

PowerGuard[®] Advanced Manufacturing: PvMat Final Report

1 July 1998—30 September 2001

T.L. Dinwoodie and J. Botkin
PowerLight[™] Corporation
Berkeley, California



NREL

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337



PowerGuard[®] Advanced Manufacturing: PvMat Final Report

**1 July 1998 —
30 September 2001**

T.L. Dinwoodie, Principal Investigator and
J. Botkin, Senior Engineer
PowerLight™ Corporation
Berkeley, California

NREL Technical Monitor: Holly Thomas

Prepared under Subcontract No. ZAX-8-17647-12



NREL

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at <http://www.osti.gov/bridge>

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: <http://www.ntis.gov/ordering.htm>



Executive Summary

PowerLight Corporation (PowerLight) has completed its Photovoltaic Manufacturing Technology (PVMaT) 5A1 subcontract, “PowerGuard[®] Advanced Manufacturing,” addressing the U.S. Department of Energy’s PVMaT goals of manufacturing improvements directed toward innovative, low-cost, high-return, high-impact PV products. PowerLight’s focus for this subcontract was its patented PowerGuard building-integrated PV roofing tile.

The objective of the subcontract over its three-year duration was to continue the advancement of PowerLight’s PowerGuard manufacturing improvements in order to reduce PowerGuard system costs, increase PowerGuard tile fabrication capability to 16-MW/year, and stimulate an increase in manufacturing of PV laminates, within the United States, by 2-MW/year.

During Phases I and II of the subcontract, PowerLight developed the PowerGuard system and manufacturing process for high volume production and cost reduction, while improving product quality. During Phase III, PowerLight expanded market penetration through strategic commercial alliances and receipt of necessary commercial certifications.

Over the course of this subcontract, production rates rose from 200 tiles per 8-hour shift to more than 500 tiles per 8-hour shift. The overall system cost of PowerGuard was reduced by 38%. The original goal of a 46% reduction was not met, due to unexpectedly high global demand for PV laminates, and limitations on supply. PowerLight has successfully reduced Balance of System costs, including the cost of installation; at the end of this subcontract, BOS costs had been reduced by 68%. As PV laminate supply increases and the per-watt cost falls, PowerGuard will become even more affordable.

PowerLight has also continued to address quality issues by working on continuous improvement of tools and processes. Many aspects of factory operation have been improved, which has helped reduce overall costs. Increased demand for PowerGuard, which has been generated in part by cost reduction measures of the earlier phases of this project, has moved PowerLight into continuous production. This has allowed a shift from a temporary work force hired for each job to a full time production staff, improving product quality and further cutting costs by reducing the need for training.

In addition, PowerLight met project goals through:

- Implementation of an automated tile manufacturing facility, in Berkeley, California, exceeding 16-MW/year capacity;
- Improved quality of finished goods due to improved tooling and processes in PowerGuard manufacturing which also simultaneously improved throughput and lowered costs;
- Completion of wind tunnel testing of all design refinements and testing of PowerGuard installations on mechanically attached roof membranes;
- Creation of an installation manual and training program for installing PowerGuard systems;
- Certification and listing of PowerGuard products with Underwriters Laboratories and international certification organizations, and application for listing with the International Conference of Building Officials (ICBO).

Patents: PowerLight has filed for three patents related to this project.

The work under this subcontract has resulted in a lower cost, higher impact PV product, as sought by the PVMaT program.

Table of Contents

1.0	<i>Background</i>	1
2.0	<i>Objective</i>	2
3.0	<i>Scope of Work</i>	2
	<i>PHASE I</i>	3
3.1	<i>Assembly Layout and Integration</i>	3
3.2	<i>PV Laminate Preparation</i>	3
3.2.1	J-box Attachment.....	3
3.2.2	Electrical Quick Connects	4
3.2.3	Adhesive Priming	4
3.2.4	Module Quality Control Testing Station.....	4
3.3	<i>Extruded Polystyrene Processing</i>	5
3.4	<i>Automated Coating Station</i>	5
3.5	<i>Automated Spacer Attachment (Flat Tile)</i>	6
3.6	<i>Inverter Controller Improvements</i>	7
3.7	<i>Sloped Tile Manufacturing Design Improvements</i>	7
3.7.1	Sloped Tile Assembly.....	8
3.7.2	a-Si Tile Packaging.....	8
3.7.3	Retrofit PowerCurb™.....	9
3.8	<i>Component Testing, Certification, and Safety</i>	9
3.8.1	Environment, Health, and Safety.....	9
3.8.2	Wind Testing: Computational Fluid Dynamics (CFD), Wind Tunnels	10
3.8.3	Underwriters Laboratories (UL) Listing.....	10
3.8.4	<i>International Certifications</i>	11
3.9	<i>Integrated Warranties</i>	11
3.10	<i>Assessment of Commercial Demonstrations – Phase I</i>	11
	<i>PHASE II</i>	12
3.11	<i>Assembly Layout and Integration</i>	12
3.12	<i>Task 12 Deleted</i>	12
3.13	<i>Automated Spacer Attachment (Flat Tile)</i>	12
3.13a	<i>Automated Spacer Attachment (Sloped Tile)</i>	13
3.14	<i>PV Module Placement</i>	14
3.15	<i>Advanced Packaging</i>	16
3.16	<i>Materials Handling Between Stations</i>	18
3.17	<i>PowerCurb Housing</i>	18
3.18	<i>PowerBus™ Harness Assembly</i>	18
3.19	<i>Modular Source Circuit Combining Circuitry (SCCC)</i>	19
3.20	<i>Amorphous Silicon Tile Packaging</i>	20
3.21	<i>Task 21 Deleted</i>	21
3.22	<i>Component Testing, Certification, and Safety</i>	21

3.22.1	Environment, Health, and Safety	21
3.22.2	Wind Testing: Computational Fluid Dynamics (CFD), Wind Tunnels	21
3.22.3	Underwriters Laboratories (UL)	22
3.22.4	International Certifications	23
3.22.5	Inverter Anti-Islanding Testing in a Manufacturing Environment	24
3.23	<i>Integrated Design Software</i>	25
3.24	<i>PowerGuard System Packages</i>	27
3.25	<i>Assessment of Commercial Demonstrations</i>	27
3.25a	<i>Sloped Tile Refinements & Testing</i>	27
3.25b	<i>Tile Edge Trimming Station</i>	29
3.25c	<i>End of Line Lifter/Stacker</i>	29
3.25d	<i>Clean-up and Waste Management</i>	30
<i>PHASE III</i>		32
3.26	<i>Optimized Retooling for Capacity Expansion</i>	32
3.27	<i>Equipment/Facility Assessment</i>	33
3.28	<i>Component Testing, Certification, and Safety</i>	33
3.28.1	Wind Testing: Computational Fluid Dynamics (CFD), Wind Tunnels	33
3.28.2	Underwriters Laboratories Listing (UL)	34
3.28.3	International Conference of Building Officials Certification	35
3.29	<i>Product Installation Information</i>	35
3.30	<i>Assessment of Improvements in Commercial Demonstrations</i>	36
4.0	<i>Patents</i>	37

1.0 Background

PowerGuard® building-integrated roofing tiles generate electricity from solar energy. With the assistance of PVMaT, PowerLight has improved the PowerGuard manufacturing process to lower costs, improve quality, and increase production capacity. By doing this, PowerLight met its overall goal to expand significantly the market for this product.

A PowerGuard tile consists of a flat plate PV laminate mounted onto a flat, rigid, extruded polystyrene (XPS) board. Two edges of the XPS board are routed into a tongue profile and the other two edges are given a groove profile, allowing PowerGuard tiles to be assembled adjacent to each other in an interlocking fashion. Adjacent tiles are tied together electrically through connectors supplied on each PV module, thus creating a string of PV modules. One or more strings are then tied together electrically at a remote location creating a solar electric array (PowerGuard system). The resulting DC current from the array is passed through a DC/AC inverter and transformer before being tied into the building's electric service.

Through this subcontract, "PowerGuard Advanced Manufacturing," PowerLight introduced incremental improvements to PowerGuard system components and manufacturing processes to significantly reduce the costs of a PowerGuard system. This resulted in a lower cost, higher impact PV product – the goal of the PVMaT program.

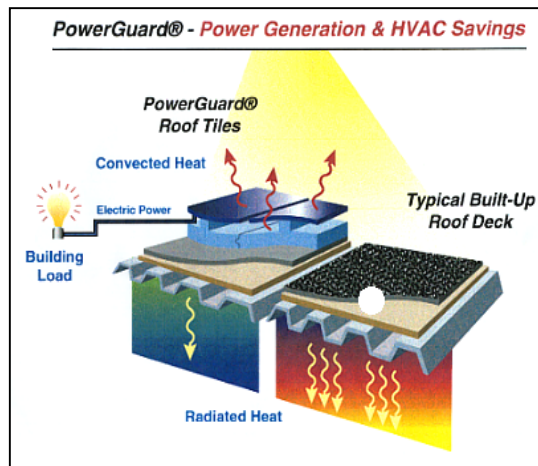


Figure 1

2.0 Objective

The objective of this subcontract over its three-year duration was to continue the advancement of PowerLight PV manufacturing capabilities and provide PV systems incorporating financing options. PowerLight was to demonstrate cost reduction of 46%, complete manufacturing improvements for PowerGuard tile fabrication capability of 16-MW/year, and stimulate the expansion of US PV laminate manufacturing to 2-MW/year.

PowerLight was to address PowerGuard system cost reduction through the following:

- Improvements in manufacturing technology related to system (non-PV) components;
- Product design enhancements;
- Increased production capacity;
- Enhanced system reliability and performance;
- Strategic alliances to leverage PV module technical improvements and cost reduction.

3.0 Scope of Work

The scope of work under this subcontract included the following:

- Reduce the cost of a system 46% for large systems;
- Develop modular and standardized packages to reduce the cost of small systems;
- Develop design software to facilitate physical and electrical system design, system QA/QC, code conformity, permitting, and bidding;
- Produce an installation manual and training program for installing PowerGuard systems;
- Develop finance packages and integrated warranties for PowerGuard systems;
- Advance several design improvements to the grid-tied inverter control board, including controller redesign, integrated Data Acquisition System, and an auditable communications system to verify PV system performance;
- Complete improvements to PowerCurb™ retrofit (RT) housing, harness assemblies, and source circuit combining circuitry, to reduce costs (materials and labor) by 50%;
- Complete wind tunnel testing of all design refinements, including RT system securement, sloped tile assembly, and the field assembly system, to confirm Computational Fluid Dynamics modeling, and to establish wind zone design guides;
- Develop methods of packaging which lower packaging and shipping costs by 25%;
- Develop a sloped PowerGuard design;
- Apply for and/or finalize UL, International Conference of Building Officials (ICBO), and international certifications for PowerGuard improvements.
- Create a manufacturing layout master plan for sequential integration of semi-automated and automated component stations;
- Conform to National Environmental Policy Act (NEPA), Occupational Safety and Health Administration (OSHA), and other federal and state regulations applicable to the proposed production processes and mitigate potential for waste streams;
- Improve clean-up and waste management processes for PowerGuard production;
- Establish plant capacity dedicated to manufacturing 2-MW/year of PowerGuard; and
- Establish performance of manufacturing modifications based upon assessment of commercial systems that incorporate the new features and processes.

