quality.

First Solar shall also implement an improved scribing technique and design associated equipment. First Solar shall conduct a thorough a review of the current process to identify throughput, labor, and equipment drawbacks. First Solar shall formulate an improved process through adaptation of state-of-the-art techniques and automation. First Solar shall engage industrial experts and vendors such as the ARRI as needed in the design, and testing of the new scribing technique to expedite task progress. The task is expected to result in high-throughput, low-cost scribing by increasing throughput by a factor of two; reducing downtime by a factor of three; and reducing equipment capital requirements by at least a factor of two.

Task 5 Product Readiness

First solar, LLC shall initiate and complete qualification testing of a modified module. Modifications may include one or more of the following depending on the market interest: 1) junction box instead of pigtails; 2) sizes other than 60cm x 120cm; 3) alternative voltage; 4) encapsulation materials or process; and 5) other product changes influenced by market demand. First Solar shall obtain UL1703 certification for its modified module. Experts from the field including Underwriters Laboratory and the Photovoltaic Testing Laboratory at the Arizona State University will be utilized as needed to expedite the successful completion of the task. The task is expected to improve acceptance into existing and new markets.

Task 6 Environmental, Safety and Health Programs

First Solar, LLC shall continue to refine and improve its Environmental, Safety, and Health, (ES&H) programs throughout its facilities. First Solar shall conduct an extensive review of its current programs and highlight areas that need improvement. First Solar shall employ industry experts such as OSHA On-Site Consultation of the Ohio Bureau of Employer Services to expedite progress on improvements and provide guidance for plan implementation. First Solar shall initiate improvements through a series of training and educational seminars for its employees affected by the targeted issues. First Solar shall complete the implementation of refinements and improvements in critical areas and establish a plan for continuous improvements in its entire program. This task is expected to result in an Environmental, Safety and Health program which ultimately will place First Solar in a leadership position relative to comparable businesses both within and outside of the photovoltaic industry

5.1. Phase II Results for Task 4,5,and 6 Milestones

5.1.1. Task 4 Milestones--- Manufacturing Line Improvements

m-2.1.1	Complete thorough review of potting preparation and potting processes including time studies; equipment utilization; materials yield; and flow	(Task 4)
m-2.2.1	Complete potting improvement plan including methodology and resource allocation	(Task 4)
m-2.3.1	Complete initial testing of potting process improvements	(Task 4)
m-2.4.1	Complete demonstration of improved potting process	(Task 4)
m-2.4.1b	Complete thorough review of laser scribing process including parameter flexibility, capital costs, and cycle time	(Task 4)
m-2.4.2	Complete the Phase II portion of the effort under Task 4	(Task 4)

Milestone Description

m-2.1.1	Complete thorough review of potting preparation and potting processes including time studies, equipment utilization, materials flow, and yield

As a result of combined team activities of First Solar and Product Search, Inc., this milestone was completed successfully. An account of these activities follows. The objectives of the potting task in Phase II were to:

- increase manufacturing throughput by a factor of four,
- reduce labor costs by a factor of ten,
- increase overall quality.

In May 1999, at the Solar Finishing Line Concept Design Review the results of the module qualification task for Phase I PVMaT were reviewed. A round of modules had been submitted for qualification to Arizona State Photovoltaic Testing Laboratory for IEEE 1262 Testing. Those modules failed two of the four sequences, the humidity-freeze test and the damp-heat test. From this report it became apparent that the polyurethane potting method for the electrical contact termination and for the molding of mounting pads may have to be replaced, in order to achieve the goals of environmentally durable device, a high-throughput manufacturing process and a cost-effective product.

In response to that, from the beginning of Phase II several alternative module finalization schemes have been evaluated toward achieving the Phase II qualification objective. Three possible solutions have been investigated simultaneously or in close sequence starting in June 1999.

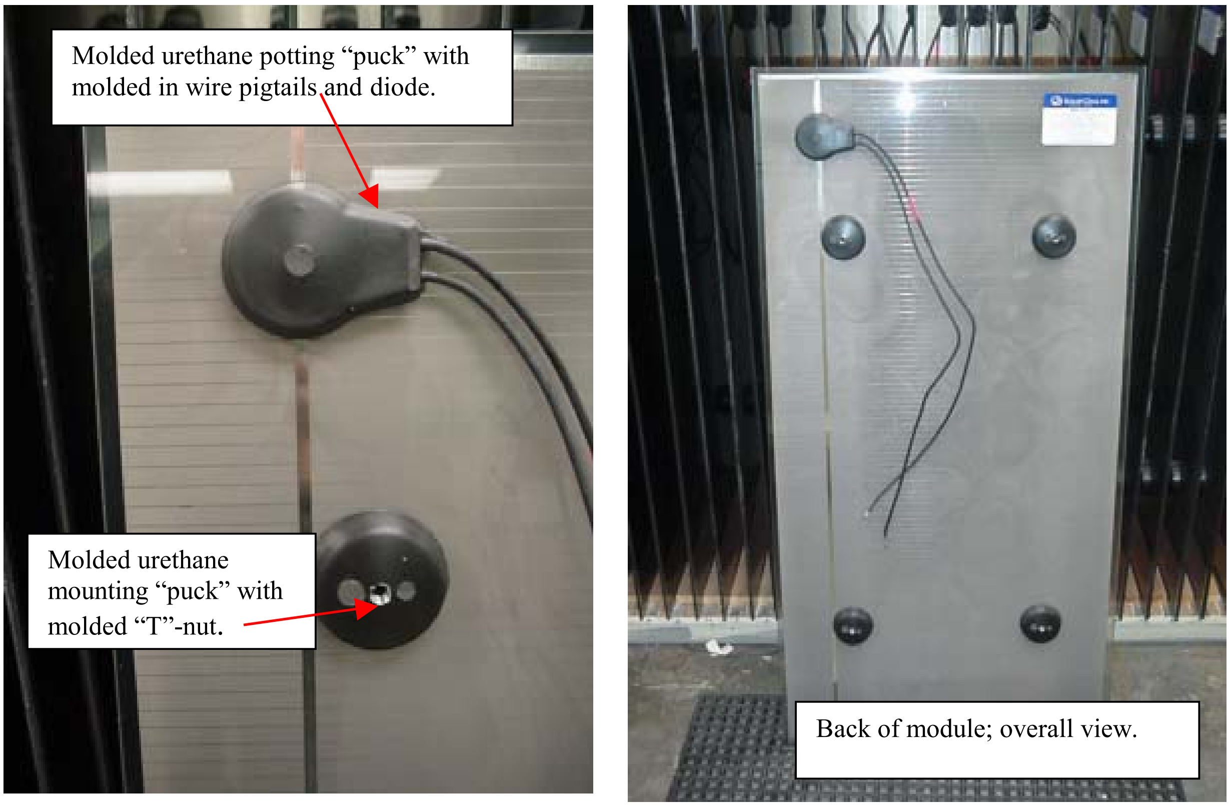


Figure 4. **Photographs of potted polyurethane termination "pigtails" and mounting pucks on the rear of PV modules—(a) a close up of the potted parts and (b) a view of the whole module.**

A practical alternative method of mounting has been identified, patented by PowerLlight, Inc. This method, developed for a horizontal mounting on rooftops, utilizes the modules bonded to a solid foam material and interlocked together, much like a puzzle, in cushioned frames. This method does not require either mounting pads or fastening of the modules to the frame. Several other sketches have been made for alternative mounting but thus far none have been selected for development, pending successful development of contact termination.

Contact Termination

The Top-Hat design for contact termination

In considering the projected production line improvements, potential cost-reduction measures have been identified in potting, labor and material and increased throughput. The Top-Hat design was one of the items where sizeable cost reductions appeared to be achievable by eliminating the potting process both for the termination and the mounting pads. For the electrical termination a small, injection-molded part called the Top Hat was designed and its development was initiated. The Top Hat is an electrical connector fixture made of polymeric material as shown in a photograph in Fig. 5.

The Top-Hat design was intended to replace the potted polyurethane termination shown in Fig. 4a that uses wire termination, referred to as "pigtails." It uses metallic "spade" terminals that are soldered to the two metallic strip conductors. In this design, the bottom rim of the Top-Hat fixture would fit underneath the cover glass. The fixture is affixed to the module by means of EVA pressure lamination. The Top-Hat connector and method were designed for high-throughput production of PV modules, low cost, and simplified method of installation of the modules in the field.

Figure 5. A photograph of the "Top-Hat" termination fixture

Milestone Description

m-2.2.1	Complete potting improvement plan including methodology and resource allocation

The plan for potting improvement, now called contact termination, was initiated during the 2nd quarter of 1999 and completed during the 3rd quarter as described below. For testing of the Top-Hat concept in finished modules, prototypes of the Top-Hat fixtures were NC-machined of phenolic material. In eventual production, the fixtures would be made by injection molding. Testing of assembly fixturing was done first, to facilitate the attachment of the lead wires to the Top-Hat connector and of the resulting assembly to the double-sided tape that's on the module. A total of over 25 modules have been made incorporating the Top-Hat connector. These modules were intended to be submitted for UL testing, following in-house testing.

The second half of the Top-Hat fixture design is a matching connector, which was to be fabricated following the planned testing.

On August 26, 1999 preliminary product specifications, including drawings were submitted to UL for their preliminary review and evaluation. In this process UL conducts an "Engineering Evaluation," of the documentation and attempts to form a visual picture of the product, what the components are and how it's put together. Then UL provides a feedback based of potential problems and issues.

Following the fabrication of the modules using the Top-Hat connector for termination, the devices were subjected to damp-heat tests, which were completed in October. Some problems with the pottant have been identified. The potting that was being used for the Top-Hat insulation, a RTV silicone, was failing under strain relief testing. This problem was due to the size of the termination cavity, being potted to provide the strain relief. It was also too thick and the RTV would require an unacceptable curing time. Otherwise, from the standpoint of moisture-proofing, RTV tested to be satisfactory. Nevertheless, the Top-Hat design was abandoned and replaced by a new termination design, named the "*Cord-Plate"* design, wherein the stress-relief failures were expected to be eliminated. Sketches of the Cord-Plate termination design are shown in Figures 4 and 5 of Milestone m-2.3.1 Section.

UL report on "Results on Preliminary Investigation" for the Top-Hat design

Some memos and documentation has been received from UL throughout October regarding the Engineering Evaluation of the product specification and module mockup submitted in September. A preliminary report was received from UL in mid-November called "Results on Preliminary Investigation," which is included in the monthly reports. It contains extensive evaluation, their comments and the feedback they gave us. The report contained mainly comments related to product materials used in the Top Hat, to passing product flame-retardant tests, other issues about thermal testing, and more on flame retardant materials, and thermal tests to which all the materials and modules were to be subjected.

A major issue that UL raised that the mounting method for the module had not been submitted. Without the mounting method, all that UL could provide was only with "Recognition" of the PV module and not an actual listing. In order to get the listing, the complete package must be submitted, including the mounting method, termination and all aspects of finalization. Reading of the entire report prior to future submission is advised. As stated above, the initial submission included the Top-Hat termination design. However, in November timeframe some strain-related problems were discovered with the Top-Hat design. On November 11 a memo was sent to UL to have the test postponed. It was anticipated that the submission to UL would be made in January 2000 following the fabrication and in-house testing of modules incorporating the new Cord-Plate design.

Milestone	**Description**
m-2.3.1	Complete initial testing of potting process improvements

This milestone was completed with success. Two major accomplishment were achieved, one in successful testing of a new module design with "Cord-Plate" contact termination and the construction, installation and initial testing of the solar finishing line for the

The Cord-Plate termination design

In going over a possible redesign of the Top Hat, a decision was made to pursue a new design, the *Cord-Plate* design to circumvent the problems posed by the Top-Hat design.

Work on the Cord-Plate design began on November 15, 1999. Thus, once again, a new line layout was developed for the termination process. It involved the design of a new electrical connection fixture, shown in Fig. 6, and the use of EVA as the encapsulant for the lamination of the module. Prototypes of the Cord Plate were made by NC machining, using a polymeric material. Incorporation of the Cord Plate in the modules was done by attaching it to the module by means of Very High Bond (VHB) adhesive tape, a 3M product. The VHB tape that is currently used to attach the Cord Plate to the surface of the module is 3M # 4941-F, 0.046-inch thick. The potting material used to pot all of the termination locations is 3M # 3748-VO-Q JET-MELT. The new design utilizes MC (Multi-Contact Corp.) connectors.

Then a potting material 3M # 3748-VO-Q JET-MELT is used to all of the termination locations. The new design utilizes MC (Multi-Contact Corp.) connectors. The new design also made use of the FC connectors. The manner in which the Cord Plate is incorporated on the rear of the PV module is shown in Fig. 7. Following the fabrication of PV modules using the Cord Plate, in-house testing of the product was conducted. The tests included the damp-heat, humidity-freeze tests, followed by the hi-pot tests, and the current leakage tests. The high-pot and the current-leakage tests were the most stringent tests that had to be passed. One of the main concerns was whether the VHB adhesive would withstand the environmental tests.

Prototypes of the Cord Plate were fabricated by NC machining from a suitable polymer. It is planned, that in production, these components will be made by injection molding. The parts were then used as electrical connectors for termination in PV modules.

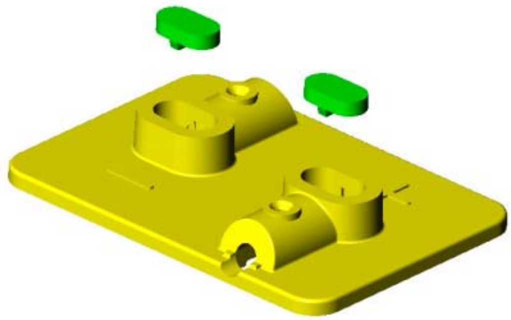


Figure 6. A sketch of the "Cord-Plate" contact termination fixture

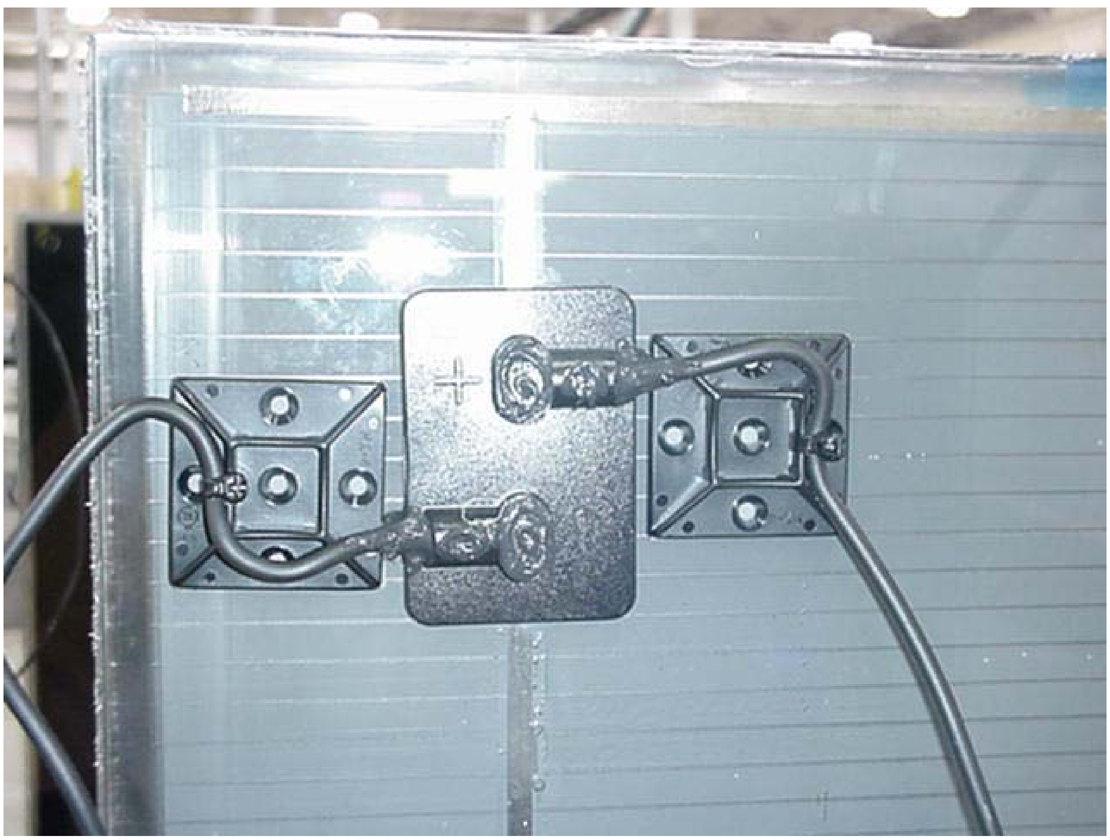


Figure 7. Photograph of the "Cord-Plate" termination fixture, including the power-lead strain relief, incorporated in a module

As stated previously, EVA was used as an encapsulant in the lamination of the modules. The modules have been fabricated through a collaborative effort between First Solar in Toledo and Product Search, Inc., in Scottsdale. The finished modules were sent to the Arizona State University (ASU) test lab for UL listing application testing.

Initial test results indicated that all the modules came out of the damp-heat test thermal chambers, with no breakage, and they went into the dry hi-pot, the humidity-freeze cycle test all passed. The modules also performed well in the wet hi-pot test, and with only one failure of a total of 24 modules sent. From previous experience, passing of the wet hi-pot was the biggest concern as indicated. There was only one minor item that required a change for power-lead strain relief, which was accomplished successfully shortly thereafter.

This accomplishment marks the completion of the front half of the finishing-line project, which includes the buss bar application, laying down the EVA, installing the back glass, putting on the silicone rings and getting it to the point where it goes into the oven or autoclave for encapsulating. There was a good indication that this process can be accomplished on the production line.

Design, construction and installation of the Cord Plate and contact termination assembly lines (A report by Product Search, Inc.)

As reported in Task 5, there are positive indications that the latest product design using the *Cord-Plate* termination method was expected to pass the UL testing. This news enabled all line assembly methods and automation design efforts to proceed at full speed. A final installation and start-up date in the new Cedar Park facility was established as April 10 thru April 28 of 2000.

Product Search, Inc. shipped the pre-lamination (buss bar, EVA, back glass and seal ring) assembly line the last week of Feb. 2000 and installed it in the Cedar Park facility the week of March 5th 2000.

All efforts were focused on the completion of the Cord-Plate assembly and contact termination assembly lines. This phase of the project also incorporated automated hi-pot testing and solar simulator testing with a production throughput rate of one module per minute. Coordination efforts with Vortec Industries as manufacturer of the simulator and Product Search as automation integrator were completed.

Product Search has completed the design and construction of the Cord-Plate assembly and hi-pot and solar simulator test equipment in Scottsdale, AZ. The planned shipment, installation and start-up is April 11 through April 28, 2000. Some documentation activity (i. e., manuals, drawings, etc.) was scheduled to continue for a few days in May 2000. This installation will conclude the activity of Product Search, Inc. in Phase II of the project. Quotes have been provided for an additional solar simulator at the submodule line. Completion and installation of the solar finishing line

Product Search completed the engineering design and build of the SOFL (solar finishing line) project at the Scottsdale, Arizona location. Limited operation of equipment and assembly tables was performed to debug equipment functions and assembly methods. However, a more intense debug test run of equipment operation was planned upon the completion of its installation at First Solar in Toledo. As stated earlier, Product Search shipped the pre-lamination assembly line and installed it in the First Solar facility during the last week of February, 2000. The remaining equipment, identified as the "Cord-Plate assembly", "I-V test station" (solar simulator), and "Hi-Pot station" were shipped and received on April 14^{th}.

Product Search personnel were on site at First Solar on April 17 through April 28, 2000. Installation and initial start-up of the equipment was completed. Photos of various parts of the new solar finishing line are shown in Figures 8, 9, 10 and 11. Because of the late delivery of the Vortec I-V test equipment, time did not allow for adequate operator training and pre-production operation of the equipment. A second trip to First Solar for actual start up and operator training was planned for later May 2000. At that time operator manuals and electronic data-base files were to be transferred.

Upon completion of the training, Product Search Inc. will have completed involvement with this phase of the project with exception of service support or other tasks requested by First Solar. The completed task, which meets the initial goals, was to design and build an effective and safe production process. Baseline production throughput and associated labor cost will need to be monitored to evaluate actual process improvement.

Figure 8. EVA sheet application station before lamination – start of solar finalization line

Figure 9. Hi-Pot testing station after lamination

Figure 10. Cord-plate contact termination application line

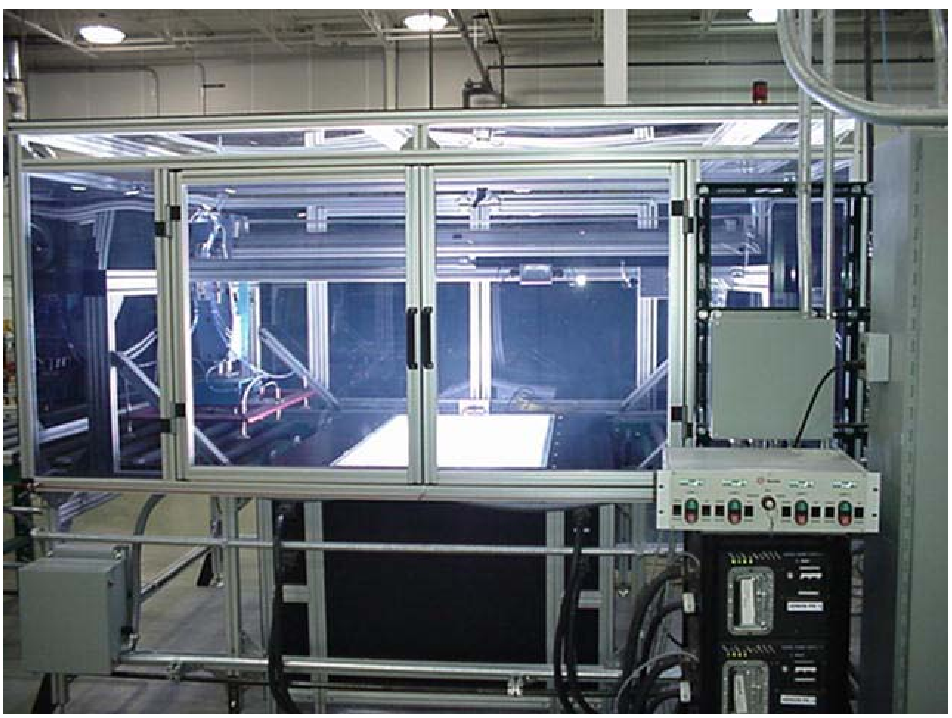


Figure 11. Current-Voltage (I-V) test station, solar simulator

Milestone	**Description**
m-2.4.1	Complete demonstration of improved potting process

Module Finalization

In May, the activity consisted of preliminary testing of the lamination process, using rejected modules for the purpose of determining yield and cosmetic quality. The yield on 20-plate batches was 95 percent for things like voids, bubbles in EVA and module breakage. In June, the next step was to undertake module production, using good quality submodules. For the past two weeks, good sub-modules were being processed up through lamination, 20 modules per day. The modules were used for test purposes—in preparation for passing the IEEE test. High yield was demonstrated with the processed modules. One of the items of interest was to determine what effect the heat in the lamination process had on the module efficiency. In the Westwood plant, where autoclave was used, the typical decrease in efficiency was 0.4% (absolute) of the module efficiency, equal to a decrease of about 5 W per module. What has been demonstrated using the new lamination process at the new Cedar Park plant, with relatively few modules, was that the decrease in efficiency was only 0.1 to 0.2 %. This improvement is attributed to a more stable cycle, being run at a slightly lower rate, with no overheating of the modules. There is no temperature uniformity problem that the autoclave had. More tests are needed to establish confidence in this conclusion.

Majority of these modules have not gone through the Cord-Plate processing, because they were consumed in other tests, which did not require the Cord Plate. In this time frame (June 2000) the Cord-Plate process was not in operation because the second half of the line was down on account of the hi-pot tester not performing reliably. These problems were being addressed as well as those of the automated I-V test station. There were also some hardware problems that are being rectified working with the vendor.

In July the status of the solar finishing line has not changed since June. The rate of module lamination has remained constant (100/week). Problems have occurred with the software of the automated I-V testing station, which required sending the modules for testing to the old pilot plant at Westwood. Some problems have also occurred with buffing of the glass side, edge deletion, and delamination of the plates which are being resolved as part of de-bugging of the manufacturing process.

Repair of the test station was completed by mid August. At this point the production rate was increased to 200 modules/week (40-hour week). Thereafter plans are to ramp up production on a monthly bases by 200 modules/week up to a goal of 1000 modules/week by the year end. A report on successful UL qualification of the product appears in the Task 5 Section.

Milestone Description

m-2.4.1b	Complete thorough review of laser scribing process including parameter flexibility, capital costs, and cycle time.

This milestone has been successfully completed. Detailed description of the work during the 2nd quarter of 2000 is listed below, followed by the summary of the accomplishments.

Laser Scribing

Review of the laser-scribing process

Cell interconnection by the use of laser scribing is a new task to Phase II. The stated objective is to implement an improved scribing technique and design associated equipment, so as to result in low-cost scribing by increasing the throughput by a factor of two, and reducing the downtime by a factor or three and reducing capital requirements by at least a factor of two.

With the imminent scale-up of PV module manufacturing throughput at First Solar, to anticipated 20 MW within a year and 100 MW within 2 to 3 years, the R&D and Engineering teams have been facing a major challenge of putting in place appropriate laser facilities to handle this task. Up until recently a Q-switched, lamp-pumped, frequency-doubled, neodymium YAG laser for the scribing, which emits green light at 532 nm. Lamp-pumped lasers operate at a low pulse frequency of up to about 20 kHz and at a long pulse width of up to several hundred nanoseconds (ns) which limit their scribing rate to about 20 cm/s, same as the maximum rate disclosed in several patents [1, 2] and published articles [3, 4]. With the existing systems, a continuously operating single laser system at a 100% yield would theoretically support a throughput of only 30,000 modules per year, equivalent to 1.5 MW/year. In addition, the frequency-doubled, green-light emitting lasers have a limited life of only about 700 hours, imposed by the frequency-doubling crystal, which along with their higher initial cost makes their use for high-rate production prohibitive. It is to be pointed out that while prior art identifies important desirable characteristics of the lasers and a number of preferred methods of operation, there is no recipe given that would teach how to increase the production rate significantly and at the same time to reduce the system and operational costs.

In order to eliminate this production bottleneck, the main objective of the effort at First Solar is to increase the rate of laser scribing per single laser by a factor of greater than two by taking advantage of newly discovered phenomena, and of ongoing improvements in instrumentation, components and methods. As it turned out, an increase by a factor of ten appears feasible.

The second objective is to develop means for predicting laser specifications and system operating conditions required for increasing the rates of laser scribing.

The third objective is to identify the most suitable lasers from the standpoint of performance, energy efficiency, cost, longevity and serviceability.

The fourth objective is to identify a laser system and method capable of performing all three types of scribe lines needed (S1, S2, and S3) at high speed, good depth and shape control, reproducibility and reliability.