PHASE I

3.1 Assembly Layout and Integration

Objectives

Under this task, PowerLight and its subcontractor were to engineer a step-by-step approach to develop cost-effective, integrated automation of the PowerGuard tile manufacturing line, to increase the production rate from 100 tiles/shift to 200 tiles/shift by mid-1999. The automated line was to meet the following criteria: throughput improvement of 125-150% (from 12 minutes/tile); 10-40% reduction in number of operators (from 10); 30-55% reduction in tile cost (from \$4/board); and compliance with NEPA and OSHA.

Results

Prior to the start of this subcontract, PowerGuard production rate was 40 tiles per shift (12 minutes per tile) and was done mostly with hand tools and simple jigs. PowerLight created a manufacturing master plan detailing the required resources for achieving the project goals. An automated manufacturing line was designed, and a location was found to set up the new manufacturing facility. The new manufacturing line was implemented, and the interim production rate goal of 200 tiles/shift (2.4 minutes per tile) – an 80% improvement – was met. Tile cost was reduced by 30%.

The number of operators increased from 10 to 16. At the end of Phase I, much of the equipment was installed but not yet commissioned, and extra people were required to perform the work. As the commissioning and “check out” process continued and was completed, in Phase II, the number of operators decreased (see 3.11).

By the end of the first year, PowerGuard tiles flowed in a continuous stream off the end of PowerLight’s new production line. Tile quality was much more consistent and cost was reduced despite a need for more labor than anticipated.

3.2 PV Laminate Preparation

Under this task, PowerLight was to design and evaluate several automated stations for preparation of the PV laminates at the upstream end of the PowerGuard production line.

3.2.1 J-box Attachment

Objectives

PowerLight was to design, implement, evaluate, and determine the cost-savings resulting from an in-line, semi-automated station for J-box attachment. The station was to meet the following criteria: throughput improvement of 60-80% (from 10 min/laminate); decrease in shipping costs of laminates by 30-70% (from \$.04/Wp for high-efficiency laminates and \$.08/Wp for low-efficiency laminates); and compliance with NEPA and OSHA.

Results

A J-box attachment station was designed and a mock up created to test the design and assess the cost savings. Based on projected savings, the station was not implemented, because the tooling was too costly; the PV manufacturer avoids this problem by combining J-box attachment with other related activities. A cost/benefit analysis based on the mock-up trials showed a potential \$.04/Wp savings in shipping. Reduction in the time required to attach the J-box was only 12% instead of the 60%-80% objective.

3.2.2 Electrical Quick Connects

Objectives

PowerLight was to design, implement, and evaluate an automated harness assembly station for fabricating selected electrical connectors into tile electrical leads. This station was to be set up in Saugerties, NY, or Berkeley, CA, and its performance evaluated with trial or actual production runs. The result was to be a 50% cost-reduction.

Results

PowerLight identified a lower cost replacement for the connectors previously used. The new connectors provided significant cost savings, better waterproofing, and easier field repair, and they allowed the use of pneumatic assembly tools in the PowerLight factory. These tools were purchased and set up in the Berkeley facility. The first tool automatically cuts and strips wires to the correct length. The next tool crimps on the appropriate connector. The final tool installs the insulating boot over the crimped-on connector. The implementation of these tools and the switch to the new connectors reduced costs by 56%.

3.2.3 Adhesive Priming

Objectives

PowerLight was to design and implement an automated alcohol-wipe station, fully or semi-automated, and evaluate its performance with trial or actual production runs. The result was to be a 50% reduction in the number of operators needed.

Results

PowerLight commissioned the design for an automated adhesive priming station but was unable to implement this station during Phase I. The focus shifted to reducing the labor required for the priming task. The required labor was reduced from one full time worker to one half time worker. This system was used during all the production runs during Phase I of this project.

3.2.4 Module Quality Control Testing Station

Objectives

PowerLight was to design and implement a semi-automated testing station for final testing of laminates prior to tile assembly. Its performance was to be evaluated with trial or actual production runs. The result was to be an in-line testing station that electrically confirms both voltage and current prior to assembly.

Results

PowerLight constructed a PV Module test station with an artificial light source and meters to display voltage and current output. This system is currently used to test every PowerGuard tile before it is packaged for shipping. The test verifies basic function of the PV laminate and insures that the electrical leads and connectors are properly installed. This test station is positioned over a section of roller conveyor so that the completed PowerGuard tiles can be rolled into position. The leads are then connected and the lights are turned on. The whole process takes only a few seconds per tile.

3.3 Extruded Polystyrene Processing

Objectives

Under this task, PowerLight was to evaluate options for redesigning the hot knife cutting station then in use with a router station for cutting the tongue and groove profile into the extruded polystyrene boards. PowerLight was to design, implement, and test the equipment and then evaluate station performance with trial or actual production runs.

The XPS processing station was to meet the following criteria:

Criterion	Existing	Expected Improvement
Throughput (minutes/laminate)	2	30%-70%
Number of Operators	2	50%
Tolerance: board square	1/8"	40%-75%
Tolerance: board lengths	1/16"	50%-75%
Tolerance: tongue and groove	1/16"	50%-75%
NEPA, OSHA compliance satisfied		Yes

Results

The router station was designed, implemented, and tested. All criteria were met (or exceeded) except for throughput, which improved 25%.

After researching options for this station, PowerLight purchased a CNC dual head router with a vacuum table. The router has a positioning accuracy of $\pm 0.002''$. This produces board dimensions much more accurately than the previous methods used to make PowerGuard backerboards. This router uses two cutters, one for the tongue profile and one for the groove profile. Previously, each board edge required two cutting operations: one to cut the tongue or groove profile, and a second to cut the rabbet on the top of the board. The new cutters cut the tongue or groove and the rabbet at the same time. This insures that the profile cut into each edge or each board matches the exact profile called for in the specification.

Operation of the router requires one worker, reducing labor by 50%. Boards cut on the CNC router vary in dimension by less than $0.015''$, which is better than the desired 75% improvement. The loading and unloading of the router is still a slow process, so the best throughput achieved was approximately 1.5 minutes, or a 25% improvement.

3.4 Automated Coating Station

Objectives

Under this task, PowerLight was to design, implement, and evaluate an automated station for coating the top surface of the XPS boards. Development of this station was targeted as essential for production volume to grow from 100 to 400 tiles/shift. The coating station was to meet the following criteria:

Criterion	Existing	Expected Improvement
Throughput (minutes/board)	12	65%-85%
Number of Operators	4	60%-80%

Criterion	Existing	Expected Improvement
Coating uniformity (thickness tolerance)	1/8"	50%
NEPA, OSHA compliance satisfied		Yes

Results

During this period, numerous alternatives to the current coating were identified and investigated. A cementitious coating was selected due to its expected durability and low cost. A coating mixture was optimized for maximum resistance to cracking, warpage, chipping, and freeze thaw damage. PowerLight worked with the National Renewable Energy Laboratory (NREL) to develop a freeze-thaw testing regimen in accordance with accepted industry testing standards.

An automated coating, mixing, and application station was designed and built. Since implementation, it has been used in actual production runs to coat more than 30,000 boards of various sizes. Boards are coated at a rate of 1 board per minute or faster – a tremendous improvement over the previous method which coated 1 board every 12 minutes. The station requires 1.5 operators (1 full time operator and 1 helper who spends 4 hours per shift at the station) for a reduction of 2.5 operators over the previous method. Finally, the coating thickness is very consistent at $\pm 0.063''$ and does not change with production line speed.

3.5 Automated Spacer Attachment (Flat Tile)

Objectives

Under this task, PowerLight was to design, implement, and evaluate automated equipment to attach spacers to the XPS backerboard for PV laminate stand-off. PowerLight was to design and review current options and research alternative spacer materials. The result of this task was to be the selection and specifications and estimated cost savings for the automated equipment.

Results

Spacer materials were selected. Attachment equipment was designed and implemented. Cost savings are greater than 50%.

Possible spacer materials were evaluated based on the following criteria:

1. Low cost;
2. +30 year life expectancy;
3. PV able to be removed from spacer intact after attachment;
4. Structural performance of 50 lb/sf tension and 200 lb/sf compression;
5. Enhance aerodynamic properties (as per wind tunnel studies);
6. Enhance low temperature operation of PV laminate (better air-flow under and around the laminate results in lower temperature, higher efficiency operation);
7. Flame resistant (non-flammable);
8. Withstand high temperature;
9. UV resistant;
10. Withstand a freeze/thaw environment;

11. Adhere to XPS board or to coating of 50 lb/sf or better;
12. Adhere to PV (glass or Tedlar) of 50 lb/sf or better;
13. Allow PV attachment in the factory or in the field;
14. Allow stacking of assembled tiles while coating is still wet;
15. Allow for continuous coating of board.

The spacer material that met all criteria was XPS foam, in blocks. More than 10,000 spacers have been fabricated with the first spacer fabrication station. One operator produces 4 spacers in 2 minutes, resulting in almost 1000 spacers per shift.

3.6 Inverter Controller Improvements

Objectives

Under this task, PowerLight and its lower-tier subcontractor Xantrex Technologies (formerly Trace Technologies) were to evaluate and modify the Xantrex inverter controller, integrate a data acquisition system (DAS), and incorporate dial-up communication capability into the Xantrex Solar Control Unit (SCU). Xantrex was to replace analog circuitry with digital circuitry and eliminate non-PV-related functionality. In addition, circuit board revisions were to be incorporated into the controller to reduce parts count and cost. The DAS was to incorporate analog inputs for weather-related sensors, and non-volatile storage was to be embedded in the controller for logging data.