The fifth objective is to achieve all three scribes without significant impairment of the transparent conducting oxide (TCO) electrode and without creating electrical shunts and shorts along the scribe lines.

The sixth objective is to provide a suitable means of scanning the laser beam at required speeds to achieve the required scribing rates. This is the most important objective for developing the production system in the PVMaT program.

Considerable effort has been expended toward these goals during the period of July 1998 to February 1999 under Solar Cells and First Solar funding, which is summarized by the way of introduction. As the first step toward achieving said objectives, modeling of the laser-scribing process was performed to facilitate the prediction of the laser scribing parameters. In this modeling the laser scribing speed and the laser wavelength were the only independent parameters. Equations have been identified or developed for predicting laser parameters or process conditions, the most important of which were average laser power, peak pulse power, and pulse frequency. Key input parameters include laser pulse width, pulse energy, scribed area and the material being scribed.

Next, a new laser, heretofore not reported as being used for laser-scribing of solar cells, has been identified as potentially suitable for rapid laser scribing of CdTe-based solar cells of up to 300 cm/s. It is a diode-pumped, Q-switched, neodymium-doped, yttrium vanadate laser, radiating at a near-IR wavelength of 1064 nm, operating at a pulse frequency in the range of 5 to 100 kHz, and with pulse width ranging from 8 to 20 ns. Single-laser units of up to 10 W are now commercially available, which can be combined in a single beam in the multiples of 10 W. Its cost is about 20% less than that of a frequency-doubled laser and its life expectancy is 10,000 hours. It is to be noted that the same near-IR laser delivers approximately twice the average power than the frequency-doubled laser. In addition, replacement of the photodiode assembly at the end of life is a simple task. In some models the replacement requires only about 15 minutes at a replacement cost of only about 20% of the cost of the laser.

At First Solar, experimentation with the vanadate laser began in early 1999 and soon after it was followed by the design of the galvanometer-driven laser scanning system for module production. A description of this effort follows.

Laser scribing experiments – establishing process latitude (parameter flexibility)

A major task was to establish whether the near-IR laser could make scribe lines in the solar-cell layers as good as the green laser, in view of the fact that the reported optical absorption of the near-IR radiation by CdTe is much less than that of the green light at low light power. The performance of the near-IR yttrium vanadate laser was therefore evaluated to determine its limits of practical performance. Very effective laser scribing has been demonstrated by First Solar for all three scribe lines both from the film side and the glass side. Scribing from the glass side was found to be several times more energy efficient and, therefore faster, than scribing from the film side, in agreement with previous reports [3, 4] for the 1064 nm radiation.

In addition, scribing of the S2 and S3 lines from the glass side using the high-pulse frequency at low pulse width, the near-IR yttrium vanadate laser has been found to be more reproducible and better quality, than with the frequency-doubled, green-light laser.

In order to take advantage of the rapid scribing capability of the Nd:yttrium vanadate laser, the "flying optics" normally used on X-Y laser-scribing tables, with a maximum linear speed of 30 cm/s have been substituted by a stationary galvanometer-driven scanning mirror, capable of order-of-magnitude increase in the scanning rate of the laser beam. Development of a module-scribing process using the galvanometer now in progress since the summer of 1999 has become a part of the PVMaT project in the eighth quarter. A summary of the activities toward establishing process latitude is given below.

- A series of bench-top tests was done with a Spectra Physics ND:YVO4, 20W, Model T80-YHP40-106QW laser. The beam was traversed with a General Scanning Z-axis Galvanometer over samples of CdS/CdTe cells on 4-inch square substrates. The beam was focused to provide minimum kerf width of approximately 50 microns, at a given speed. No attempt was made to measure theoretical spot size.
- These tests are being performed to establish the feasibility of scribing the solar cell layers from the glass side. This involves the laser radiation passing through the glass substrate undisturbed, and then selectively removing semiconductor and/or metal coatings based on energy density.
- Earlier tests have shown a window of energy needed to create each scribe. An example of laser-scribing parameters investigated to determine process latitude is given in Table 1.
- Data of this type are used for the determination of window of conditions of average laser power, pulse repetition rate and pulse energy for obtaining the desired scribe. As shown in Table 2, these three conditions are interrelated.

Construction of the laser-scribing equipment

During the seventh quarter, the effort was focused on building of the laser-scribing equipment in Scottsdale, AZ. At the same time, some test runs to determine the cause of what appeared to be erratic pulses from the laser. Scribing was being done to further determine the parameters for optimum ablation. It was noticed that some portion of the scribe lines appeared to have areas where the laser was turning off. These scribes were done at 2000 to 3000 mm/second at repetition rates of 70 to 80 kHz. Subsequent tests showed this pattern changing with different 10 cm x 10 cm panels. Tests were then made on panels from the new 100 kW/year deposition system, called GDS, and the pattern disappeared. When analyzed at the First Solar Technology Center in Perrysburg, these samples did not show any significant film thickness variation. However, here was small difference in grain size.

Delivery and installation of the rapid production laser system to Cedar Park

Through the month of June 2000 the laser system from Arizona Manufacturing was shipped to Cedar Park and installed. This system employs a galvanometer-driven, laser-scanning system for rapid laser scribing. The wiring was connected, air supply and nitrogen supply provided (the latter for the lenses) and communications connected to the local network. Currently the software is being completed to control the overall system. The system consists of six major parts: (1) the load station, (2) the scribe station, (3) the unload station, (4) the laser with galvanometer-driven mirrors, (5) the process control (PCs), and (6) the power station. Figures 12 and 13 show photographs taken from the entrance and exit sides of the system.

INPUT	wavelength (nm)	Rep. Rate (khz)	Ave. Power (watts)	Pulse Duration (nsec)	Dot Dia. (microns)	Line Speed (mm/sec)	Pulse stability (%)	OUTPUT	Resistance (ohms)	Dot area (cm2)	Dot Spacing (microns)	Dot Overlap (d-V)/d	Energy/Pulse (uJ)
1331-05		60	12.4	60	75	3000			900	4.E-05	50	33%	207
1332-07		60	12.4	60	75	3000			1000	4.E-05	50	33%	207
1331-03		60	13.4	60	75	3000			1200	4.E-05	50	33%	223
1331-04		60	13.4	60	75	3000			3000	4.E-05	50	33%	223
1331-02		60	14.5	60	75	3000			500	4.E-05	50	33%	242
1331-01		60	15.3	60	75	3000			1200	4.E-05	50	33%	255
1333-01		70	8.0	69	75	3000			250	4.E-05	43	43%	114
1333-02		70	9.2	69	75	3000			220	4.E-05	43	43%	131
1331-12		70	10.0	69	75	3000			40	4.E-05	43	43%	143
1331-14		70	10.0	69	75	3000			35	4.E-05	43	43%	143
1332-02		70	10.0	69	75	3000			35	4.E-05	43	43%	143
1333-03		70	10.0	69	75	3000			40	4.E-05	43	43%	143
1333-04		70	11.3	69	75	3000			190	4.E-05	43	43%	161
1333-05		70	12.5	69	75	3000			120	4.E-05	43	43%	179
1333-06		70	12.5	69	75	3000			800	4.E-05	43	43%	179
1331-13		80	10.4	75	75	3000			30	4.E-05	38	50%	130

Table 1. Example of laser-scribing process parameters for determination of process latitude

Rep Rate (Khz)

Average Power (diode current)	40	50	60	70	80	90	100	Average Power (watts) at 70 Khz
28								4.8
29			1408 E=98	1404 E=83	**1402 E=73 poor**	1399 E=64		5.8
30			1407 E=113	1403 E=99	**1401 E=86 poor**	1398 E=77		6.9
31	E=200 poor		**1332-08 E=133 good S2**	**1331-01 E=114 good S2**	1406 E=101	**1397 E=88 poor**		8
32		**1332-10 E=176 poor**	**1331-08 E=152 fair**	**1331-02 E=131 good S2**	1405 E=116	1396 E=102		9.2
33	E=250 poor		**1331-09 E=167 poor**	**1331-14 E=143 fair**	**1331-13 E=130 good S2**	1395 E=113		10
34				**1333-04 E=161 poor**		1400 E=128		11.3
35				**1333-06 E=179 poor**	1410 E=156			12.5
36								13.5
37								14.7
38								15.5
39			E=255 poor					16

Table 2. A chart showing the process latitude of laser-scribing parameters for scribe-2, including average diode current, average laser power at 70 kHz, pulse rate, and pulse energy.

Figure 12. Photograph of First Solar rapid laser-scribing system, showing the loading station, the process control station the scribing station (enclosed in cabinet), and the power-supply station (to the rear)

Figure 13. The laser scribing system - the unloading station and system side view

Shortly after the installation, first glass plates have been successfully moved through the laser scribe station, which is in the center of three stations. After minor adjustments, moving of the glass appears to be working well.

The immediate goal was to finish up the movement of the glass and also to integrate the laser into the system, making it ready to test laser scribing of the modules. Accordingly, during July the following tasks have been completed:

- The mechanical, optical, and electrical alignment of the entire optical train
- Installation of sufficient software to move the glass panel through the machine in proper sequence.
- Installation of sufficient software to scribe the glass accurately and rapidly. The first few tests show that Scribe 1 can be done easily at ~ 1600 mm/s, scribe 2 at ~2500 mm/s, and Scribe 3 at ~ 3300 mm/s compared with ~300 mm/s for the existing scribing system now in use.
- Installation of sufficient software to control the system with both "step and cut" scribing and "continuous motion" scribing. The first timing demonstrations at a scribing speed of ~2500 mm/s resulted in the scribing portion of the machine cycle, yielded times for ~32 seconds for the "continuous motion" method and ~79 seconds for the "step and cut" method per panel.
- Completed some accuracy tests with excellent results. Measuring over 90 scribes with 1-cm spacing, the tests show the system accuracy in the range of ~100 microns cumulative error, or ~ 1 micron per scribe. In comparison with scribing done on the present, production ILM system, the same measurement indicated ~ 1490 microns over 90 cm.

It is expected that within the next few weeks the process parameters will be established for the laser and machine variables, reduce process time, and interface and maintenance software capabilities added. This system will be used for Scribe-1, in which the semiconductor layers and TCO are patterned.

At the First Solar Laser Group in Scottsdale, AZ, the second laser scribing system is nearing completion, which will be used for Scribe-2 and –3, in which the semiconductor layers and the metal electrode layer are patterned, respectively. For all three scribes, scribing is done from the glass side, which is several times faster than scribing from the film side. The scribing procedure will be described in future reports. Wiring of the second system has been completed and checked and mechanical connections finalized. Upon completion, the system will also be moved to the Cedar Park production plant in Perrysburg, OH. Additional work was conducted and documented under section 6.1.1 Task 7 on page 46.

Summary of Milestone m-2.4.1b accomplishments

Description of the laser-scribing process

- A panel is loaded into the Load Station either by an operator or automated equipment. This loading equipment is in-house but has not been integrated as of this date.
- The panel is operator inspected for debris or smudges and cleaned as needed.

- The operator presses the start button and the panel moves to a vertical position and indexes to the bar code read position.
- The panel then moves into the Scribe Station and is automatically transferred to the scribe carriage.
- The scribe carriage moves into the scribe location and fiducials are read and scribe position errors compensated for.
- At this point the vacuum/air pucks are holding the panel at the correct focal point and 3 laser distance gauges have verified the focal plane.
- The panel is then scribed, from the glass side, with 117 scribes as the carriage moves at a constant velocity.
- An alternative scribe process for scribes 2 and 3 is to locate scribe 1 with the vision system, calculate position error, compensate for error, add next scribe, locate next scribe 1 and repeat. This greatly slows down the process but may need to be done until the ILM can place scribes repeatedly in the same location. It may be done on each panel or on a sample basis until confidence is gained.
- After the last scribe has been completed the panel is transferred automatically from the scribe carriage to the exit rollers.
- The panel exits the machine and is placed in the Unload Station.
- The panel is then removed by the operator or by automated equipment (in house).

Parameter flexibility
Initial bench tests described above show the windows for the scribes. Determination of the parametrics on the actual installed production equipment is forthcoming.

Capital costs
The first two systems look like they will be about $320,000 each plus design labor. Additional systems are estimated to cost $300,000 plus $160,000 labor. For comparison, ILT had given us a bid of $720,000 for a four-head system much like the current ILM system.

Cycle time
The systems were designed to meet a one-minute per 120 cm x 60 cm panel cycle time allowing 37 seconds for a scribe. The present speed is two minutes per panel, as we have not yet started to optimize the speed on various functions. If we are required to locate each scribe as described above the time goes to 4 to 5 minutes per panel. This is viewed as temporary but does add flexibility to the system.

Milestone	**Description**
m-2.4.2	Complete the Phase II portion of the effort under Task 4.

This milestone has been accomplished.

5.1.2. Task 5 Milestones--- Product Readiness

m-2.1.2	Initiate contact with the module testing laboratory and complete preliminary module design review	(Task 5)
m-2.2.2	Complete preliminary testing of First Solar's modified modules	(Task 5)
m-2.2.3	Establish qualification testing schedule.	(Task 5)
m-2.3.2	Initiate qualification testing on First Solar's modified module	(Task 5)
m-2.4.3	Complete qualification testing on First Solar's modified module UL1703	(Task 5)
m-2.4.4	Complete the Phase II portion of the effort under Task 5.	(Task 5)

Milestone Description

m-2.1.2	Initiate contact with the module testing laboratory and complete preliminary module design review

This milestone was accomplished. Periodic communication with UL was maintained both for contact termination and module finalization (Tasks 4 and 5) throughout Phase II.

Preliminary Module Testing Report and Testing Schedule

In Phase I of this work, testing by the Arizona State University Photovoltaic Testing Laboratory according to IEEE 1262 protocol resulted in module failure for the damp-heat test (sequence "C") and the heat-humidity-freeze test (sequence "B"). Based on these results, a plan was developed to identify and correct module design and lamination process issues to allow passage of both IEEE 1262 and UL 1703 qualification tests during this phase of the work. This was not only an important objective for PVMaT, but the PV market demands these certifications and First Solar must achieve them to be commercially successful in the short term.

Specifically, the plan elements to achieve certification were to:

- Evaluate increased edge deletion area as a way to prevent or delay moisture ingress
- Test various edge potting concepts to provide another barrier at the semiconductor/encapsulant interface
- Continue testing of the liquid resin alternative to EVA
- Test insulated glass encapsulation as an alternative to a full contact interlayer
- Verify the thermal uniformity of the autoclave laminating device and confirm appropriate pressure and temperature cycles
- Review the First Solar lamination process with STR (the EVA supplier)
- Test alternative edge preparation techniques
- Investigate different potting techniques
- Develop more rigid cover glass flatness requirements with the cover glass vendor

Solar Finishing Line Concept Design Review

The design review was already discussed in Task 4 in reference to the solar finishing line.
At the design review meeting it was also recognized that the issue of the module lamination had not yet been settled. Accordingly, work was to continue at First Solar in Toledo on the

cold-cure polyester lamination that had shown promising results to date, and in parallel a new effort was to begin at Product Search. Accordingly, evaluation of other alternatives with two other resin manufacturers was initiated and was well underway by the end of May.

Milestone Description

m-2.2.2	Complete preliminary testing of First Solar modified modules

Prior to completing preliminary testing of modified modules both the contact termination (see Task 4) and module lamination had to be firmly established. The work on module lamination is summarize next. By the end of the sixth quarter the milestone was completed.

Module Lamination

In response to the failed qualification tests of the modules – from the beginning of Phase II several alternative module finalization schemes have been evaluated toward achieving the Phase II qualification objective. In addition to work on the EVA pressure-lamination process, several possible solutions have been investigated simultaneously or in close sequence starting in June, 1999.

Problems and improvements in the EVA pressure-lamination system

Toward the end of Phase I, two failure modes have been identified. The first one is migration of moisture from the edges of the module along the interface of the front substrate glass and of the EVA laminate to the metal and semiconductor layers, causing their corrosion and failure. Several solutions to this problem have been attempted, including work on three different lamination concepts. These attempts are described in detail in the November 1999 Deliverable 2.2.2. The following is a summary of this work.

The migration of moisture along the edges is facilitated by a 1-cm wide, "edge-delete" region along the periphery of the coated substrate, which is actually a small step in the glass, formed by grit ablation of the deposited layers. Another cause of failure was found to be the deionized water used to wipe off the dust following the edge deletion. By changing to isopropanol, the modules survived the test, thereby removing the main cause of failures.

In an attempt to find another solution to the moisture-ingress failure mode, development of *an edge-potting technique* was attempted, similar to that used in the crystalline silicon modules. The modules were failing the damp-heat test. The likely reason that edge potting works for the crystalline silicon and not for thin-film modules is that with silicon modules use two layers of EVA, whereas the thin film modules use only one layer.

A secondary mode of failure has to do with incomplete adhesion of the back substrate to the front substrate, which is exacerbated through thermal cycling or thermal stress. Sometimes there would be just a wholesale mechanical failure where the module will delaminate or delaminate in places. Then the electrical contacts get torn off and the module quickly fails.

Several test failures in pressure-laminated modules using EVA have been traced recently to the autoclave, the racks on which the modules rest, the means of applying vacuum between the plates, and the non-uniform heating of the modules. A painstaking review of these issues was made, followed by modifications in the laminating system, as described in the monthly reports. Substantial improvements in the module performance and durability have been achieved, as well as increased production capacity. Eventually with continued improvements the EVA pressure lamination process proved to be sufficiently reliable to be adopted for submission of the modules for UL qualification and for production.

Concurrently with the improvements on the pressure lamination process, three alternative lamination methods were under development, as summarized next.

The cold-cure liquid polyester resin laminate system

Work on the cold-cure liquid polyester resin laminate system had been initiated during Phase I. The process involves placing a cover glass over the substrate plate bearing the solar cell layers, placing a double-sided tape on all four sides, leaving a release liner in place on the fourth side, dispensing the resin in it, removing the liner and closing the glass envelope.

Three modules were made with each of three types of cold-cure liquid polyester resin supplied by Zircon, Inc. They were subjected to an in-house environmental testing. In the best cases the modules passed the severe damp-heat test. All three gave indications of exceeding the high temperature/high humidity requirements of the IEEE qualification testing.

The advantages to this system, include process simplicity, low equipment cost, one half the material cost, compared with the EVA process, and the use of flat, annealed back glass. The process also achieved two goals of Phase II, namely, a 25 percent materials cost reduction, and a throughput of 60 modules per hour. Furthermore, there is no degradation in conversion efficiency upon lamination, compared with a relative loss of about 5% in the EVA pressure lamination process. The main disadvantage of the cold-cure process is that it was designed to cure in 24 hours. This lengthy cure would impose a requirement of providing enough space to carry a day's inventory and for allowing the product to cure before it is shipped.

The insulated glass concept for module finalization

Insulated glass technology, originally developed by Pittsburgh Plate Glass, is a concept widely used in commercial building and residential home windows as a means for thermal insulation. A company named Glass Equipment Development uses an improved process called *glass-intercept system,* capable of processing 16,000 square feet of glass in one 8-hour shift. It is a well-proven system, having been put through a very extensive and rigorous environmental testing. Golden Photon used this concept in its PV module finalization; their modules passed both the IEEE 1262 and UL 1703 testing.

Arrangements were made for finalization of three First Solar prototype PV modules to be done by this process. All three modules finalized by the insulated-glass process passed the damp-heat test readily, showing relative decreases in efficiency of 0.1, 4.8 and 9.4%, respectively, thus indicating a viable process for a durable product.

The advantages of the insulated glass product are that it is a proven concept and that the cost of finalization is lower by factors of two and four compared with the polyester resin system, and the EVA system, respectively.

Submissions of product specifications to UL

Product Search submitted the product specifications in September, and received some application forms from UL. Then a preliminary module mockup was completed by the end of September and sent to UL for engineering evaluation by October 1.

Milestone	Description
m-2.2.3	Establish qualification testing schedule.

The qualification testing schedule was established in January, 2000 by submitting modules to UL testing, thereby completing the milestone.

Modification of the manifold on the twenty-module lamination rack

Two changes were made to eliminate the bowing of the modules laminated on the 20-module rack. The spacer, made a silicone caulk, was replaced by accurately machined Teflon spacer, that had a lower coefficient of friction, allowing the module could slide on it. Secondly, center supports have been installed to protect the module from sagging in the middle. Initial tests with this modified rack have shown that the bowing problem has been resolved.

A third change consisted of modifying the manifold on the 20-module rack for the autoclave. It was found that using these two manifolds was that if we had a module that fractured during the evacuation cycle, there was a risk of losing vacuum along with all ten modules being laminated. The modification consisted of providing ten pairs of manifolds, each connected to a pair of modules. That way, if a module cracked, the only other module at risk, namely, its twin. This change resulted in an improved yield and reliability of the process. The change in the manifold design increased the product yield to 90 percent or better through the autoclave cycle. This improvement was specifically with respect to cosmetic failures, such as bubbles and voids that would occur in the EVA.

Submission of PV modules made with the cord plate to UL testing

Efforts to resolve the environmental problems with the cord plate continued into mid-January. Finally, by January 17 the results of internal testing with the humidity-freeze cycles, the environmental chamber, hi-pot testing, current-leakage tests were positive. Internal statistical evaluation indicated that the new cord-plate design had a good chance of passing the UL test and that the company had a good, viable product. Hence, the modules incorporating the Cord Plate have been submitted for UL testing in January.

The major issue then was to get through the UL testing. At this point there was some uncertainty about the material currently used for the cord plate. The intention was to use material called Valox that was used for the top hat. The Valox material was specified because of its dielectric strength and intended use for the top hat design which would have been inside a J box mounted to the module surface. The Lexan # 950 is also a good dielectric material but, in addition, it is also resistant to heat and ultraviolet light. This is required because the cord plate is not intended to be utilized within a J-box enclosure. However, a switch was made to Lexan, or a second alternate material. This switch was made in anticipation of better performance through the destructive testing to which UL subjects it.

It was expected that there would be some detail design changes in the cord plate, to enhance the manufacturability, the moldability, and performance of the cord plate. If the product were to pass the UL test a certain change would be that of going to injection-molded cord plates instead of the NC-machined parts used in these tests.

Manufacturing throughput and costs

Internal evaluation of the progress on the cord-plate termination process to date has made it possible to make projections of the manufacturing throughput and costs. Because of the elimination of potting, which was a time-consuming process, the projected production rate is one finished module per minute, which is about a ten-fold increase over the present rate. With respect to materials costs, First Solar achieved or will achieve the goal, of under $20 per unit, from the present $27 per unit. The materials include all items in the module except the substrate plate containing all of the deposited layers up through the back metal film electrode. It was also estimated that the direct labor cost will drop from the existing $20 to below $5 and conceivably down to $3.75 to $4 per unit. More accurate figures about the costs can be projected following the UL tests and listing.

Following the UL listing, preparations will be made for a new round of IEEE tests in view of fact that the module failed in two of the four tests in Phase I.

The urgency of obtaining the UL listing first is that the customers for First Solar product are demanding it, prior to making any substantial commitments for its purchase. In time, the IEEE approval will also be important for the installation, in obtaining building and construction permits. That is the reason for placing emphasis on UL listing at this time.

Milestone Description

m-2.3.2	Initiate qualification testing on First Solar's modified module.

This milestone was accomplished on schedule.

UL qualification testing of the Cord-Plate PV module

By the end of March tests to date have indicated passing with the exception of one minor change that was required for power lead strain relief. As shown in Figure 7, additional strain relief brackets were subsequently added external to the Cord Plate module (termination connection) to satisfy UL requirements for two levels of strain relief protection. Final documentation of all related components is being prepared to satisfy documentation and routing paper work that the UL Field Engineer will need to see when he visits the First Solar plant.

Additional in-house testing and improvement of the *Cord-Plate* contact termination

The modules that are passing the UL tests utilized machined polymer Cord-Plate fixtures. When it became apparent that the concept was promising, equipment for injection molding of the fixtures was purchased and sufficient quantity of the fixtures for additional in-house testing was produced. The molded parts showed slight irregularities and bending on the bottom side. In order to obtain a flat bottom, the parts were ground on a belt sander. Modules made with the ground parts showed an 80-percent failure rate in the high-pot testing. Apparently the microscopic grooves formed by the grinding contributed to moisture ingress and test failure.

The next attempt to produce a flat, smooth bottom surface was to place the Cord Plate fixtures on a flat surface heated to 150 ^oC. This treatment produced the desired characteristics and resulted in a substantial improvement in the high-pot testing.

Milestone Description

m-2.4.3	Complete qualification testing on First Solar's modified module UL1703

This milestone was successfully completed on schedule.

Completion of UL qualification testing of the Cord-Plate PV module

Underwriter Laboratories testing was nearing completion in June. First Solar completed UL testing in July and are now certified against UL 1703.

Also in July, First Solar began preparing samples to submit to PTL for IEEE and IEC validation testing. A purchase order was placed with PTL for the testing in July.

Mr. Tim Pruder, site inspector for Underwriter Laboratories (UL) from Novi, Michigan, arrived during July for inspection to the First Solar Cedar Park manufacturing plant. He inspected the documentation and materials listed by First Solar and verified the sources. He found no problems. The First Solar 60 cm x 120 cm PV module based on cadmium telluride is now a "recognized component," approved by UL to be installed in "listed" mounting systems. A copy of the letter from UL in reference to completion of the Initial Production Inspection appears in Attachment A.

On July 10 Underwriter Laboratories issued a Report on COMPONENT – PHOTOVOLTAIC MODULES TO First Solar, LLC, (File E205874, Project 99NK42717). In the Conclusions of this report it is stated that ***the products are judged to be eligible for Component Recognition and Follow up Service.*** This 31 page report and letter will be made a part of the Deliverable D-2.4.5, entitled "Testing report summary and letters of certification for First Solar modified module under UL1703 (Task 5).

Milestone Description

m-2.4.4	Complete the Phase II portion of the effort under Task 5.

With the successful UL qualification of the First Solar modified module and the building and installation of the equipment for producing it, this milestone has been successfully accomplished. Additional work on encapsulation, using alternative concepts to eliminate back glass cover was undertaken. Description of this work follows.

New module encapsulation projects

Generation-3 (GEN-3) module encapsulation

In March, 2000 a new encapsulation process came under development in which the back glass cover plate is substituted by a combination of a polymer layer as a dielectric and aluminum foil as a moisture barrier, affixed to the front PV plate with adhesives. A confidential full report on this ongoing project is included in the March 2000 report. The main purpose of this project is to reduce the weight, production rate and cost of the PV modules.

Several variants of this concept have been fabricated and are undergoing testing. Tests have continued on the concept of using a thin aluminum foil and polymer film laminate at the back surface of semiconductor to seal panels. Problems of differential expansion in tests have caused wrinkles in all films that have had an aluminum foil component in the laminate on the full size modules. All other versions of films with aluminum foil have shown delamination wrinkles after just one full thermal cycle of 20 hours. A double-ply polyester with acrylic adhesive has not shown any delamination in damp heat-cycle tests.