The result was to be an SCU with an integrated inverter/DAS package for grid-tied PV applications with dial-up communications. Parts count was to be reduced by approximately 50% and reliability was to double. The final parts count was expected to decrease by 75% and the calculated Mean Time Between Failures (MTBF) was expected to increase 33%, from 44,000 hours (5 years) to 59,000 hours. The DAS was to record DC voltage and current, DC power, AC power, ambient temperature, wind speed, insolation, and module and membrane temperatures.

Results

The first prototype SCU was installed at the PowerLight factory in Berkeley in April of 2000. Its features are as follows:

1. Parameters for the inverter can be modified offsite from the Graphic User Interface (GUI). This significantly reduces both travel time and system downtime, since the inverter can be reset remotely if it faults or if a parameter needs to be modified.
2. Analog inputs for the meteorological sensors have been incorporated. The system can log six such sensors. Currently, only three are used, for ambient temperature, wind speed, and irradiance. Limiting the number of inputs and functionality has reduced the cost of the SCU by 6- 48% depending on its size compared to a conventional datalogger.
3. Circuitry and functionality not related to PV have been eliminated from the inverter and the number of parts has been reduced by 50%.
4. Remote access over a dial-up connection has been incorporated.

3.7 Sloped Tile Manufacturing Design Improvements

Under this task, PowerLight was to improve product design to take advantage of new/alternative products and materials. These advancements are detailed in the three subtasks discussed below.

3.7.1 Sloped Tile Assembly

Objectives

PowerLight was to refine the design of a module spacer assembly to simplify the design, make the assembly easier to manufacture, and allow tiles to ship flat and tilt to slope in the field, all while minimizing additional costs. The result of this task was to be an assessment of an integrally designed spacer mechanism for sloped PowerGuard tiles that meet the following criteria:

Criterion	Existing	Expected Improvement
Design life	5 years	20 years
Cost per tile	\$35	20-50%
Shipping height	10"	100-150%

Results

An extensive design effort led to a production prototype for a “pop-up” sloped-tile assembly. Custom sheet metal parts replaced more expensive hinges and mechanisms. Wind tunnel testing proved that these parts, with some modifications, were structurally sound. The collapsed tile was less than 4.5” tall; it has an expected 30-year life.

Cost objectives were nearly met. However, further design options were investigated, with the aid of a product design consultant, in Phase II of this subcontract.

3.7.2 a-Si Tile Packaging

Objectives

PowerLight was to evaluate modifications required to manufacture an advanced PowerGuard tile that uses the Solarex a-Si PV laminates. The low temperature coefficient of a-Si and the seasonal enhancement due to annealing provide the possibility of a PowerGuard tile which is uniquely low-profile yet operates at higher temperatures.

The result of this task was to be a prototype tile design achieving a 10-20% reduction in board fabrication costs while maintaining a 30 year design life and not exceeding laminate temperatures of 90°C.

Results

Several prototype tiles were constructed and tested using a-Si laminates mounted on spacers of various heights. While the spacers could not be eliminated, it was discovered that a 1” spacer results in sufficient cooling of the PV laminate such that performance is not compromised.

Laminate temperatures were observed to reach 77°C (170°F). The resulting tile was 3.25” tall, a full 2” shorter than typical PowerGuard tiles. Shipping density improved as PowerGuard tiles could be stacked 16 per pallet instead of the usual 12. This improvement reduces shipping costs by 15-20%. The cost improvement of the tile itself is minimal, because the labor to fabricate and install 1” spacers is the same as installing taller spacers, and material savings are insignificant. This design could not achieve the desired 10-20% cost reduction.

3.7.3 Retrofit PowerCurb™

Objectives

PowerLight was to investigate alternative designs for the Retrofit (RT) PowerCurb housings (PowerGuard roof tile retrofit mounting) prior to committing to a manufacturing plan. (PowerGuard RT mounting is the array perimeter securement used when PowerGuard is installed as a retrofit “island” on an existing roof, as opposed to installing with LightGuard® pavers covering the rest of the roof, as in new construction applications.)

The result of this task was to be a PowerCurb design that meets the following criteria:

Criterion	Existing	Expected % Improvement
Unit cost (\$/linear ft)	\$8	40-60%
# part types in assembly	6	50%
Passes Class A fire tests		Yes
Close packing for shipping		Yes
20 yr. design lifetime		Yes

Results

The final design was composed of two parts: a galvanized sheet metal pan and a custom shaped concrete curb. Concrete curbs would be manufactured using either a wet cast process or an extrusion process. The curbs would replace the blocks as ballast. The curbs would have the same aerodynamic profile as the sheet metal housing, eliminating the need for the housing and reducing material cost, as concrete is much less expensive than bent sheet metal. Costs were reduced 50%, and the number of parts fell from 6 to 2. Further cost reduction was part of Phase II.

3.8 Component Testing, Certification, and Safety

3.8.1 Environment, Health, and Safety

Objectives

Under this subtask, PowerLight was to incorporate federal and state regulations applicable to the proposed production processes, system installation practices, and system operation; evaluate options to reduce wastes and hazardous substances; and investigate opportunities to use recycled materials.

Results

A report was produced with a summary of relevant state and federal regulations. PowerLight then took the following steps to implement the safety systems required by these regulations.

In accordance with California Occupational Safety and Health Administration (CAL/OSHA), an Injury and Illness Prevention Program has been in place at PowerLight facilities for some time (T8 CCR, Section 3203). Emergency and fire plans are in place in

compliance with Title 8, sections 3220 and 3221. A training program for factory workers was implemented with a focus on mandatory training for noise protection (section 5099), personal protective devices (3380), medical services and first aid (3400), and respiratory protection. A Hazard Communication Standard was established in accordance with CAL/OSHA General Industry Safety Order (GISO) 5194. NOTE: PowerLight's use of hazardous or toxic chemicals is extremely limited per the Environmental Protection Agency's "Designation of Hazardous Substances" (40 CFR Part 116) and CAL/OSHA's "Hazardous Substance List" (Chapter 3.2 Article 5 Part 339).

PowerLight maintains a copy of these regulations as a reference for design staff.

3.8.2 Wind Testing: Computational Fluid Dynamics (CFD), Wind Tunnels

Objectives

Under this subtask, PowerLight was to conduct wind tunnel testing on prototypes of all modifications to the PowerGuard tile system.

Results

Design changes implemented during PVMaT have neither degraded nor improved PowerGuard's ability to withstand 140 mph winds on most buildings.

PowerLight conducted testing on aerodynamically accurate models of PowerGuard systems installed per specifications on model buildings. Sensitivity to array size, PV slope, curb weight and shape, array location on roof, building and parapet height, presence of water on the roof, high-wind securement options, roof texture, and wind direction were studied. Failure criteria were established. Friction coefficients of PowerGuard system components on various roof surfaces were measured for modeling in the tunnel and for structural analysis. Aerodynamic improvements were made to the sloped tile, including reducing the uplift coefficient by 50% without increasing drag coefficient or tile cost. Sensitivity of failure velocity to building and parapet height, array orientation on roof, array size, and curb design were also studied.

3.8.3 Underwriters Laboratories (UL) Listing

Objectives

Under this subtask, PowerLight was to submit modified products to UL for listing. These products include the sloped tile assembly, a-Si packaging, RT PowerCurb, electrical quick-connects, new adhesives and/or coatings, and source circuit circuitry.

Results

PowerLight submitted the following PowerGuard prototypes to UL for testing and listing during Phase I of this subcontract: five different frameless PV modules, an a-Si PowerGuard tile, the selected electrical quick-connects for PowerGuard tiles, a new field combiner box, and PowerGuard RT system specifications.

3.8.4 International Certifications

Objectives

Under this task, PowerLight was to work to receive appropriate listings and marks for candidate international markets, including Japan, Germany, Austria, Australia, Switzerland, Italy, Spain, Mexico, Canada, and England. PowerLight was to submit selected products for the listing or mark for one or more countries.

Results

PowerLight investigated the appropriate listings and marks for candidate markets, including Austria, Australia, Canada, England, Germany, Italy, Japan, Mexico, Spain, and Switzerland.

Certifications in Japan were initiated. A license partner was identified, and codes were acquired through the Japanese Ministry of Construction.

3.9 Integrated Warranties

Objectives

Under this task, PowerLight was to develop a PowerGuard comprehensive system warranty, including a service and maintenance option, integrating the warranties from PowerLight and component suppliers.

Results

PowerLight developed a PowerGuard comprehensive system warranty, integrating warranties from the PV manufacturers, inverter manufacturers, and other system components. A service and maintenance option was also established.

3.10 Assessment of Commercial Demonstrations – Phase I

Objectives

Under this task, PowerLight was to assess the results of a commercial demonstration, minimum 40-kW, to demonstrate the improvements made under Phase I of this program. PowerLight was to evaluate system performance, review cost savings, and assess effectiveness of changes.

Results

Ten identical 6-kW systems (60-kW total) were manufactured and installed for the New York Power Authority. A 7.7-kW system was installed at the State University of New York, New Paltz. A 28-kW system was installed for the Western Area Power Administration, Elverta, CA.

The new tongue and groove profile improved the ease of installation. The coating was found to be robust, i.e. there was no sign of warpage, shrinking, or chipping. Two key components required further improvements: the sloped tile assembly and RT PowerCurb. The Elverta system demonstrated that laminate strength is central to a-Si tile development. In the months after installation and commissioning of this system, more than 115 a-Si laminates were replaced due to cracking. This problem was primarily due to a flaw in manufacturing by the PV vendor.

PHASE II

3.11 Assembly Layout and Integration

Objectives

Under this task, PowerLight continued efforts initiated in Phase I to complete the design and development of equipment for cost-effective, integrated automation of the PowerGuard manufacturing line. Specifically, the redesigned production line was to reduce system costs by 20% by meeting the following criteria: increase per shift production by 100% (from 200 to 400); increase throughput 40-60% (from 3 min/tile); decrease number of operators by 20-30% (from 8 operators); comply with NEPA and OSHA.

Results

Advanced automation improved throughput and product quality. In sum, system costs were reduced 57%. The production rate improved more than 100%. Throughput time was reduced 80%. The process complies with NEPA and OSHA. The number of operators rose 50%: it was discovered that to lower the cost of finished goods, maximizing throughput is more important than minimizing labor.

Timing and quality studies completed at the end of Phase I revealed that production bottlenecks were being caused by problems with coating application and XPS spacer cutting. Both problems were solved through equipment and process redesign.

The original coating system was labor-intensive, delivered inconsistent quality, and thus limited throughput. The mixing machine now used delivers a consistent coating mix to the distribution hopper with minimal labor. The new hopper can be disassembled in just a few minutes with a minimum of tools, greatly decreasing cleaning time. Additionally, all adjustments are retained when the hopper is disassembled, so that setup for the next run takes only a few minutes. Coating quality has been improved and is much more consistent with the new hopper.

The original spacer cutting process was inconsistent. Engineers determined that with custom made bits, the computer numerical control (CNC) router could be used to cut spacers. With minimal modification to the router, operators are now able to cut spacers with less waste and greater accuracy. In addition, one worker can set up the stock, start the cycle, and do other work while the router runs, returning at the end of the cycle to reload.

3.12 Task 12 Deleted

3.13 Automated Spacer Attachment (Flat Tile)

Objectives

Under this task, PowerLight was to design, implement, and evaluate equipment to adhere XPS spacers to the XPS backerboard. The following criteria were to be met: 100% improvement in throughput (from 90 to 45 seconds per tile); one operator; improvement of position tolerance from $\pm 0.25''$ to $\pm 0.0625''$; compliance with NEPA and OSHA.

Results

When PowerLight first opened its Berkeley factory, spacers were glued to the PV panels. This was done manually with two alignment jigs, used in parallel. At each jig, two people placed spacers on the PV panels. A fifth person applied glue to all spacers prior to their placement on the PV. This process was slow and labor intensive. The PV panels and spacers had to be stacked and weighted and then left to cure. These assemblies would then be attached to backerboards during the coating process.

The production method was redesigned so that spacers are attached to coated backerboards, and PV panels are attached to the tops of the spacers after the coating has cured. This improved process has resulted in increased throughput. Various methods of completely automating the positioning of spacers have been investigated, but they have proven prohibitively expensive. The goals for throughput and position tolerance can be met with a semi-automated system.

To insure that spacers are placed on the coated boards in a consistent manner, a semi-automated stop bar and alignment jig have been installed on the production line. An optical sensor detects the presence of a coated board at the alignment jig. One worker pushes the board against the alignment jig. A projector is mounted above the spacer placement station. This projects an image onto each board in the alignment jig showing clearly the positions of the four spacers with four bright rectangles. This allows the workers to position the spacers quickly and accurately. If a board is detected at this station, the stop bar at the spacer placement station will not rise up to allow another board to enter. As long as the press station is clear, when the worker at the spacer placement station pushes the button, the stop bar will rise, allowing the board with spacers to move downstream to the spacer press. When the board clears the optical sensor, the stop bar automatically drops into position to wait for the next board.

Throughput improvement exceeded expectations, decreasing processing time to 20 seconds or less per tile. Two operators are required for this station instead of the five listed above. Position tolerances stayed at 0.25", which is acceptable, as this does not affect product quality. This station is in compliance with NEPA and OSHA.

3.13a Automated Spacer Attachment (Sloped Tile)

Objectives

Under this task, PowerLight was to design, implement, and evaluate the performance of semi-automated equipment for attaching the sloped spacer components to the XPS backerboard. PowerLight was to design and specify the equipment for the coating station and evaluate station performance based on trial or actual production runs to achieve throughput of 2-5 minutes per tile and reduce the number of operators by 50%.

Results

It was originally expected that when the design work was finished for the sloped version of PowerGuard, special equipment would be required to place the sloped tile spacers on the backerboards. However, with the final design, the method of spacer attachment is the same as for flat tile PowerGuard.

The spacers for the sloped tile consist of three long metal strips shaped to provide the base of the sloped tile. These are placed on the coated boards using the same equipment as that used for the flat tile, but the projected image is changed to match the three long metal spacers. The sloped tile design is shown in Figures 10 and 11 (see **3.25a**).

3.14 PV Module Placement

Objectives

Under this task, PowerLight was to design and evaluate PV module placement equipment to apply adhesive and accurately position the PV module on the backerboard, and eliminate the need for curing racks by stacking the modules directly onto a shipping carton or pallet base.

The objectives of this task were a 50% throughput improvement, a reduction of labor, and a 50% improvement in positioning accuracy.

Results

Throughput improved by more than 50%, while positioning accuracy was increased. Initially, goals were to increase throughput a modest amount and decrease the number of operators significantly by moving toward a completely automated system. As the work progressed, it became clear that reducing the cost of finished goods depended more on increasing throughput than reducing labor. Therefore, PowerLight focused on increasing throughput. With the new system, labor increased from 1 to 2 workers, because the tools to allow one worker to accomplish this task proved to be awkward and slow or prohibitively expensive. It was found to be more efficient to have two workers attaching the PV laminates. This provided an overall improvement in throughput and a resulting reduction in cost. Completed tiles are stacked directly onto shipping pallets for curing.

Several methods to place the PV modules onto PowerGuard backerboards were investigated. A conveyor line was set up to test the method of attaching PV panels to the spacers. In the first stage of equipment development, an alignment jig with a pneumatically powered articulated stop bar was placed on top of the conveyor. A backerboard with spacers is positioned in the alignment jig. Glue is applied to the top of the spacers, and the PV panel is laid on top. Operators wait for the glue to cure, then raise the stop bar and push the completed tile to the end of the conveyor where the tile is lifted and stacked on a pallet. When this pallet is full, weight is applied to the top until the glue has cured. The pallet is then wrapped for shipment.

This system was used for several production runs, and the quality of the PowerGuard tiles was consistently good. However, throughput was less than optimal.

The second stage of equipment development specifically addressed throughput. Engineers determined that most issues could be addressed using two custom jigs with integrated rollers to provide easy positioning of the backerboard. Each jig is only slightly bigger than the PowerGuard tile, which allows easy access to all sides. A vacuum hoist has been installed to allow one operator to handle the PV laminates.

A cured backerboard with spacers is placed on an alignment jig. Glue is applied to the spacers on the backerboard. The operator then maneuvers the vacuum hoist over to an alignment jig and places the PV laminate on top of the waiting backerboard (Figure 2). That operator then retrieves another backerboard, places it on the other alignment jig, and then retrieves another PV laminate. At the same time, another operator moves between the alignment jigs with the glue dispensers. Once the PV laminate has been attached to the backerboard and the glue has cured, the tile is removed from the jig and stacked on the shipping pallet. Two stacking jigs have been constructed where one was used before. This allows the operators to continue without interruption. Once they have completed one stack, they move to the second stack, instead of waiting for the pallet to be removed from the jig and replaced with an empty one.

Using one alignment jig, workers were recently able to process PowerGuard tiles at the rate of one per minute. By using two jigs simultaneously, the throughput is doubled.



Figure 2: Laminate Placed on Backerboard

An additional jig was designed and constructed for handling PV laminates prior to adhesion to the tiles (Figure 3). The laminates are removed from their packing crate and set in the V-shaped jig if they need to be turned over. In this flip jig, the laminates can be leaned one way or the other, and then easily lifted using the hoist.



Figure 3: PV Prep-and-Flip Jig

3.15 Advanced Packaging

Objectives

Under this task, PowerLight was to specify and evaluate packaging for PowerGuard tiles. Goals were to maximize shipping efficiency, reduce costs, and provide easier handling, rigidity for product protection, and cost-effective return shipment to the factory. PowerLight was also to explore the use of recycled materials. Expected results were overall cost savings of 30-50% and an increase in shipping efficiency to the point where 90-100% of the available shipping volume is used.

Results

To improve shipping efficiency, PowerLight experimented with filling more of the potential shipping space (e.g. in a transport truck). However, this caused loading and unloading to take longer, increasing labor costs. Current shipping methods proved more cost-effective.

Regarding pallets, historically, PowerLight has stacked and shipped PowerGuard Tiles on wooden pallets. The tiles were stretch-wrapped with protective cardboard edging on all 4 corners. The pallets were either returned by truck to the factory or disposed of at the destination.

Based on our studies, the best off-the-shelf replacement for a wooden pallet was a plastic stackable pallet, which would be returned by truck to the factory. These pallets would consume less space than wood pallets during return transit and in storage at the manufacturing facility, and they would be more roof friendly because they lack protrusions, splinters, and nails.

The best plastic pallet for PowerLight's needs is made from high-density polyethylene and can be recycled at the end of its life cycle, which is 20+ shipments of product depending on damage sustained during shipping. The pallet can be moved by a pallet jack or forklift. Use of these pallets would still require stretch wrap with corner protection.

Cost comparisons are as follows for the life cycle of the plastic pallet:

	WOODEN PALLET	PLASTIC PALLET
Size	48" x 40"	48" x 40"
Uses per unit	1	20
Cost of Pallet	\$4.80	\$16.00
Weight of pallet	N/A	35 lb.
Cost of return shipping	Not returned	\$17.50 (\$.50/lb rate)
Total cost for 20 shipments	\$96	\$348.50
Cost per shipment	\$4.80	\$17.43

The shipping cost to return the pallets overwhelms any advantage that reusing them may provide.

PowerLight also investigated the possibility of making pallets with the polystyrene foam dust created by the cutting processes in the factory. A sample of the dust was sent to a company specializing in molding pallets out of reused material. A prototype was created, but the finished pallet weighed 80 lbs., more than twice as much as a wooden pallet, and would be very cumbersome.

Based on this information, wooden pallets still seem the best option for PowerLight at this time.

PowerLight has also made some packaging improvements to reduce breakage of PowerGuard tiles made with thin-film PV laminates. Thin-film PV laminates are made with untempered glass, and thus are more easily cracked or broken by rough handling. During shipping, some laminates had been broken in a way that indicated that they had been subject to flexing during shipping, and this seemed a result of the laminates not being supported at the edges. To address this problem, a foam and cardboard insert was created to help support the edges during shipping. The insert is made from an open-cell foam insert (Figure 4) cut to conform to the space between the PowerGuard tiles as they are stacked for shipping (Figure 5).

Test pallets of PowerGuard incorporating thin-film laminates were packaged with these new foam inserts and shipped across the country to determine if the new inserts reduced the amount of breakage. While breakage was not eliminated completely, there were no flexing failures as had been observed in previous shipments. These inserts are now used when PowerLight ships PowerGuard tiles made with thin-film laminates.



Figure 4: Packaging Insert for PowerGuard with Thin-Film Laminates



Figure 5: Packaging Insert in Use

Shipping volumes did not change, as an increase was not cost-effective. None of the alternatives to the present pallet was cost-effective. Improvements were made to reduce breakage during shipment. Because breakage was unpredictable, it is difficult to estimate cost savings.