The latest combination tested was a polypropylene film with a vacuum-deposited aluminum coating. The sample was made up as a three-ply construction; it also failed the test. A low bond strength between polymer and the aluminum was suspect. This test is going to be repeated with just a single ply and making sure the aluminum coating is in contact with the adhesive to increase bond strength.

The activities in April continued to focus on solving the wrinkling problems with metal (aluminum) backing materials and the associated differences in thermal expansion.

The tests of thin vacuum-deposited aluminum / polypropylene films bonded to the panel on the aluminum side, seems not to be causing the previous wrinkle problem. This is done with a .002" thickness of a standard Acrylic adhesive system. The next tests was to involve a laminate that is built up of multiple layers and tested for moisture penetration. The test was to be conducted in the damp-heat testing system.

In addition, samples of other materials backed by rubber/EPDM and rubber/vinyl were also undergoing tests. These materials would be relatively inexpensive if moisture migration is low enough not to degrade module performance.

Systems for mounting / backing the module are also being reviewed. At this time the focus was mainly on extruded, vacuum-formed or blow-molded members. The issue was mainly of what type of encapsulation would result in the least material usage and still achieve the desired 20 year life. Materials being considered are: polycarbonate, vinyl, polypropylene and ultra-high molecular weight polyethylene (UHMV).

In May, testing continued with plastic film / foil combinations and pressure sensitive adhesives for bond and lamination strength. All samples have failed so far from wrinkles in the aluminum layer. The two assumptions are that the strength of the bond is not sufficient to prevent the aluminum from delaminating. The other is the issue of the aluminum having over twice the temperature expansion of the glass. With the thermal expansion rates in mind we built samples with a thin galvanized steel backing and bonded it to the panel with a two-part urethane compound. This has survived the 200-hr thermal freeze cycle test with no signs of delamination. It has also shown no signs of delaminating the semiconductor layer. In addition a panel with a layer of polyester film and the urethane / steel was also tested; this resulted in a delamination of the urethane from the polyester. This test will be redone with a plastic film that has a better bond property to the urethane. This construction would allow for a wider range of intermediate bonding agents to the panel and backing metal surface.

A Seaman's panel that uses a composite backing film (ISOVOLTA type) was also run through the thermal cycle and, as expected, it did pass. These films use the intermediate layer of EVA to get a stronger bond, but are also only going against a glass surface and don't need to worry about damaging the semiconductor.

CoralPlast sheets were obtained and tested with the existing films. The results indicated that addition pretreating of the surface would be needed to get a better bond. Also long term effects of the plasticizer leaching form the material would be a concern for weakening the bond to the film or metal surface.

Encapsulation Project

A contact was made with TruSeal about the extruded hot melt. They have not as yet been able to extrude any 4" wide material at this time. They are confident that it can be accomplished; however, their lab equipment has not been able to make satisfactory product. They will be discussing the issue with their engineers to make equipment modifications to their extruder. They were advised about the urgency of the project and informed that First Solar would be willing to apply some "seed" money to expedite the project. They will contact us the first week of June 2000 with a timetable. In the meantime, several more mini-modules have been put into damp heat testing using the hot melt. The main focus is the use of primers to improve the bonding between the sealant, glass and foil in an attempt to improve upon previous good test results.

There were several samples in damp-heat testing. One test is a repeat of an earlier failed test with an aluminum foil and a hot-melt edge seal. The only change was to use a primer to improve the adhesion to the foil and glass. Another test was a repeat of a test that passed. This was a glass-to-glass lamination with an edge seal of hot melt. The only change was to use a primer to improve adhesion to the glass. Another test was using a PIB type extrusion, with a vinyl backer, from Plymouth. They will have the ability to extrude a 24-inch wide ribbon by the end of this year. This material is used for insulating electrical cables. Later test results were not acceptable.

Work was continuing on the aluminum foil buckling problem. One option that is being tested is to bond the foil to a rigid backer, in this case a Coroplast panel. Coroplast is a polypropylene corrugated panel used as a cardboard substitute. It is expected to maintain the foil's planar shape and prevent it from buckling. This panel will be laminated to the sub-module with an adhesive and an edge sealant. (EVA as an adhesive with this contruction was not used because of difficulty bonding the EVA to the polypropylene, further work could be done) This joint will have to be sufficiently flexible to accommodate the thermal expansion differential between the glass and the panel, without losing the hermetic seal. Product Search is making up the panels and performing the thermal cycle tests.

Alternatives are being explored to the aluminum foil for the vapor barrier. A film from Multi-Film Packaging, (double ply polyester with acrylic adhesive), was shipped at the end of March 2000 and testing began it in June. Some other films have been identified with low MVTRs from ISOVOLTA. They are sending samples for us to evaluate. As reported by the company, these films have been used with success in the production of several MW of PV panerls. They would be flexible enough to correct for thermal expansion and still maintain a good vapor barrier.

In June 2000, TruSeal has obtained a four-inch die for their extruder. The company was attempting to make a .020" x 4" hot-melt ribbon on an aluminum foil backer with a paper liner. They were having difficulty rolling the ribbon into a coil because the paper/hot melt/foil stack-up would kink during the coiling process. A discussion of the problems ensued, including the foil wrinkling problem occurring during the thermal cycle test. Based upon that discussion First Solar requested to supply a hot-melt ribbon on a paper liner only. This material can be easily rolled into a coil. This ribbon will facilitate testing of mini-modules and also full modules by laying up several strips of the ribbon. Delivery of the hot-melt ribbon was scheduled for July.

After less than 300 hours, none of the damp-heat test mini-modules tested in March of 2000 passed the test. (These included several polypropylene films with aluminum backing and well as Tedlar/aluminum/Tedlar provided by Isovolta) The best results were with the glass-to-glass lamination with a performance drop of 11.04% (relative %). The worst results were with a VM tape with a performance drop of 54%. Most of the decrease was through a drop in Voc.

Work on the back vapor barrier continued. Bonding of aluminum foil with different adhesives to a Coroplast corrugated panel is being tested. Another material on order is honeycomb polypropylene from Nida-Core. This panel has a polyester scrim thermally fused to the face, which should make it easier to bond. Product Search performed a thermal cycle test using 32 GA galvanized steel for the vapor barrier. Steel more closely matches the thermal expansion rate of glass than does aluminum. At First Solar a steel foil was tried in the past, but it also wrinkled. However, the thicker-gauge, galvanized steel has enough stiffness that it was able to resist wrinkling during the test. Although it is not as cost effective as aluminum foil (< \$0.04/ft2 @ 1 mil), the cost is still reasonable (approx. < \$0.30/ft2). It has a significant weight disadvantage of 4.36 lb vs. 0.11 lb for aluminum. It does have some advantages over foil. It is stiff enough to resist the impact tests. It is thick enough to resist the cut test. It may be strong enough to mount directly to it.

The custom film from Flexicon was received. TruSeal performed a MVTR test and found it to be 9.2g/m2/d, which is higher than the hot-melt material. A mini-module will be put through the damp-heat test. Preparations were in progress for this testing, the Thermatron is in the process of being moved from the Westwood Plant in Toledo to the Technology Center in Perrysburg this month. The Thermatron will be operational in July.

We received the ISOVOLTA film laminate. This is a lamination of Tedlar/aluminnum foil/ Tedlar/EVA. The laminate is relatively expensive ($0.80/ft2). Siemens uses this material for encapsulation with an EVA film. First Solar sent a Siemens module to Product Search for testing in the thermal cycle test.

In the future First Solar is considering alternatives for encapsulation. One alternative is a barrier coating. This would be a metal oxide film such as tin oxide, aluminum oxide or zinc oxide that would use a low-temperature film-deposition process. First Solar personnel is exploring a low-temperature CVD process. Alan McMaster of First Solar is working with Tom McMahon at NREL, who is sputtering barrier layers. His first test used aluminum mirrors on a glass substrate. Initial test with aluminum oxide barriers showed corrosion in less than 24 hours in the damp heat (DH) test. He subsequently ran tests with thicker films ~ 1μ. These film were resisting corrosion after four days. Based upon these results, barrier coatings were planned be deposited on dot cells. Testing was to begin in July.

A "hot-melt" ribbon was delivered from TrueSeal early in July and encapsulation mini-modules for the damp-heat testing was begun. The material is approximately 0.030" thick and 4" wide. It was supplied in a roll with a Kraft back-up paper. Several different types of mini-modules with different back coverings were laminated, using the hot-melt. Some of the mini-modules were covered with 0.003" aluminum foil, others with a glass cover plate, with just the hot-melt alone, and some others with no cover plate. Other coverings used were the Icosolar foil film lamination, Lexan, and the Flexicon film and also the 0.03"-thick galvanized steel; all of them were subjected to damp-heat testing. After two weeks of damp-heat testing the PV performance was again measured. To date, the only one that is still performing to specifications is the mini-module with the glass cover plate on it, which had a performance drop of 5.5 %. All of the other combinations had more than 10 % performance loss after two weeks. The Thermotron, previously located in another building, at Westwood, was moved to the Technology Center, in Perrysburg, early in July and set up in the first two weeks in July. This move facilitated continuing the damp-heat testing at a more convenient location.

Damp-heat testing will be continued with different combinations of encapsulating stack-ups. One that has not been tested up to this point is with alternative edge-delete treatments. Currently we are using sand-blasted edge delete, which leaves a pitted and micro-cracked glass surface, that has been shown to create problems with degradation, as reported recently, because of vapor ingress.

Edge-deletion techniques are under consideration that are non-ablators, which will leave a pristine glass surface to which the encapsulating films will be bonded. It is felt that the existing edge deletion is the weak link in the encapsulating process. The CdS and CdTe semiconductor materials are relatively easy to remove. The underlying low-emissivity tin oxide layer is very hard and difficult to remove. One method to remove the tin oxide would be a pre-deletion, before the semiconductor layers are deposited. The tin oxide could be removed either chemically or electrolytically, leaving a smooth glass surface.

Another edge deletion treatment under consideration is to isolate electrically the tin oxide film and coat it with another material that lends itself to bonding to tin oxide. To date no equipment suppliers have been able to provide an adequate system to deliver a chemical to the edge delete area without some contamination of the active area, or contamination during the rinsing process. Historically, when lamination to the tin oxide surface was attempted, the bond between it and the encapsulant was not good, which allowed water vapor to ingress to the semiconductor, causing a severe drop in performance. By treating the tin oxide with another chemical, so as to increase its surface energy, an improved bond to the encapsulant is expected. No further work was done to identify bond enhancement chemistries.

5.1.3. Task 6 Milestones---Environmental, Safety and Health Programs

m-2.1.3	Complete extensive review and survey of current ES&H programs.	(Task 6)
m-2.2.4	Develop plans for critical areas of ES&H improvement with the assistance of industry experts such as OSHA On-Site Consultation.	(Task 6)
m-2.3.3	Initiate EH&S improvement projects.	(Task 6)
m-2.4.5	Complete a comprehensive ES&H program assessment including prioritization of improvement areas; established measurement targets; and comparisons to industry historical levels.	(Task 6)
m-2.4.6	Complete the Phase II portion of the effort under Task 6	(Task 6)

All of the above milestones have been accomplished, with the exception of the external and internal audits, which are now planned for Phase III Task 9. The reason for postponing the audits was because all EHS items had to be introduced to the new manufacturing plant

The formation of the First Solar LLC partnership has added a major new responsibility on the EHS activity. It is to prepare environmentally sound and a safe working environment in the new Cedar Park manufacturing facility, and to provide training of new employees in accepted EHS practices. Since its formation, the number of employees has more than doubled.

The goal of the EHS program is to conduct an extensive review of its current programs and address issues that need improvement. Altogether over thirty different activities have been conducted in the EHS program over the period of the Phase II project. Among these activities were: development and implementation of fifteen EHS-related plans and programs; obtaining permits concerning PV manufacture; generating reports to municipal and state agencies; cooperating with said agencies in conducting inspections; environmental sampling of R&D and production equipment and facilities for hazardous substances; installation and monitoring of EHS equipment; conducting safety inspections of all manufacturing equipment; periodic evaluation of employees for baseline cadmium; establishing first aid medical supply station; training of new employees on the EHS Handbook; conducting first aid training; establishing "Safety Council" meeting to address and assign controls to hazards in the start-up of the Cedar Park facility. The ultimate goal of the EHS program is to place First Solar in a leadership position relative to comparable businesses within and outside of the photovoltaic industry. Description of other accomplishments were included in Letter Deliverables D-2.4.6 and D-2.4.7.

6. Phase III Task Overview

Task 7. Manufacturing Line Improvements – Laser Scribing and Potting

First Solar, LLC shall continue to implement an improved scribing technique and design associated equipment initiated under Task 4 of Phase II. First Solar shall conduct a thorough review of the current process to locate potential industry processes and material handling solutions and establish parameters for integration of an improved throughput, labor, and equipment process improvements into the First Solar production line. First Solar shall formulate an improved process through adaptation of state-of-the-art techniques and automation. First Solar shall engage industrial experts and vendors such as the ARRI as needed in the development, design, and testing of a new scribing technique which is directly scalable to 60 modules per hour with potential of exceeding that capacity with nominal upgrades. First Solar shall complete off-line development of the individual scribing processes such as substrate registration, isolation measurement, and substrate conveyance. First Solar shall carry out the prototyping of material handling steps for the scribing process such as: handling large sheets of glass in and out of buffers; feeding glass in and out of the scribing table; and parts feeding. First Solar shall test a prototype scribing station to demonstrate the improvement elements and provide functional information for the high-throughput design. First Solar shall complete testing of the improved high-throughput scribing system, including process and material handling components, on its module production line. This task is expected to result in high-throughput, low-cost scribing by increasing throughput by a factor of four, reducing downtime by a factor of ten, and reducing equipment capital requirements by at least a factor of two.