3.16 Materials Handling Between Stations

Objectives

Under this task, PowerLight and its subcontractor were to develop additional motorized conveyors and equipment to integrate the various stations of the PowerGuard assembly process into a seamless production line with an even throughput. Experience indicated that some additional production stations were necessary to ensure fully automated conveyance of the feedstock. These stations were to be fully integrated with the conveyor assembly and were to include these processes: loading boards into the conveyor line, cutting boards to proper dimensions prior to routing, scoring board surfaces for improved adhesion of the coating under the spacers, and separating boards following the coating station.

Expected results were continuous, station-to-station operation, and a 50% reduction in operators.

Results

PowerLight has implemented a continuous, station-to-station operation. The number of operators has been reduced from 4 full time workers to one half time worker, which represents an 87% reduction in labor.

3.17 PowerCurb Housing

Objectives

Under this task, PowerLight was to evaluate in-house capability to fabricate the PowerCurb housings while reducing cost per linear foot of curb and increasing quality assurance and quality control (QA/QC). Results were to include an assessment of unit cost and a 50% labor reduction.

Results

Three methods – molding, extruding, and stamping – were assessed on the basis of cost goals. None proved cost effective at current production volumes. PowerLight is pursuing the molding method in anticipation of larger production volumes in the future.

3.18 PowerBus™ Harness Assembly

Objectives

Under this task, PowerLight was to assess options to lower the cost of assembling wire harnesses which connect AC PowerGuard tiles in parallel and high-voltage DC tiles in parallel. PowerLight was to select a vendor to develop a mold to fully encapsulate and environmentally seal the splice, perform environmental exposure testing of sample harnesses, and evaluate harness performance in system installations. The revised design was expected to reduce unit costs by 80 to 90% and was to be submitted to UL for listing.

Results

PowerLight researched many different methods to make the T-connection for this assembly. A spliced connection with an overmolded insulator showed promise at first but failed life cycle testing. It also proved difficult to find a UL listed or recognized material for overmolding that would bond with the insulation material of the wire.

The final design uses an ultrasonically welded connection with a heat-shrink, insulating jacket. The complete harness consists of a trunk wire with several branch wires extending off at even intervals. Connectors are installed on the ends of the trunk wire as well as the end of each branch

wire. Typically the connectors are installed in PowerLight's factory, but this can also be done on-site if necessary. The connectors are the same as those used in the standard PowerGuard tiles, so the parallel wiring connections can be made on-site just like regular PowerGuard array installations. Provisions have also been added for inserting a diode in each branch wire when necessary.

This new design was developed both to satisfy UL requirements and to be compatible with the connected wire so that this connection will comply with National Electric Code (NEC) requirements. The new design has passed all functional and life cycle testing and has been submitted to UL for listing. When all parts of PowerGuard systems are UL listed, permitting of new installations will be simplified, which will help cut costs.

3.19 Modular Source Circuit Combining Circuitry (SCCC)

Objectives

Under this task, PowerLight was to design an integrated circuit board to replace the discrete components of PowerLight's array J-box; a modular scheme for connecting the array J-boxes to system combiner boxes in the field; and a system combiner box with integrated circuitry components.

The result was to be the development and assessment of a newly standardized Source Circuit Combining Circuitry scheme with integrated circuitry, modularity with system size, and integrated components. Costs were to be reduced by 30-50% and installation time of SCCC components reduced up to 50% for larger systems.

Results

The revised modular SCCC design incorporates two boxes. A terminal box on the roof provides a weatherproof transition from outdoor grade wire to less expensive indoor grade wire. Wire gage can be upgraded at this point to accommodate voltage drop considerations. A combiner box near the inverter provides over-current protection and parallels strings prior to entry into the inverter DC disconnect.

Because a typical 100-kW installation now requires three boxes instead of twelve, the savings in labor and materials are considerable without applying integrated circuit technology (originally a task objective). Also, with the simplification of the components in the boxes, an integrated circuit board is not only unnecessary (since diodes have been eliminated) but would be much more costly to develop. Each pair of boxes is custom sized for each job, with modular parts. The advantages of the current SCCC design are clear:

- Material cost savings of 60% and labor cost savings of 80% have been realized by reducing the number of electrical boxes, placing the DC circuit surge protector in the inverter, and removing blocking diodes;
- The strings are clearly marked in the combiner box and are easily accessible for diagnostics and voltage checks. The box is near the inverter, which greatly aids troubleshooting. It is possible to measure open circuit voltage (Voc) and operating current for every string of a 100-kW array in 15 minutes.
- The terminal box on the roof significantly cuts down on labor time, since the array wires terminate on the roof. The continuing wires are pulled through the rooftop conduit in a bundle.

- The terminal box allows the transition from outdoor-rated RHW wire to less expensive THHN wire, and provides the opportunity to use larger gage wire, if the voltage drop to the inverter is too high with the 12 gage harness.
- The terminal box provides a weather-tight method of getting wires from outside to inside the building and provides a transition for conduit attachment.
- Access to boxes does not require disassembly of the PowerCurb, which reduces diagnostic and maintenance labor time significantly.
- Boxes can be assembled in the shop, with wire tie-downs pre-installed to cut down on field assembly time.
- More than one rooftop terminal box can be used for arrays split up around the roof.

The revised design has cut material costs by 60% and labor costs by 80%. Installation time of SCCC components has been reduced by 90%.

3.20 Amorphous Silicon Tile Packaging

Objectives

Under this task, PowerLight was to deliver a prototype a-Si tile for testing at NREL or Sandia National Laboratories (SNL). The tile design was to achieve a 10-20% reduction in board fabrication costs, while maintaining a 30-year design life and not exceeding laminate temperatures of 90°C.

Results

In sum, all objectives were met. Cost savings exceeded 30%. The tile has a 30-year design life. It does not exceed laminate temperatures of 90°C.

A thin-film module with a 1" spacer was shipped to NREL for testing on May 1, 2000. The a-Si tile may be fabricated using one of two preferred thin-film laminates.

The a-Si tile is constructed in the same way as the PowerGuard tile, except that 1" tall stand-offs (spacers) are used in the place of spacers that are typically 2" or 3". Therefore, cost reductions already achieved for the PowerGuard tile are identical for the a-Si tile. During Phase I, PowerLight documented savings in PowerGuard tile fabrication of 30% or more. Additionally, the reduction in spacer height results in material savings as well as shipping savings due to higher shipping density.

Accelerated life testing already conducted on the PowerGuard tile suggests that it can withstand 30 years or more in a rooftop environment. This testing has been conducted by UL, Arizona State University, Colorado State University (wind tunnel), the manufacturer of the PowerGuard adhesive, and internally by PowerLight. Testing has focused on the bond strength of the spacer attachments, resistance of the coating to freeze-thaw, and wind resistance of the PowerGuard arrays. While the a-Si tile design results in slightly higher PV operating temperatures, field results show that these temperatures remain below 90°C. Because prior accelerated life testing on PowerGuard components included temperature cycling between 90°C and -40°C with no performance degradation, the increased PV temperature should not reduce the life of the a-Si tile. In addition, our measured operating parameters are within the operating range guaranteed by the manufacturer; thus no decline in lifetime is anticipated.

A series of field tests in July and October, 1999, in Sacramento, CA, showed that a spacer height of 1" resulted in peak PV operating temperatures as high as 77°C under open circuit conditions,

when the ambient temperature was over 33°C. However, further research is being conducted to monitor PV and tile temperatures in various ambient conditions. An array of 1” a-Si tiles has been installed for long term monitoring on the PowerLight factory where ambient temperatures greater than 33°C are expected.

3.21 Task 21 Deleted

3.22 Component Testing, Certification, and Safety

3.22.1 Environment, Health, and Safety

Objectives

Under this subtask, PowerLight was to incorporate applicable Federal and State Regulations into equipment design, operations, worker safety programs, installation manuals, Operations and Maintenance (O&M) manuals, and training programs. PowerLight was to ensure compliance with all applicable safety and environmental regulations.

Results

Federal and State regulations governing the manufacture, installation and operation of PowerGuard PV roof tiles have been reviewed since the beginning of 1998. An assessment was conducted to identify those regulations within Federal and State Codes that apply to PowerLight’s activities and therefore are relevant to process and equipment design.

PowerLight has ensured that all pertinent environmental and OSHA regulations are being met by initially reviewing these guidelines and incorporating them into equipment design, and by employing an OSHA representative and an environmental consultant to inspect the facility. In addition to these actions, PowerLight has also ensured worker safety by updating the installation and O&M manuals to incorporate the latest design and safety practices. These manuals and the initial training programs that PowerLight has begun will ensure that these systems are installed in a manner compliant with all OSHA and environmental regulations.

In addition, PowerLight has made a concerted effort to recycle its manufacturing by-products and has made the reduction of wastes a manufacturing priority. For instance, 95% of foam waste is recycled.

3.22.2 Wind Testing: Computational Fluid Dynamics (CFD), Wind Tunnels

Objectives

Under this subtask, PowerLight was to complete additional wind tunnel studies on PowerGuard RT systems; compile data from wind tunnel studies on PowerGuard RT systems into a final report; analyze failure data for PowerGuard RT systems and create final wind design tables; and create wind design tables for European and Japanese markets.

Wind tunnel tests are used to fully characterize PowerGuard’s unique aerodynamic performance.

Results

Pressure tapping was conducted on roof models used in this study to draw comparisons to published data and validate the entire study. This effort was successful in that non-intuitive trends in some of the failure data were explained through the pressure measurements. Peer reviews of the pressure data and failure measurements were positive.

The effects of water on the rooftop, a more accurate model of the RT curb, and extended securement options for RT arrays were studied and included in the creation of final wind tables. A table was created for corrugated metal roofing, as this type of roofing is commonly used on commercial buildings in Japan.

Full-scale testing of sloped PowerGuard in high winds revealed that the deflector panel experienced large oscillations and needed structural reinforcement. This was accomplished by incorporating a support mechanism at the center of the PV and deflector panel.

Wind testing results were used to establish wind tables, which are used by the PowerLight sales staff to determine the best PowerGuard system for a specific roof in a specific location. This reduces the amount of repetitive engineering work for each PowerGuard installation, thus reducing system cost.

3.22.3 Underwriters Laboratories (UL)

Objectives

Under this subtask, PowerLight was to continue working with UL to expand PowerGuard's original UL listing, add additional modules to the PowerGuard system, complete additional fire testing, and add components to PowerGuard's Accessory File.

Results

PowerGuard's UL listing was expanded to include four new modules. Additional fire testing was completed. During this period, PowerLight began the process of updating the PowerGuard Accessory file to reflect current practices.

PowerGuard was originally listed with only the one module. In November 1999, PowerLight submitted an application to list three additional module assemblies – each module from a different manufacturer – as components in the PowerGuard mounting system.