Task 8. Product Readiness

First Solar, LLC shall initiate and complete qualification testing of modules with a different design than that of the one certified in Tasks 2 and 5. Modifications may include one or more of the following depending on the market interest: 1) junction box instead of pigtails, 2) sizes other than 60 cm x 120 cm, 3) alternative voltage; 4) encapsulation materials or process, and 5) other product changes influenced by market demand. First Solar shall obtain IEEE 1262, IEC 1215, and UL 1703 certification for its modified module. Experts from the field including Underwriters Laboratory and the Photovoltaic Testing Laboratory at the Arizona State University shall be utilized to review the design of the module; conduct preliminary testing on certain design components; establish sample and schedule requirements; and complete the certification testing. The task is expected to improve acceptance and variety of First Solar's product line in order to provide opportunity to penetrate market segments other than those that are served by its standard frameless, 60 cm x 120 cm module.
Note: Certification requirements were revised to include IEC 61646 and UL1703 only The IEEE 1262 was no longer in force at the time First Solar reached this task milestone. IEC 1215 was originally intended for certification of Silicon modules. IEC 61646 was created specifically for "Thin-film terrestrial photovoltaic (PV) modules"

Task 9. Environmental, Safety, and Health Programs

First Solar, LLC shall continue to refine and improve its Environmental, Safety, and Health, (ES&H) programs by beginning activities related to obtaining ISO 14000 (or equivalent) certification. First Solar shall initiate activities related to obtaining ISO 14000 by surveying and interviewing industry experts to assist First Solar. First Solar shall complete a comprehensive plan outlining the key milestones to obtaining ISO 14000 certification. First Solar shall assign and/or hire professional personnel to head up the implementation of the ISO 14000 project. First Solar shall begin the process of becoming certified under ISO 14000 by beginning the documentation of First Solar's current system within the ISO format and identifying areas of greatest need and highest priority. First Solar shall conduct a comprehensive review of the progress of their PVMaT Environmental, Safety, and Health programs and summarize the status of these efforts. This task is expected to result in a safe and healthy work place as well as an environmentally friendly manufacturing process and product.

6.1.- Phase III Results for Task 7, 8, and 9 Milestones

6.1.1. Task 7 Milestones---Manufacturing Line Improvements

m-3.1.1a	Complete scribing improvement plan including methodology and resource allocation.	(Task 7)
m-3.2.1a	Complete initial testing of scribing process improvements.	(Task 7)
m-3.3.1a	Complete demonstration of improved scribing process.	(Task 7)
m-3.4.1a	Complete demonstration of scribing process improvements.	(Task 7)
m-3.4.2	Complete the Phase III portion of the effort under Task 7.	(Task 7)

As described below, milestones m-3.1.1.a, m-3.2.1a, m-3.3.1a, m-3.4.1a, and m-3.4.2 have been completed.

Laser Scribing

Laser scribing of solar panels using thin film solar cells is used for cell interconnections [i]. The objective of Task 7 of Phase III of this project was to develop a system for scribing solar panels, measuring 120 cm x 60 cm, with a throughput of one per minute, at a reduced capital cost, improved reliability, improved scribe control and requiring the use of a single laser beam per each of three types of scribes.

Traditional laser processing systems fall into two categories using either a fixed head with an X-Y table or a moving head. The first system's major drawback is the speed limitation of large X-Y tables, which is in the range of 300 to 500 mm/sec. The second system suffers from sizeable vibration caused by the rapidly moving head.

Improved Laser Scribing System

The system selected for this work is capable of achieving a 60 cm long scribe line having a minimum theoretical spot size of 70 microns. Scribe-to-scribe location is easy to control. The scribing can reach speeds in excess of 3400 mm/sec requiring the use of pulsed lasers having a high rep-rate. A key benefit of this system is the ability to use a correction factor in the software, which allows cell mapping and correcting the focus for uneven surfaces.

Laser-Scribing Methodology

Traditionally, solar panels have been scribed from the coated side in which case scribing speed is limited to 300 to 400 mm/sec by the plume of vaporized material. The vapor plume absorbs and scatters the laser light and limits the power delivered to the scribe site. In order to achieve speeds in the range of 2000 mm/sec, scribing through the glass side of the solar panel, reported earlier [5], was pursued.

Green-light (532 nm) lasers are typically used for solar cell scribing in order to match the wavelength to the optical absorption of the material. In this project we made use of near-infrared lasers after determining that the CdTe absorption increases greatly with temperature for near-infrared wavelengths.

Considering the structure of the solar panels, at the time of the first two scribes, it consists of a soda-lime glass plate superstrate that has been coated with layers of TCO, CdS, and CdTe. The TCO signifies transparent conductive oxide. Each layer has a lower energy gap than the layer before it. As lower band gap materials convert more of the laser power to heat needed to vaporize material, the outer layers, e.g. CdTe, can be removed at relatively lower laser power without damaging the inner layers, e.g., TCO. Scribe #1 removes all the layers on the glass; scribe #2 removes the CdS and CdTe without ablating the TCO. The back metal electrode is deposited after scribe #2 and scribe #3. Scribe #3 removes metal to isolate the back electrode. The metal is removed chiefly by the high-pressure CdTe vapor formed at its interface by the beam reflected by the metal. The scribing speeds for the three scribes are 1500, 2000 and 2500 mm/sec, respectively.

Figure 14. Sequential Function of the Scribing System

Each of the three scribing system consists of a Load Station, Scribe Station and Unload Station. Figure 14 The first phase of the Load system accepts the panels via manual loading by the operator. The Scribe-1 Station receives the panel from the Load Station and indexes it into the scribe location. Any curvatures in the panel are measured for calculating a factor to maintain focus over the entire panel. For scribe-2 and -3 the systems operate similarly, except that the fiducial marks, scribed during scribe-one, are able to be read for position errors and software is capable of providing a correction factor for scribing.

Loading glass into the Load Station and removing it from the Unload Station are done manually. During the second phase of the scribing project both the Load and Unload Stations will be automated.

Improvements over Conventional Systems

The improvements with the improved scribing system include: (1) Reduced capital cost - the cost of high-speed improved laser system is about 1/3 of the cost (parts and labor) of a conventional system, with four nozzles; (2) reduced and lower-cost maintenance, which reduces down-time by a factor of ten; (3) greatly enhanced location accuracy of subsequent scribes through the use of fiducials, coupled with automated correction for panel growth/ shrinkage caused by temperature variations as well as panel rotation; (4) substantially reduced kerf widths and scribe spacing, whereby the active area of the panel is increased; (5) IR lasers deliver about twice the power of frequency-doubled green lasers and have life expectancy of up to 10,000 hours, 14 times greater than green lasers, and lower cost; (6) increased production throughput by a factor of four.

6.1.2. Task 8. Milestones---Product Readiness

m-3.1.1b	Complete encapsulation design review	(Task 8)
m-3.1.2	Initiate contact with module testing laboratory and complete preliminary module design review	(Task 8)
m-3.2.2	Complete preliminary testing of modules	(Task 8)
m-3.2.3	Establish qualification testing schedule	(Task 8)
m-3.3.2	Initiate qualification testing on First Solar's modified module	(Task 8)
m-3.4.3	Complete qualification testing on First Solar's modified module for IEEE 1262, IEC 1215, and UL 1703	(Task 8)
m-3.4.4	Complete the Phase III portion of the effort under Task 8	(Task 8)

Milestone Description

m-3.1.1b	Complete encapsulation design review	(Task 8)

Milestone m-3.1.1b has been completed. There have been several factors that contributed to the difficulty in passing module qualification testing. Figure 15 shows a cross section of a GEN 2 module. With the GEN 2 and earlier forms of encapsulation, the modes of failure have been moisture ingress to the semiconductor, moisture ingress to the bus bar and delamination. Moisture ingress is a result of insufficient bonding between the EVA and the glass, which allows moisture to penetrate along this interface. Moisture can also penetrate through the EVA that is exposed along the perimeter of the module. Moisture in contact with the semiconductor or bus bar causes degradation resulting in a loss in device performance.

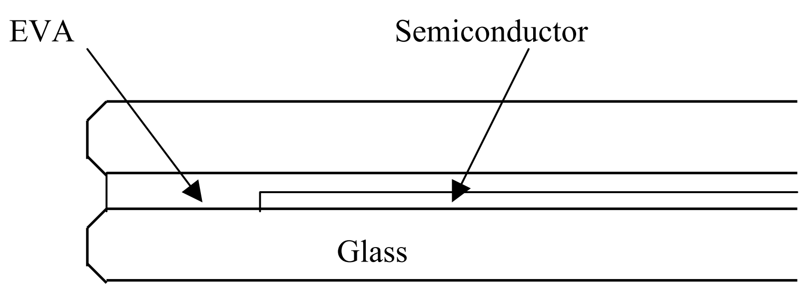


Figure 15. GEN 2 Encapsulation

Delamination occurs as a result of stresses induced in the module during lamination. Typically, the lamination is done with an autoclave or vacuum process. Usually the glass superstrate, after going through the semiconductor deposition process, is no longer as flat as the cover glass. The superstrate-EVA-cover glass sandwich is put under a load of one atmosphere or more during lamination. The resulting module contains residual stresses. Stresses can also occur even if the superstrate remains flat after deposition. A small amount of glass is removed during edge delete process resulting in a step around the perimeter. In addition there is variation in the amount of glass removed that gives the edge delete border a wavy surface. Bus bars are also mounted to the superstrate surface. Any of these non-planar qualities can cause stress risers in the laminated product. EVA goes through a cross-linking cure during the lamination process and there is some shrinkage associated with this cure that can also add stress to the system.

The module can delaminate during thermal cycling. Delamination typically begins in the deleted area and works its way into the body of the module. Sometimes there is internal delamination where the back contact has been pulled away from the semiconductor. Stresses can be high enough to break the cover glass or superstrate after a period of time. Stress in the glass can also be attributed to the positioning of the bus and terminal strips. Earlier potting methods have also allowed moisture ingress due to the failure of the potting material to withstand the damp heat test. Moisture absorbed in the potting material causes it to degrade and delaminate.

There is limited potential for reducing costs associated with GEN 2 encapsulation and earlier designs. The cover glass, potting and EVA comprise over 80% of the module encapsulation material costs. Listed below are some of the desirable encapsulation material properties that have been identified:

- Low MVTR < 1 g/m^2/24 hours
- Sealant material with low surface tension <50 dyne/cm
- Vapor barrier material with high surface tension >500 dyne/cm
- Low system cost < $\$0.625/ft^2 \Rightarrow \$0.10$/watt
- 20 year service life
- Service Temperature -40C to 110C
- CTE compatibility with glass
- Good peel strength 10 ppi
- Lap shear 25 PSI
- Elongation >100%
- Non flammable
- Dielectric strength >2500 V/mil
- UV resistance 20 yr life
- Low cure time < 1 min.
- Low cure temperature < 200C
- Good green strength
- Low VOC
- Ease of automation (roll lamination, spray, gun, etc.)
- Low capital equipment costs
- Low labor costs
- Chemically inert

- Light weight < 1.6 lbs/ft^2
- Low shrinkage < 2%
- Pass UL 1703 and IEEE 1262

Milestone Description

m-3.1.2	Initiate contact with module testing laboratory and complete preliminary module design review	(Task 8)

This milestone is complete. Underwriters Laboratory Inc., Northbrook, IL, and Arizona State University Photovoltaic Testing Laboratory were selected as module testing laboratories.

Milestone Description

m-3.2.2	Complete preliminary testing of modules	(Task 8)

This milestone is complete. Typically, the damp heat qualification test is the most difficult to pass. Hence, this is where most of the effort has been focused. In order to improve performance, the edge-deleted area was increase to 14mm wide from the original 10mm. The increased path length was sufficient to lower the moisture ingress to the semiconductor. This substantially improved module performance through the damp heat test.

Milestone Description

m-3.2.3	Establish qualification testing schedule	(Task 8)

This milestone is complete (see m-3.3.2).

Milestone Description

m-3.3.2	Initiate qualification testing on First Solar modified module	(Task 8)

This milestone is complete. One of the tasks of Phase III was to initiate and complete qualification testing of PV modules with new design. First Solar was to obtain IEEE 1262, IEC 1215, and UL 1703 certification for its modified module.

In November 2000, fifteen modules were submitted for testing to the Photovoltaic Testing Laboratory (PTL) at the Arizona State University in Scottsdale, AZ, in accordance with the IEEE standards. The modules did not pass the entire battery of tests because one of the modules fractured during the static load test and other modules failed various combinations of the damp heat test, humidity-freeze, and wet hi-pot tests. All modes of failure are traceable to the mounting structure, which rusted and fell off, as opposed to the encapsulated module itself. Modifications have been made and new modules will be resubmitted for testing. However, it is significant that First Solar's PV modules themselves did successfully pass the most demanding set of tests. The PV modules passed the humidity freeze, damp heat and subsequent Hi-Pot tests. Performance decreased by 6% or less in power output through this sequence. This is a major accomplishment for a thin film module.

Several in-house tests have been conducted in June to improve the understanding of First Solar's product prior to resubmitting for IEEE certification. The tests revealed some concerns while undergoing damp heat trials. It was concluded that the IEEE resubmission should be postponed until better understanding is gained to resolve these issues.

Milestone Description

m-3.4.3	Complete qualification testing on First Solar modified module for IEC 61646, and UL 1703	(Task 8)

The UL 1703 qualification testing has been completed. At the start of Phase III First Solar PV modules received "recognition" from the Underwriter Laboratories, which allowed the modules to be used on listed mounting systems.