To list these tiles, UL requires that the frameless module be certified as a UL recognized component. Then PowerLight is required to follow the re-test requirements in UL 1703 that are applicable to mounting structures. These tests include accelerated aging testing, fire testing, humidity testing, mechanical load, temperature cycling, and a voltage current and power test.

Since these tests were completed with the original listing of PowerGuard, UL only required additional mechanical load testing to be completed. Additionally, since these modules are dimensionally similar, UL required only one of the three to be tested and its similarity to the other two qualified.

In December 1999, PowerLight sent a PowerGuard tile with one of the three modules to be listed to UL to undergo mechanical load testing. It withstood 293psf uplift load, which more than surpassed the 45psf required by UL 1703.

In January 2000, PowerLight submitted an application to list an a-Si module with the PowerGuard mounting system. Since this module's backing is glass and not Tedlar, UL

required additional adhesive testing. In February, PowerLight submitted samples of XPS adhered to glass with its preferred adhesive to undergo testing. This testing was successful, and in March 2000 this module was listed with the PowerGuard system.

As most modules have only been tested to Class C fire requirements, when PowerGuard was originally listed under Phase I it was tested to these requirements as well. However, during October 1999, PowerLight conducted extensive internal testing, to Class B and A requirements. Through this testing PowerLight found that the concrete coating allowed the product to withstand a Class B burning brand without exposing the roof deck.

In November 1999, PowerLight submitted a PowerGuard tile incorporating a preferred module for Class B fire testing at UL. This testing was successful, and since this module is intrinsically a Class C module, UL listed all PowerGuard tiles that incorporate modules with a Class C fire rating as Class B PowerGuard tiles.

At the same time, PowerLight submitted an additional PowerGuard tile for Class A fire testing, as it incorporated a module that already holds a Class A fire rating. This testing was successful and in December 1999, UL listed this tile as a Class A PowerGuard tile.

When PowerGuard was originally listed under Phase I, PowerLight listed three accessories to be used with PowerGuard. These included PowerBox™, PowerCurb, and PowerBus. In the fall of 1999, PowerLight received a quote from UL to submit an updated PowerCurb to the PowerGuard Accessory File to reflect current design practices.

3.22.4 International Certifications

Objectives

Under this subtask, PowerLight was to continue working with the International Compliance Services (ICS) department of UL and other organizations to determine the standards applicable in the European Union (EU) and Japan. In this phase, PowerLight focused on the requirements of the CE Mark, International Electrotechnical Commission (IEC) and Institute of Electrical and Electronics Engineers (IEEE) standards, and the specific requirements of Germany and Japan.

Results

PowerLight has met all EU requirements to apply the CE Mark, required for any product exported to Europe. In addition, all relevant IEC and IEEE testing has been completed.

Germany and Japan have favorable markets for PowerGuard, and so under Phase II PowerLight thoroughly researched the specific requirements of these countries.

Germany: In addition to IEC and IEEE standards, Germany also requires PV systems to have the TUV safety mark and conform to fire standards outlined by the Otto-Graf-Institute, Research and Testing Establishment for Building and Construction Products (FMPA). In August of 2000, PowerLight submitted samples to FMPA for B2 fire testing. PowerLight has received certification from the Otto-Graf-Institute for PowerGuard based on DIN 4102 part 1, building materials class B2.

Japan: A license partner in Japan was identified and has acquired appropriate building and fire codes through the Japanese Ministry of Construction. These codes were being updated to conform to IEC requirements. The new standards were published in January 2001. At that time, the Japanese Ministry of Construction specified that they would recognize IEC certification until 2003.

3.22.5 Inverter Anti-Islanding Testing in a Manufacturing Environment

Objectives

Under this subtask, PowerLight worked with subcontractor Xantrex Technologies (formerly Trace Technologies) to develop a load test that includes a motor with inertia (sized for the 10-kW inverter); a capacitor bank (capacitance recorded for unity power factor at 120V); a resistive load in addition to the motor load; and a time constant (time for the motor terminal voltage to drop by half from nominal AC test voltage when R & C are connected).

The effectiveness of this testing was to be demonstrated in a larger unit—up to 120-kW—in a commercial application.

Results

A test plan as described above was developed and implemented by the subcontractor. The results of the inductive motor load test were evaluated against the requirements of UL1741/IEEE929-2000. Under each of the test conditions, the inverter detected an island condition and shut down within the allowable time limit.

The anti-islanding circuitry and software was then installed in a 100-kW inverter connected to a PowerLight commercial PV system in Hopland, CA (Figure 6). There were no problems with the installation, and the system has been operating for more than 18 months in this configuration. During that time, the inverter has had no problems associated with the anti-islanding software.



Figure 6: 100-kW system, Hopland, CA

3.23 Integrated Design Software

Objectives

Under this task, PowerLight was to simplify the physical and electrical design of PowerGuard systems by developing custom Integrated Design Software based on an AutoDesk® program called Actrix® Technical 2000. This software would easily incorporate drawing specifications into MS Excel® spreadsheets, which allow a Bill of Materials (BOM), permit drawings, and quotations to be generated in an expeditious manner.

This software was to automate the design process, the creation of the BOM, and quotation packages based on the array layout and electrical drawings generated by the user; allow both experienced and inexperienced AutoCAD users to create an array layout and electrical drawings; and allow a user to move drawings between AutoCAD and the software.

Results

PowerLight has adapted off-the-shelf integrated design software to meet all objectives.

After receiving quotes from qualified consultants, PowerLight chose to use an off-the-shelf software, Actrix Technical 2000. PowerLight chose Actrix because it was developed by AutoDesk and is therefore inherently similar to AutoCAD. Actrix also has many key features, including the ability to create active shapes. It can also be customized by Visual Basic® for Applications to create a user-friendly, automated interface.

Once Actrix was selected, PowerLight worked with the subcontractor to create three templates (rooftop array layout, electrical schematic, and electrical room elevation) in which a user could create a drawing. Figures 7, 8, and 9 show these templates and a sample drawing created in Actrix using the template.

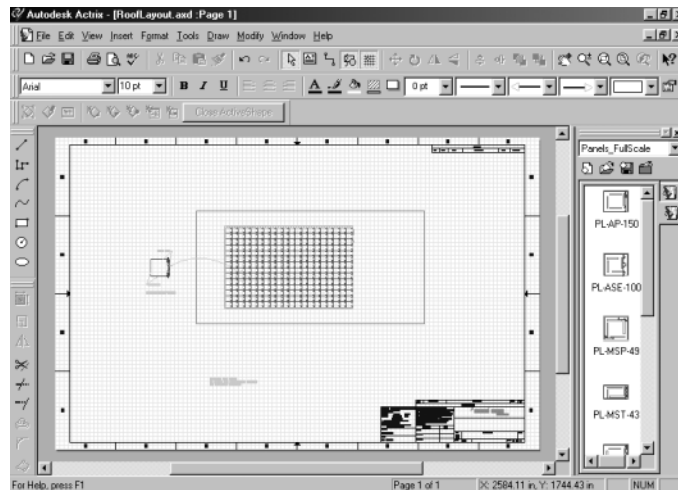


Figure 7: Sample Rooftop Array Layout Created in Actrix Technical 2000

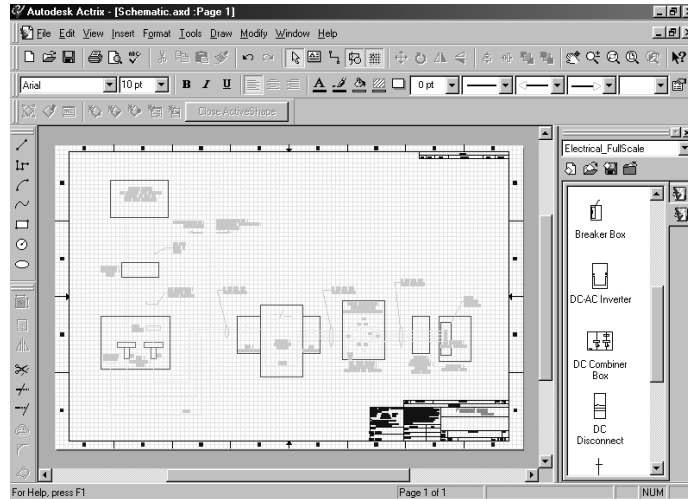


Figure 8: Sample Electrical Schematic Drawing Created in Actrix Technical 2000

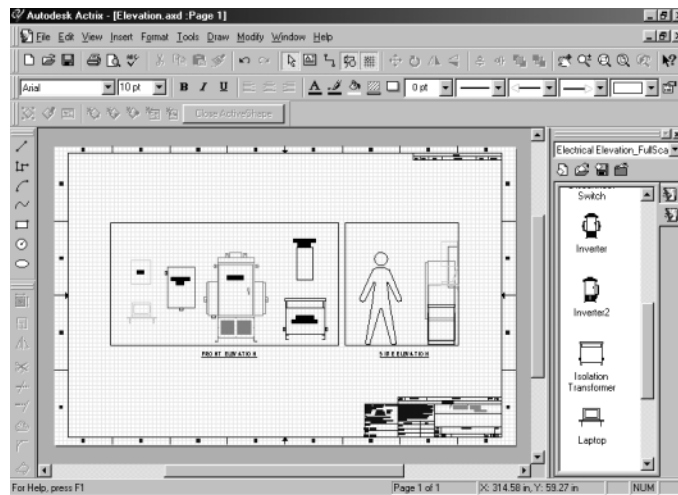


Figure 9: Sample Electrical Room Layout and Elevation Drawing Created in Actrix

In each template, the active shapes are shown to the right of the drawing field. Each shape has an associated cost, power, and backerboard dimension. These properties can be edited and added to over time as the parameters of the selected laminate tile are modified. The user places the shapes into the drawing field. Actrix can then generate a property report or bill of materials (BOM), incorporating the chosen shapes' properties, in a tab delimited (.txt), comma separated (.csv), or Microsoft Excel (.xls) format. The property report wizard is similar to an Excel Chart wizard, in that it allows users to choose the fields to be included in the report. These reports can eventually be linked to a Material Requirements Planning (MRP) system.

Although Actrix has some limitations, PowerLight has found it to be a cost-effective design tool. The customized software allows both experienced and inexperienced AutoCAD users to design a PowerGuard system with ease. This software will save many hours of engineering and marketing time by automating the design process, and creation of the BOM and quotation package. As PowerLight quotes and designs more and more projects, this will be increasingly important.

3.24 PowerGuard System Packages

Objectives

Under this task, PowerLight was to evaluate its systems and new products to redefine PowerGuard system packages based on the most economical modular increments. The smaller the project, the higher the per-watt cost of a PowerGuard installation, due to the variety of fixed costs involved in designing, permitting, and installing. For relatively straightforward installations, substantial cost savings can be realized if some of the processes associated with fixed costs are standardized.

Results

PowerLight has created a series of system packages based on economical modular increments. An installation manual was created for the specified systems and was distributed to qualified Value Added Resellers (VARs). When this was originally done, the standard systems were sized at 4-kW, 10-kW, 25-kW, and 100-kW. Since then, PowerLight has focused on larger average system sizes. Consequently, the list of standard system sizes has been expanded to include systems up to 500-kW.

Three standard size systems have been listed with the federal government's General Services Administration (GSA). PowerLight has negotiated pricing with GSA for 100-kW, 250-kW, and 500-kW PowerGuard systems.

3.25 Assessment of Commercial Demonstrations

Objectives

Under this task, PowerLight was to assess commercial demonstration projects in order to evaluate system performance, review cost savings, and assess the effectiveness of changes made during Phase II of this project.

Results

PowerLight compared performance and cost of projects manufactured before Phase II with projects manufactured and installed after Phase II. System performance has not been compromised, and the quality (for example, fit and finish) has improved. Overall manufacturing costs were reduced 57%; an additional 74% reduction in materials costs was realized during installation. Labor requirements have been reduced, as demonstrated in batch production runs. For example: for a pre-phase II project, it took 6 weeks and 6 workers to manufacture 350 boards. For a post-phase II project, it took 2 days and 8 workers to manufacture 500 boards.

3.25a Sloped Tile Refinements & Testing

Objectives

Under this task, PowerLight was to continue Phase I efforts to develop sloped tile PowerGuard.

Phase I work yielded a sloped tile product that performed well in the field. However, design refinements necessary for commercialization included a better hinge mechanism between the spacer and backerboard, to improve manufacturability, and an improved clasp mechanism joining the upper edge of the PV with the tile backplate. In addition, the sloped tiles were to be fabricated in a flattened configuration for shipment but not cost much more than standard PowerGuard.

The resulting sloped tile was to be stronger and meet standards for European products.

Results

Research and field-testing show that the resulting design meets design and performance criteria and will meet European product standards.

The design consists of just four parts in addition to the PV laminate and the coated backerboard. Cost is reduced because the materials are shipped flat to the factory. Perforations in the sheet metal make bending straightforward and repeatable with the help of simple jigs. Three metal strips are bent and attached to the coated board. The wind deflector includes legs which support the PV laminate and the deflector at the top edge of the slope. The design is shown in Figure 10 and Figure 11.



Figure 10: Sloped Tile Base Strips



Figure 11: Sloped Tile Base Strips and Deflector Completely Assembled

3.25b Tile Edge Trimming Station

Objectives

Under this task, PowerLight was to design and implement a system to trim the edges of the coating on PowerGuard backerboards. The result of this task was to be a semi-automated system that reduced the number of operators needed by 2/3 and improved both repeatability and quality of the edge shape.

Results

A series of prototype tools were designed and fabricated. They fit snugly into the tongue and groove contour and hold a blade set at a firmly maintained angle to trim the coating. The final version is made of sheet metal with a plastic insert to match the tongue or groove contour. The number of operators was reduced from 6 to 1. That one worker can easily keep up with the production line even though production line speed has increased significantly during this project. Repeatability and quality of the edge shape have been improved.

3.25c End of Line Lifter/Stacker

Objectives

Under this task, PowerLight was to experiment with end-of-line methods that ensure board straightness and proper stacking and that anticipate semi-automated methods, and then to design the semi-automated equipment for lifting and stacking, preferably from off-the-shelf assembly equipment. The results of this task were to be a 50% reduction in labor, a 25% improvement in throughput (from 60 seconds/tile to 45 seconds/tile), improved quality assurance of bonded parts, and elimination of the need to periodically restack finished pallets.

Results

The new stacking system meets or exceeds all objectives. Labor has been reduced 50%. Throughput was increased to 20 seconds per tile. Quality assurance has improved, and periodic pallet restacking has been eliminated.

The original stacking method raised concerns about the integrity of the bond between the spacers and the board coating. The boards flex when they are lifted by hand from each end, which could cause the spacers to separate from the coating in the center of the board. Because boards of different dimensions behaved differently, two new stacking methods were developed.

For long and narrow boards, sag is only an issue in the long direction. Two rails were constructed, with handles at each end. The boards are slid onto a narrow table, and the rails meet the board along each long side, sliding toward the center of the board a specific distance. Brackets on the other side of the rails align with the board's tongue profile. Two workers then lift the two rails and the board and move it to a pallet stack. The rail brackets align with brackets on the top board on the stack, and the new board is lowered into place. Thus the boards are lifted without sagging and are stacked in consistent, straight stacks.

For boards closer to square, sag is a concern in both directions, and a different lifting and stacking method was designed. A retractable fork and frame assembly was constructed on top of the platform built on the hydraulic lift. The board slides over the frame, and the forks lift the board. The forks span the board in one direction and are spaced an optimum distance from the center so the board will not sag in the other direction.

3.25d Clean-up and Waste Management

Objectives

Under this task, PowerLight was to develop methods to handle and dispose of all primary waste at the factory. This was to include a cleaning station for the hopper and for the coating mixer; a method of disposing of or recycling the polystyrene foam dust which exits the router; and construction of an apparatus to manage cement dust at the dry goods silo intake. The results of this task were to be a reduction in cleanup time from 3 to 1 hours per shift (increasing plant throughput to 420 tiles/shift); a 50-75% reduction in the cost of XPS waste disposal; and the capture of 95% of the dust at the intake feed of the dry goods silo.

Results

Cleanup time was reduced to less than 1 hour per shift. A method has been identified to reduce the cost of XPS waste disposal by the target amount, and the equipment was purchased, but it will not be ready for installation until early 2002. Capture of silo dust has not been formally measured; however, with the following improvements, the factory is now virtually dust-free.

Clean-up

Improvements to many parts of the PowerGuard manufacturing line have reduced cleaning time to less than one hour. Changes to the design of the coating hopper and the creation of a cleaning trough for the mixing shaft of the continuous mixer have significantly reduced cleaning time of the parts of the production line associated with the coating process. Further improvements in the consistency of the coating mixture have resulted in less contamination of the rollers of the conveyor system. This eliminates a time consuming cleaning task.

One of the design priorities for the second generation coating hopper was ease of assembly and disassembly. The original coating hopper was very difficult to disassemble, and when it was

disassembled, all adjustments were lost. The new hopper is held together with special clamps so that it disassembles in about a minute or two making cleaning easy and fast. Most parts can be cleaned before the coating has a chance to start setting up, making the cleaning process a wiping down rather than a scrubbing process. Re-assembly of the hopper takes about five minutes since all the adjustments are retained even when the hopper is taken apart. This allows for easy set-up of the line to prepare for the next shift's operation.

XPS Waste

The dust collection system for the router has been modified to provide for easier and more efficient removal of the XPS dust from the collection bags. Previously, emptying the collection bags was time consuming, and it was difficult to contain all the XPS dust. New collection bags were fabricated with drawstring closures on the bottom. The system (Figure 12) was raised off the floor and a hoop placed under the collection bag to hold a plastic bag. When the drawstring is opened the collection bag empties into the plastic bag. The plastic bags of XPS dust are sent to the recycler, which also collects the scraps of XPS boards.



Figure 12: Modified XPS Dust Collection System

Silo Dust

A vacuum system and dust containment box have been installed on top of the dry goods silo. The vacuum uses a special filter to maximize dust capture. This system was recently upgraded to one installed in a second hole in the top of the silo. The new system (Figure 13) sucks air out of the silo and blows it through a filter. This creates airflow into the silo around the opening of the dry goods sack being emptied into the silo.



Figure 13: Dust Containment Box on Dry Goods Silo

PHASE III

3.26 Optimized Retooling for Capacity Expansion

Objectives

Under this task, PowerLight was to work with selected U.S. PV partner(s) to design any required modifications or retooling of their standard PV laminate manufacturing plant to expand production capacity for PowerGuard products. The result was to be a plan for expansion of U.S. PV laminate manufacturing capacity for application with the PowerGuard product.

Results

In September 2000, PowerLight reached a purchasing agreement with a U.S. PV manufacturer for 1.4-MW of laminates within the next year. This agreement required the PV manufacturer to increase capacity by 2-MW in order to deliver this quantity. PowerLight fabricated equipment to enable final assembly of PowerGuard tiles to be done at the factory of the PV laminate manufacturer.

However, after this agreement was made, the PV laminate manufacturer experienced product problems that it has yet to overcome. This has prevented the planned expansion. More recently, PowerLight reached an agreement with a different U.S. PV manufacturer. This agreement involves the installation of assembly equipment at the PV manufacturer's facility to enable final assembly of PowerGuard tiles to be done there. The PV manufacturer is in the process of rearranging its manufacturing facility in order to place the PowerGuard assembly equipment at the end of the production line. The annual output of the combined production system is expected to be 2.5-MW.

This arrangement will be advantageous for both the PV manufacturer and PowerLight. The PowerGuard production process will use the entire current production output of the PV manufacturer's facility. Assembling PowerGuard tiles in the same facility where PV laminates are manufactured will remove the packaging and shipping steps from the overall process, thus reducing cost.

The combined production line is expected to be ready by the end of January 2002.

3.27 Equipment/Facility Assessment

Objectives

Under this task, PowerLight was to assess the performance and manufacturing improvements resulting from the retooling/expansion of the PV laminate capacity of a U.S. manufacturer as designed in the previous task, Optimized Retooling for Capacity Expansion.

Results

As explained above, PowerLight set up assembly equipment at the end of the PV laminate production line of a U.S. PV manufacturer. This production line will produce 2.5-MW annually specifically for use in PowerGuard tiles. This increase did not require any special equipment except for PowerGuard assembly equipment, which PowerLight sent to the factory of the PV manufacturer.

The PV manufacturer has continued to produce PV for use in PowerGuard tiles as specified in the purchase agreement. The PV laminates being produced meet PowerLight's specifications and will continue to be assembled into PowerGuard tiles.

3.28 Component Testing, Certification, and Safety

3.28.1 Wind Testing: Computational Fluid Dynamics (CFD), Wind Tunnels

Objectives

Under this task, PowerLight was to investigate installations on roofs with mechanically attached membranes under varying wind conditions. Installation of PowerGuard on mechanically attached roof membranes requires understanding if and how such roofs must retrofitted so that the installed systems meet performance requirements. To accomplish this, PowerLight worked with subcontractors to test the behavior of PowerGuard tiles on a roof simulator with a mechanically attached membrane under varying wind conditions.