During April 2001, and September 2002 modules were resubmitted to the Arizona Testing Laboratory with a c-channel and d-channel mounting system respectively. HF-10 and static load testing were successful and First Solar received authorization to use the UL Listed mark on its FS-50c and FS-50z and FS50d modules. These are complete modules with mounting attachments secured to the back side. The c, d, and z designations indicate the style of mounting with the c denoting aluminum c-channel rails, the d denoting aluminum d-channel and the z denoting aluminum z-bar rails. A photo of a module with the c-channel rails is shown in Figure 16

A package was submitted to the California Energy Commission to qualify for the CEC buy-down program, which was approved in August. First Solar was officially listed on their web site on 8 Aug. 2001.

Figure 16. A photograph of the rear side of a module with the "c" channel mount rails

The first array of UL-listed First Solar PV arrays is shown on the left front side of Figure 16, consisting of two inclined rows of nine modules in each row.

Figure 16. First Solar modules at ASU PTL. The first array of UL-listed First Solar PV modules with c-channel mounts is shown on the top front side of the photo

Milestone Description

m-3.4.4	Complete the Phase III portion of the effort under Task 8	(Task 8)

This milestone has been completed.

R&D Activities for Product Improvement

During Phase III, the following R&D activities were conducted to facilitate product certification:

1. Heat strengthening of glass to avoid breakage -- several modules installed in the First Solar test field experienced breakage of the glass. By using-heat strengthened sub-modules the in-field breakage rate has decreased from 11% to zero. Sample sizes were: 45 non-heat-strengthened and 52 heat-strengthened.

2. Through the use of a hot-melt pottant to extend the time to failure in the Hi-Pot test, the time to failure doubled from two to four minutes. Using the silicone RTV as the sole pottant, failure times are measured in days. This process is being qualified for use on the production line.

3. After determining that a significant fraction of completed modules would fail a subsequent Hi-Pot test, a total of 4679 modules were retested. Modules failing the Hi-Pot test were reworked and retested. After the testing was completed 4480 modules were put back into the Finished Product inventory. The failure mode was caused by incomplete coverage by the RTV silicone sealant around the wires or solder cavity. Minor modifications have been made to the process by which the pottant is introduced to the cord plates. The changes allow a higher pressure buildup within the cavities in the cord plate while potting. This change has resulted in demonstration of longer survival times in test-to-failure Hi-Pot tests.

4. The hole in the cover glass for the wire leads has been relocated from 10 cm to 25 cm off the edge of the glass; thereby lowering the tensile stresses in the laminated module an average of 500 PSI.

5. Search for solutions to excessive electrical conductivity of soda-lime glass -- Recently it was found that the electrical conductivity of sodium-lime glass accounts for approximately 50% of the UL allowable limit. It has also been found, that the EVA encapsulant, currently in use, has poor electrical insulating properties when subjected to the "Damp Heat" accelerated life testing. Currently, alternate encapsulants to EVA are being screened; as well as potential solutions tested using EVA to improve electrical insulation during damp-heat testing.

6. Control of the gel content of the EVA -- Statistical control of the minimum gel content of the EVA has been established. The process average is 83% and the control band is +/- 6%. This measurement consists of sampling the EVA cross-linked in the coolest rack location of the oven. Each sample is measured in four locations the average and range is then plotted on the control chart.

7. Problems with delamination of modules continued from time to time, even though reducing the curvature in the glass supplied by the vendor has helped. Variation of the lamination temperature has produced positive results; however, because of the small temperature changes used, it is not clear that temperature was involved in the improvement.

8. Search for alternative pottants to for use with the cordplate process -- In the later stages of Phase III, problems with the reliability of the cordplate process were once again experienced during damp-heat testing. Three alternative pottant materials were evaluated in an effort to replace the existing 3M-jet-melt material. The preliminary results indicated that all three materials, bond very well to the cordplate material, Lexan; however, there appears to be a concern about the adhesion to the wire insulation jacket.

9. Removal of air bubbles around lead wires by applying vacuum -- Another leading cause in lower yield was entraining bubbles along the lead wire. The old process to reduce bubbles was to put in a piece of rubber over the hole when applying vacuum, to keep the air from rushing in around the hole. However, the rubber leaked air. A complicating factor was that the lead wire passing through the hole was the thickest structure and it provided a path for the air to pass into the module. A partial solution was to apply vacuum to the hole itself by using a machined aluminum disk with a silicone rubber applied to the surface and plumbed up by using silicone tubing. The problem was thereby substantially reduced. The scrap rate for the process thereby decreased from about 15 % down to 8 %; which still indicated the need for other solutions. Hence, the aluminum vacuum disk was replaced with a silicone RTV vacuum cup. This new cup allows a better seal to the cover glass, resulting in better evacuation. As a result, the process average for voids has been reduced to zero. Consequently, the control chart for voids was discontinued and the incidence level was set to one void per run.

10. Changes in the process of injecting the pottant at higher pressure to the cord plates, resulting in longer survival times in Hi-Pot tests.

11. The automated Hi-Pot station has been brought on line to facilitate damp-heat testing of finished modules.

	% Tolerance	% Study
Part to Part	128.0%	100%
Total Gage	2.7%	2.1%
Repeatability	0.8%	0.6%
Reproducibility	2.6%	2.0%
Distinct Categories	68	

Table 3: Hi-pot Gage R&R: Each panel was tested twice on both the manual and the auto Hi-pot tester. Since the panels do not retest the same, 10 dummy panels were used. The positive lead was connected to one end of the dummy and the other end of the dummy was placed in various locations in the liquid.

Panel 1	40 Mohm	Panel 6	50 Mohm
Panel 2	170 Mohm	Panel 7	110 Mohm
Panel 3	40 Mohm	Panel 8	50 Mohm
Panel 4	140 Mohm	Panel 9	120 Mohm
Panel 5	200 Mohm	Panel 10	40 Mohm

Table 4: Table 4 shows the resistors used in the dummy panels.

12. Significant steps were made in June towards overcoming the potting issues. Currently, life cycle tests are in process to gain understanding and optimization of the potting process. These tests are on schedule, which calls for obtaining sufficient information by the end of August, 2001, for incorporating a better and more robust potting process that will meet all field extremes for the life of the product. It appears that the iterative optimization may require slightly more time.

13. A new engineering project has been initiated in July using the Taguchi methodology. It is designed to result with a robust cord plate design/process. The noise experiment portion of the project has been completed, which has led to a clear understanding of the critical areas of this sub system. This project will be completed in late November of 2001.

Module Encapsulation

1. Studies were conducted in order to determine whether a chemical etch could improve the surface qualities of the TCO to allow for better bonding to EVA. At the start, four 10 cm x 10 cm TCO substrates were treated with $SiCl_3$ and $SiCl_4$ in both liquid and vapor form and encapsulated with EVA and a glass cover plate. A small hole was cut in the middle of the EVA and filled with indicator desiccant prior to lamination. The chemical etch is to improve the surface qualities of the TCO to allow for better bonding to EVA. The samples have been placed in damp-heat testing along with a sample using bare glass only, for a comparison. The results indicate that the desiccant has reacted with water vapor after 1000 hours of damp heat testing.

2. Additional un-encapsulated glass plates were coated with $SiCl_3$ and $SiCl_4$ tested in damp heat. After 1000 hours, the bare glass side of the plates showed some pitting while the coated side appeared to be undamaged.

3. A small-scale vacuum laminator was fabricated. It is capable of encapsulating 10 cm x 10 cm samples. Several laminations were performed using EVA with glass substrates to test the laminator operation. Initial results show good laminating performance, which signified a go-ahead for generating additional test samples for damp-heat testing. We have received some proprietary films from one of the vendors that we work with to begin the tests.

4. Damp-heat test samples were made on 10 cm x 10 cm glass substrates laminated with EVA and no back sheet. Humidity indicators were imbedded in the lamination. The laminations were done in the new vacuum laminator by using a teflon sheet to replace the glass back sheet. After lamination the teflon sheet was peeled off, exposing the EVA. Similar samples were made with the Truseal hot melt film. Both samples were placed in

damp heat to compare the effectiveness of the films as a vapor barrier. After 4 hours exposure, the humidity indicators on the EVA films showed signs of exposure to moisture. With the hot melt material 23 hours were required to show the same amount of moisture exposure. We are working with vendors to develop a 2-foot wide extruded ribbon of hot-melt sealant. We received samples of 4-inch ribbons and are in the process of fabricating 10 cm x 10 cm test samples.

5. An environmental chamber relocated from Arizona has been installed in the Perrysburg Technical Center and became operational for thermal-cycle testing. Initial tests were to determine thermal expansion compatibility of back-sheet materials with the glass substrate. Standard-size plate samples, measuring 60 cm x 120 cm, were made with .001" aluminum foil, laminated to a glass substrate using an acrylic adhesive. Similar samples with .002" stainless steel foil were also made. A thermal cycle test was performed to test the effects of thermal expansion differentials between the glass and the foils. After one day of testing the aluminum foil began to wrinkle and de-laminate. After two weeks of cycling the stainless steel foil showed no visible change.

6. In May 4" X 4" test samples were made and sent to NREL. The purpose of the test is two-fold. First, an adhesion test will be perform on EVA bonded to glass with several different deletion processes, including grit ablation, chemical etch and electrolytic etch. Second, the TCO glass was patterned to conduct current leakage tests after damp heat stress tests. Since commercial equipment was not found for chemical edge deletion, no follow-up has been made.

7. First Solar investigated possibly alternative encapsulation projects with the Polymer Center from Battelle, Columbus, OH, and with the Southwest Research Institute (SWRI), San Antonio, TX. The materials identified were not commercially available and were high cost materials. Work was discontinued in lieu of research and developments through the NREL reliability team.

   During April 2001, and September 2002 modules were resubmitted to the Arizona Testing Laboratory with a c-channel and d-channel mounting system respectively. HF-10 and static load testing were successful and First Solar received authorization to use the UL Listed mark on its FS-50c and FS-50z and FS50d modules. These are complete modules with mounting attachments secured to the back side. The c, d, and z designations indicate the style of mounting with the c denoting aluminum c-channel rails, the d denoting aluminum d-channel and the z denoting aluminum z-bar rails.

   Based on the improvements that had been made over the course of this subcontract, nine standard production modules were submitted for testing to the Photovoltaic Testing Laboratory (PTL) at the Arizona State University, in accordance with the IEC standards. First Solar modules completed the certification testing in accordance with IEC 61646 and have obtained international certification. This completes the final readiness task and was the last open task in Subcontract ZAX-8-17647-06.

6.1.3. Task 9 Milestones--- Environmental, Safety, and Health Programs

m-3.1.3	Complete industry survey and interviews and determine what assistance, if any, is needed to begin the ISO 14000 planning	(Task 9)
m-3.2.4	Complete planning for ISO 14000 implementation	(Task 9)
m-3.3.3	Complete allocation and assignment of capital and personnel resources required for the ISO 14000 project	(Task 9)
m-3.4.5	Initiate ISO 14000 certification activities	(Task 9)
m-3.4.5	Complete comprehensive review of the First Solar PVMaT Environmental, Safety, and Health programs	(Task 9)
m-3.4.6	Complete the Phase III portion of the effort under Task 9	(Task 9)

Milestone Description

m-3.1.3	Complete industry survey and interviews and determine what assistance, if any, is needed to begin the ISO 1400 planning	(Task 9)

This milestone has been completed. Support materials needed to begin the process of ISO 14000 are available in hard copy publications as well as software packages. First Solar has purchased a copy of *ISO 14001 Certification Environmental Management Systems* by W. Lee Kuhre which is a book designed to provide essential information necessary to do practical environmental management in compliance with the ISO 14000 standard. A software package accompanying this book has nineteen template files containing the major procedures necessary to obtain an ISO certification. This is an excellent resource for gaining startup knowledge and certification status however, there is additional software available to better manage the ISO programs.

First Solar has reviewed several ISO software packages for management of the program and is currently interested in the CEBOS Inc. product MQ1 software package that will incorporate efforts for ISO 9000 and ISO 14000 certification.

Milestone Description

m-3.2.4	Complete planning for ISO 14000 implementation	(Task 9)

This milestone has been completed. The following plan has been outlined for the implementation for ISO 14000:

I. Steps to Achieve Certification

- Generate a list of major applicable regulations
- List major impacts of the operation
- List current environmental controls
- List additional activities needed to be added to the environmental controls
- Estimate cost and benefits

II. Environmental Elements and Components Needed

- An environmental policy statement (purpose) must be established and agreed upon by all management at First Solar
- At least one management representative must be given the authority to ensure implementation of the system
- Additional employee resources will be needed, including but not limited to; laboratory technician, environmental engineer, and training specialist
- Training must be provided for the environment management and all other employees in the organization
- Environmental aspects and effects must be identified and corrected through; internal audits, monitoring data, input from employees, and outside audits
- Risk assessment procedures must be established including but not limited to; immediate employee impact, immediate environmental impact, regulatory compliance, and long term impacts

III. Environmental Management Programs and Operational Procedures

- Establish procurement and vendor controls of both environmental and non-environmental related purchases
- Establish an environmental review process for all equipment and chemical applications for the manufacturing process
- Establish emergency procedure plan for immediate protection of employees and the environment in case of accidents, fires, and chemical releases
- Establish audit procedures of the environmental system to ensure compliance with regulations and company policies
- Establish document controls for all of the environmental management systems including but not limited to: identification of document, indexing of document, filing and storage of documents and removal of obsolete files

Milestone Description

m-3.3.3	Complete allocation and assignment of capital and personnel resources required for the ISO 14000 project	Task 9)

This milestone has been completed. The following capital and personnel resources will be required for the ISO 14000 project:

- Initial software (CEBOS, MQ 1 program) = $60,000 one time cost
- One full time employee to manage program = $55, 000 per year
- Registration fee = $5,000 start up than $1,000 per year annual fee
- All employee eight hours of training per year
- Eight hours of auditing and document control for process operations per week

Milestone Description

3.4.5a	Initiate ISO 14000 certification activities	(Task 9)

This milestone has been completed. First Solar will continue to implement documentation control and incorporate an environmental management system consistent with ISO 14000 requirements. Effective environmental practices will be an everyday part of First Solar's Environmental, Health, and Safety program however; at this time registration for the ISO 14000 certification will not take place. With manufacturing startup problems and expected equipment and process changes in 2002, the logical approach will be to wait until the manufacturing process has stabilized to obtain this certification.

Milestone Description

3.4.5b	Complete comprehensive review of the First Solar PVMaT Environmental, Safety, and Health programs	(Task 9)

This milestone has been completed. First Solar currently has the following (eleven) written Environmental, Health and Safety programs:

Cadmium Compliance – First Solar is keenly aware of occupational and environmental concerns associated with cadmium and cadmium compounds. Compliance with the OSHA Cadmium Standard is achieved is communicated through the following training topics:

- Communication of Cadmium Hazards and Health Effects
- Permissible Exposure Limits for Cadmium Compounds
- Exposure Monitoring
- Hygiene Areas and Practices
- Medical Surveillance

Hazard Communication /Dot/ RCRA Training – also known as the "Right to Know" law established to ensure workers get information about chemical hazards in the workplace:
- Discuss the HazCom Standard
- Discuss the Physical and Health Hazards of Chemicals
- Explain the DOT Hazard Classifications
- Discus Information & Hazard Warning Labels
- Explain the Use of the Material Safety Data Sheet (MSDS)

Hazardous Waste Compliance - The goal of hazardous waste personnel training at First Solar is to teach personnel safety in regards to hazardous waste:
- Identifying Hazardous Wastes
- Properties of Hazardous Wastes
- Explain the RCRA Hazardous Waste Requirements
- Waste Minimization Procedures

Respirator Compliance - The guidelines of this program are designed to help reduce employee exposure to occupational air contaminants:
- Procedures for selecting respirators for the work place
- Medical evaluations of employees required to use respirators
- Procedures for cleaning, disinfecting, storing, inspecting, repairing, discarding, and otherwise maintaining respirators
- Procedures for regularly evaluating the effectiveness of the program

Personal Protective Equipment Compliance – it is the policy of the Company to provide its employees with a safe and healthful work environment. The guidelines of this program are designed to reduce employee exposure to occupational hazards. The primary objective is to assess workplace hazards and to select and provide protective equipment to protect the employees from the hazard. Personal protective equipment is provided at no cost to the employees.

Ergonomics Program – ergonomics is the science of fitting jobs to the people who work in them. The goal of an ergonomics program is to reduce work-related musculoskeletal disorders (MSDs) developed by workers when a major part of their jobs involves reaching, bending over, lifting heavy objects, using continuous force, working with vibrating equipment and doing repetitive motions.

First Aid / Blood borne Pathogen / Means of Egress Plan – First Solar has 12 First Aid Responders trained for CPR, First Aid, and Prevention of Disease Transmission. The Red Cross provided all training programs.

Electrical / Lockout Tag out Program – The procedure identifies electrical hazards, establishes safe work practices when working on or near exposure, and establishes requirements for locking out energy and isolation devices to ensure that the machine or equipment is stopped and isolated before maintenance can be performed.

Powered Industrial Truck Operation – This program consist of a four hour class room lecture on safe operation of industrial trucks and identification of First Solar's hazards. A driving evaluation is also required. Passage of a written test and driving test is necessary for all First Solar forklift drivers.

Spill Response and Emergency Procedure Plan – A plan outline response and emergency procedures has been established for the First Solar Manufacturing and Technology facilities.

Milestone Description

m-3.4.6	Complete the Phase III portion of the effort under Task 9	(Task 9)

Phase III portion of Task 9 has been completed.

The objective of this activity was to continue to refine and improve the Environmental, Safety and Health (ES&H) programs by beginning activities related to obtaining ISO 14000 certification. During Phase III, 16 different activities have been completed to this end, which are summarized below.

- During the First Quarter the Company conducted procurement and vendor controls for environmental related purchases, identified equipment and chemical approval tracking, updated Emergency Response Plan, and developed a Disaster Recovery Plan.
- During the Second Quarter we identified frequency and personnel involved with audit reviews and verification, audit procedure/compliance verification procedure, corrective action procedures for non-compliant items audit documentation, analyses of audit data, and audit reporting and management review.

- During the Third Quarter we identified data collection and handling, data collection procedures, data interpretation procedures, and we monitored, maintained, and calibrated measuring equipment.
- During the Fourth Quarter we developed procedures for recording and documentation control, conducted minimizing of discharges to air, water bodies, and sewer, implemented reduction of hazardous waste generation, and prepared to apply for ISO 14000 Certification, in conjunction with current efforts of First Solar with ISO 9000 compliance.
-

There were numerous specific activities, which are listed next. Frequent references are made to three locations where most of these activities took place. They are:

1. Cedar Park (CP) -Manufacturing Plant
2. Eckel Junction (EJ) -Technology Center
3. Westwood (WW) -Pilot Plant (now decommissioned)

Environmental

Environmental Sampling and Monitoring:

- Continued air sampling the Cedar Park manufacturing facility concentrating on emissions from "coater" maintenance and re-build activities, the new "Arizona Laser," the C24 tin oxide coater at the research facility (for tin emissions), from the module recycling process, and from the areas not directly related to the manufacturing process.
- Sampled and recorded the flow rate, temperature, and pH value for discharges of non-contact coolant water and completed an entire evaluation of the well discharge from the Cedar Park facility.
- Evaluated particulate dust (particle sizing) for the Cedar Park facility.
- Analyzed dust in the manufacturing area to gather information on fugitive dust, which may contain cadmium and be emitted during manufacturing and maintenance activities.
- Completed an extensive sampling profile for both the Cedar Park and Eckel Junction facilities for cadmium. Over (50) "wipe" samples were taken at each facility to determine the overall status. The data will help identify areas were fugitive dust maybe collecting and help establish a "housekeeping program".
- Determined a chemical treatment for the cerium oxide waste generated from the automated buffing operation at CP.
- Monitored and assisted with module recycling at the Cedar Park facility.
- Monitored effluent discharges for the Cedar Park facility.

Decommissioning of the Pilot Plant:

- Continued environmental clean up and decommissioning efforts at the Westwood facility, had chemicals transferred from the Westwood to the Eckel Junction and Cedar Park facilities.

Testing, Evaluation and Equipping of Facilities:

- Along with the Building Engineer, evaluated the entire ventilation system for the Cedar Park facility and for the “Light Soak” area at the Eckel Junction facility.
- Sized wastewater system for the Eckel Junction facility
- Sized and ordered a new ventilation system for the Edge Delete system at the Cedar Park facility
- Sized and ordered a new ventilation system for the Arizona Laser #1 system at the Cedar Park facility
- Installed ventilation dust collector for the edge delete process at the Cedar Park Facility.

Environmental Evaluation, Auditing and Reporting:

- Prepared and participated in an annual environmental inspection from the *City of Toledo, Environmental Services* Department. The inspection took place at the Cedar Park facility.
- Prepared and submitted an application to the Ohio EPA for a permit to install a wastewater treatment system at the Eckel Junction Research facility.
- Continued daily sampling of effluent discharge from the CP wastewater treatment system as part of a biannual reporting requirement with the City of Toledo, Environmental Services Department.
- Continued working with outside consultants to audit environmental procedures for both facilities.
- An intern from the University of Toledo began a summer internship with the EHS department by drafting an extensive air and wipe sampling program for both the CP and EJ facilities.
- Worked directly with a representative from NCEC (National Center for Environmental Communications) to audit both First Solar facilities for environmental issues.
- Started detailing an “Emission Source Report” for both facilities.
- Drafted a *Emission Source Report* for the Cedar Park Manufacturing facility.

Health

Health Training of Employees:

- Conducted cadmium training for all First Solar employees.
- The American Red Cross conducted training on First Aid – CPR- Bloodborne pathogen training for (8) employees, on CPR Refresher course for (8) employees and on the use of Automated External Defibrillator for (16) employees.

Evaluation and Installation of Systems for Health and Safety:

- Evaluated ventilation system for the “light soak” station at the Cedar Park facility, and chemical lab for the Eckel Junction facility.
- Established an industrial noise sample study for the Cedar Park facility.
- Arranged for installation of ventilation systems in the Eckel Junction laboratory.
- Evaluated all four cells in the manufacturing facility for hazard identification and controls.
- Worked with outside contractors to design and ventilate a room for the sandblasting operation and roller cleaning process at the CP facility.

- Worked with outside contractors to re-design the ventilation for the EJ C-24 TCO-coating project. Explosion-proof ventilation was required for projected chemical application in this system.
- The ventilation system for the EJ C-24 project was installed.
- Mechanical Testing Company performed an on-site evaluation of our existing HEPA ventilation systems. This company has the capability of measuring particulate particle sizes down to 0.1 micron and will confirm that our current HEPA filtration system is collecting particulate matter to manufacture specifications. They will also assist with identifying the particulate size of dust generated in each of our processes and confirm that the current filtration system is adequate.

Health Plans, Programs, and Reports:

- Updated Cadmium Compliance Programs for 2001.
- Drafted updates and changes for the First Aid and Blood borne Pathogen Programs
- Updated First Aid and Personal Protective Equipment Program for both facilities.
- Generated Industrial Hygiene plan for Cedar Park experiments involving ammonium hydroxide
- Began Industrial Hygiene Plan for new chemicals proposed for the C-24 coater at the EJ facility.
- Developed an "Industrial Hygiene Plan" to assist maintenance activities on the GDS to minimize cadmium exposure to employees performing the maintenance activities.

Health Testing of Employees:

- (17) employees were medically evaluated as part of First Solar's industrial hygiene program.
- 30 employees received cadmium medical monitoring as part of our ongoing industrial hygiene plan.

Safety

Safety Meetings, Plans, Programs, and Reports:

- Continued drafting " *Return to Work Program* "for both the Cedar Park and Eckel Junction facilities.
- Held Safety Council meetings every other Wednesday.
- Worked on "Lab Safety Program" for Eckel Junction.
- Discussed first aid, hazard recognition, personal protective equipment, fall protection, lockout-tag out issues and ergonomics programs for the Cedar Park and Eckel Junction facilities.
- Evaluated all four cells in the manufacturing facility for slip, trip, and fall hazards.
- Discussed labeling of all panels, breakers, and disconnects for the electrical sources at both the CP and EJ facilities.
- Evaluated current "*Lockout*" program for internal manufacturing procedures and fieldwork on outdoor arrays.
- Annual "Lockout-Tagout" training took place at both facilities for 36 employees at the CP facility and 11 employees at the EJ facility.
- Completed evaluation and labeling of all electrical breakers, disconnects, switches and outlets at the CP facility. Started similar labeling at the EJ facility.

- Zee Medical (outside consultant) performed "*safety audits*" at both the Cedar Park and Eckel Junction facilities.
- Modified the Contractor Guide to Safe Operations form, for all contractors working at First Solar facilities.
- Developed a facility safety audit for both facilities, that will take place bi-weekly.

Safety Training of Employees:

- New employee "*Safety Orientation Training*" for 51 new employees.
- Trained and "fit tested" 27 employees for respiratory protection.
- Created "Lab Safety" procedures and requirements and trained 30 employees at the Eckel Junction facility.
- Annual training on *Means of Egress, First Aid, Bloodborne Pathogen, Personal Protective Equipment, and Ergonomics* was conducted for all employees.
- Five employees participated in Forklift Training.
- Six employees have been certified as Powered Industrial Truck operators.

7. References

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6. AUTHOR(S)
J. Bohland, A. McMaster, S. Henson, and J. Hanak

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First Solar, LLC
28101 Cedar Park Blvd.
Perrysburg, Ohio 43551

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13. ABSTRACT *(Maximum 200 words):* Results of a 3+ year subcontract are presented. The research was conducted under Phase 5A2 of the subcontract. The three areas of effort in the subcontract were 1) manufacturing line improvements, 2) product readiness, and 3) environmental, safety, and health programs. The subcontract consisted of three phases, approximately 1 year each. Phase I included the development, design, and implementation of a high-throughput, low-cost lamination process. This goal was achieved using the support of key experts such as Automation and Robotics Research Institute (ARRI) to identify appropriate lamination equipment vendors, and material handling. Product designs were reviewed by Arizona State University Photovoltaic Testing Laboratory and Underwriters Laboratories. Modifications to the module designs were implemented to meet future testing requirements. A complete review of the Environmental, Health, and Safety programs was conducted, along with training by the Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA). Work conducted during Phase II included the implementation of an improved potting procedure for the wiring junction. The design of the equipment focused on high-throughput, low-cost operations. During Phase III , First Solar made significant progress in three areas: Manufacturing Readiness; Product Performance; and Environmental, Health, and Safety (EH&S). First Solar's accomplishments in laser scribing significantly exceeded the stated goals. Innovations implemented during Phase III were made possible by adopting a new type of high-frequency, low-pulse-width laser, galvanometer-driven laser-beam system, and numerous advanced, automated, equipment features. Because of the greater than one order of magnitude increase in the throughput and laser life, a factor of two decrease in equipment cost, and complete automation, a major impact on lowering the cost of the PV product is anticipated.

14. SUBJECT TERMS: PV; manufacturer; manufacturing line improvements; product readiness; lamination process; wiring junction; cost reduction; laser scribing; module.

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