Results

The wind stability of PowerGuard tiles on fully adhered roofing systems, and single ply roofing systems with air barriers, has been proven through wind tunnel studies. Mechanically attached, single ply membrane systems without air barriers present a unique challenge for PowerGuard systems, because these roofing systems have the potential to balloon, or billow, in relatively low winds (5psf uplift pressure). Such billowing could displace the loose-laid roofing pavers.

Models of PowerGuard tiles were installed on a test apparatus that simulated the billowing of a mechanically attached TPO membrane. The test apparatus consisted of an enclosed test bed with a mechanically attached roof system on the top surface. This set up can be pressurized internally with various pressures. Deflections of the membrane and tile system were measured with and without PowerGuard tiles installed on top of them, using surveying equipment.

The data were analyzed so that the pressures that were used could be translated into typical field conditions representing various building heights, rooftop location, and surrounding terrain. If acceptable deflections were obtained in the experiment for the pressures that could be experienced in the field, then the recommended membrane securement can safely be used with the PowerGuard system.

It was determined in this experiment that additional membrane securement with batten bars placed under the array area in a specific pattern would limit deflections to allowable levels for most PowerGuard installations.

3.28.2 Underwriters Laboratories Listing (UL)

Objectives

Under this subtask, PowerLight submitted modified PowerGuard® products to UL for listing. This is the final phase of UL listing for this project.

Results

PowerGuard tiles

In the course of the PVMaT subcontract, seventeen PowerGuard tiles, using PV modules from different manufacturers, have been listed by UL. PowerGuard’s original listing was for the PL-MSX-120 using the Solarex MSX-120 module. The following chart shows all the UL listed PowerGuard tiles to date.

PowerGuard Tile	PV Module
PL-MSX-120	BP Solarex MSX-120
PL-AP130	Astropower AP130
PL-AP120L	Astropower AP120L
PL-AP75	Astropower AP75
PL-AP75 Double Module	Astropower AP75
PL-ASE100	ASE Americas ASE100
PL-SP-75	Siemens SP-75
PL-SP-75 Double Module	Siemens SP-75
PL-SP-135	Siemens SP-135
PL-SP-150	Siemens SP-150
PL-SP-150-24L	Siemens SP-150-24L
PL-FS-415	First Solar 415
PL-PW750	PhotoWatt PW750
PL-BP-2150S	BP Solarex BP-2150S
PL-BP-TF-80L	BP Solarex TF-80L
PL-MST-43	BP Solarex MST-43
PL-MST-43 (Alternate construction)	BP Solarex MST-43

Accessories

PowerCurb, for both RT and LG PowerGuard systems, was listed as an addition to the PowerGuard Accessory File.

T-harness

Internal testing was completed for the parallel connector harness, or T-harness, in June, and samples were sent to NREL for accelerated life testing. Samples were then submitted to UL for listing.

Combiner boxes

PowerLight engineers are currently designing five standard combiner boxes, each covering a range of voltages, to be used for all installations. It is highly likely that these boxes will be fabricated by an outside vendor. When specifications are complete, samples will be fabricated and submitted to UL for design review.

3.28.3 International Conference of Building Officials Certification

Objectives

Under this subtask, PowerLight was to work to obtain International Conference of Building Officials (ICBO) Certification. The Uniform Building Code (UBC) is used by over 2500 building departments nationwide and is by far the predominant code standard. ICBO certified products are reported to every building department on an annual basis informing local officials of compliance. ICBO certification would reduce costs by streamlining permitting processes, which can be time-consuming.

Results

PowerLight worked with ICBO officials to establish evaluation criteria for PowerGuard. Based on these discussions, PowerLight submitted an application for evaluation.

ICBO will compare PowerGuard to roofing products currently ICBO-certified, to determine appropriate acceptance criteria. Once criteria are set, the submitted wind, fire, and other test data will be examined, and any further required tests will be identified. Evaluation will then proceed.

3.29 Product Installation Information

Objectives

Under this task, PowerLight was to develop product installation information for the installation of PowerGuard systems.

Results

An installation manual was developed and has been distributed to all Value Added Resellers (VARs) and certified installers. It contains sections on system description and safety, siting and roof preparation, system parts, tile installation, RT curb installation, electrical intertie, system start-up, and trouble-shooting and repair. The manual also provides the specifications for UL listed PowerGuard tiles.

3.30 Assessment of Improvements in Commercial Demonstrations

Objectives

Under this task, PowerLight was to assess the results of a commercial demonstration. PowerLight was to evaluate the performance of the systems, review the cost savings, and assess effectiveness of changes made during Phase III.

Results

The commercial demonstration projects for each phase of this PVMaT subcontract were used to compare costs and manufacturing improvements.

In Phase I, PowerLight assessed a commercial demonstration project as a snapshot of the PowerGuard production process before all the improvements implemented in the course of this subcontract. At the end of Phase II, PowerLight assessed another commercial demonstration to gauge the effectiveness of the next wave of improvements to both process and product. Now, at the end of Phase III, PowerLight has continued to greatly reduce PowerGuard system costs while steadily improving product quality, as shown by the results of the cost assessments of the first commercial demonstration project and this latest one, completed in 2001.

At the end of Phase I, the cost of PowerGuard tiles had been reduced by 30%, and the production rate was more than 200 tiles per shift. At the end of Phase II, the cost of PowerGuard tiles had been reduced by 57%, and the production rates was more than 400 tiles per shift.

The tasks in Phase III did not focus on improvements in product and process as they were in Phases I & II. However, PowerLight has continued to bring costs down by streamlining and improving the manufacturing process. Production rates were over 500 tiles per shift during this phase. PowerLight has also continued to address quality issues by working on continuous improvement of tools and processes. Many aspects of factory operation have been improved, which has helped reduce overall costs.

Increased demand for PowerGuard, which has been generated in part by cost reduction measures of the earlier phases of this project, has moved PowerLight into continuous production. This has allowed a shift from a temporary work force hired for each job to a full time production staff. This has improved product quality and reduced cost by reducing training needs.

After Phase I, system cost had been reduced by 15% compared to the first commercial demonstration project. After Phase II, system cost had been reduced by 21%. Now at the end of Phase III, system cost for this commercial demonstration project shows a reduction of 38%. This project was done with crystalline PV laminates. Based on the current cost of PowerGuard tiles for crystalline and thin-film laminates, if the project had been done with thin-film laminates, it would have cost 47% less than the Phase I system. However, none of the PowerGuard installations with thin-film laminates done this year was timed properly to serve as the commercial demonstration for this task.

The original project goal for this subcontract was to reduce system cost 46%, to \$3.05/watt. This target was set assuming that the cost of PV would go down as the volume of PowerGuard produced went up. Unfortunately, over the last year, the cost of PV laminates has actually gone up in many cases due to the large demand generated by the high cost of energy in the U.S. Because of this, PowerGuard system costs have not gone down as much as had been hoped. Over the course of this subcontract, the cost of a PowerGuard system has been reduced by 38%, as demonstrated above, while the Balance of System costs for PowerGuard systems including installation costs have been reduced by 68%.

4.0 Patents

Three patents were applied for during the course of this project. They are listed below:

1. Pressure-Equalizing Photovoltaic Assembly and Method. This application describes a method for reducing wind uplift forces on a photovoltaic array through the use of various features which counter these forces.
2. Stabilized PV System. This application describes a method for stabilizing a photovoltaic array through the use of a perimeter assembly and various methods of strapping.
3. Multi-Position Photovoltaic Assembly. This application describes a photovoltaic assembly which can be shipped to an installation site in a flattened configuration and then can be installed with the photovoltaic panel at the desired inclination angle.

REPORT DOCUMENTATION PAGE			Form Approved OMB NO. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE October 2002	3. REPORT TYPE AND DATES COVERED PVMaT Final Report 1 July 1998 – 30 September 2001		
4. TITLE AND SUBTITLE PowerGuard® Advanced Manufacturing: PVMaT Final Report, 1 July 1998 – 30 September 2001		5. FUNDING NUMBERS CF: ZAX-8-17647-12 TA: PVP2.6101		
6. AUTHOR(S) T.L. Dinwoodie and J. Botkin				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) PowerLight Corporation 2954 San Pablo Avenue Berkeley, CA 94710		8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393		10. SPONSORING/MONITORING AGENCY REPORT NUMBER NREL/SR-560-32064		
11. SUPPLEMENTARY NOTES NREL Technical Monitor: Holly Thomas				
12a. DISTRIBUTION/AVAILABILITY STATEMENT National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161			12b. DISTRIBUTION CODE	
13. ABSTRACT (<i>Maximum 200 words</i>) This final report describes the PVMaT results of manufacturing improvements directed toward innovative, low-cost, high-return, high-impact PV products. PowerLight's focus for this subcontract was manufacturing improvements for its patented PowerGuard® building-integrated PV roofing tile. These manufacturing improvements were selected to reduce PowerGuard® system costs, increase PowerGuard® tile fabrication capability to 16 MW/year, and stimulate an increase in manufacturing of PV laminates, within the United States, by 2 MW/year. Production rates rose from 200 tiles per 8-hour shift to more than 500 tiles per 8-hour shift. The overall system cost of PowerGuard® was reduced by 38%. The original goal of a 46% reduction was not met, due to unexpectedly high global demand for PV laminates and limitations on supply. PowerLight has successfully reduced balance-of-system costs, including the cost of installation. At the end of this subcontract, BOS costs had been reduced by 68%. Project goals included: Implementation of an automated tile manufacturing facility, in Berkeley, California, exceeding 16-MW/year capacity; improved quality of finished goods due to improved tooling and processes in PowerGuard® manufacturing, which also simultaneously improved throughput and lowered costs; completion of wind tunnel testing of all design refinements; testing of PowerGuard® installations on mechanically attached roof membranes; creation of an installation manual and training program for installing PowerGuard® systems; certification and listing of PowerGuard® products with Underwriters Laboratories and international certification organizations, and application for listing with the International Conference of Building Officials (ICBO).				
SUBJECT TERMS: PV; flat plate; roofing tile fabrication; wind tunnel; thin-film laminates; adhesive priming; amorphous silicon; solar electric array; dc/ac inverter; electrical quick connects; extruded polystyrene processing; capacitor bank; single-ply membrane system; building-integrated PV roofing tiles; balance of systems; installation			15. NUMBER OF PAGES	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL	