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Subcontractor Report

PowerGuard® Advanced Manufacturing

PVMaT Phase I Technical Report
June 1, 1998—September 30, 1999

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EXECUTIVE SUMMARY

PowerLight Corporation (PowerLight) has completed the first of three phases of a 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 patented PowerGuard® building-integrated PV roofing tile is the product upon which cost reduction efforts have been focused.

The objective of this subcontract over its three-year duration is 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 the United States’ PV laminate manufacturing expansion to 2 MW/year.

During Phase I, PowerLight has addressed these goals through:

- the design of an automated tile manufacturing facility exceeding 16 MW/year capacity
- the construction and commissioning of a new manufacturing plant in Berkeley, CA which incorporates several portions of the automated design
- a comprehensive design review of the PowerGuard® tile and system

During Phase I, these accomplishments have resulted in:

- greater than 200 PowerGuard tiles per 8-hour shift (up to 10 MW/year with 160 Wp PV modules) manufacturing capacity
- 15% cost reduction for overall PowerGuard system
- 30% cost reduction for PowerGuard tile

As PowerLight progresses into Phase II of this PVMaT contract, it will continue to introduce incremental improvements to PowerGuard system components and manufacturing processes to:

- increase manufacturing capacity from 10 to 16+ MW/year
- achieve additional reductions in cost of PowerGuard systems
- achieve additional reductions in cost of PowerGuard tiles

This will result in a lower cost, higher impact PV product, as sought by PVMaT.

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1.0 Project Background

PowerLight Corporation (PowerLight) has completed the first of three phases of a Photovoltaic Manufacturing Technology (PVMaT) 5A1 subcontract, 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 patented PowerGuard® building-integrated PV roofing tile is the product upon which cost reduction efforts have been focused. This product is shown in Figures 1 and 2.

A PowerGuard tile consists of a flat plate PV laminate mounted onto a flat, rigid, cellular foam board, also known as extruded polystyrene (XPS). The top surface of the XPS board is coated with a layer of cementitious material for durability. Several XPS blocks (spacers) are embedded into the wet cementitious coating and adhered to the underside of the PV module to serve as the mountings. 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, normally on the flat roof of a building. Adjacent tiles are connected electrically through electrical 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). Such a system is shown in Figure 3. 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" seeks to introduce incremental improvements to PowerGuard system components and manufacturing processes to significantly reduce the costs of a PowerGuard system. This will result in a lower cost, higher impact PV product, as sought by PVMaT.

2.0 Objective

Cost reduction is a key for grid-connected PV markets. The objective of this subcontract over its three-year duration is to continue the advancement of the PowerLight's manufacturing of PowerGuard roofing tiles in order to reduce cost, increase manufacturing technologies, and provide PV systems incorporating financing options. PowerLight will reduce the cost of a PowerGuard system, complete manufacturing improvements for PowerGuard tile fabrication capability of 16 MW/year, and stimulate the United States' PV laminate manufacturing expansion by 2 MW/year.

PowerLight will 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 - Phase I

During Phase I of “PowerGuard Advanced Manufacturing”, PowerLight conducted parallel efforts and accomplished the following advancements:

- decreased system cost reduction of 15%
- increased PowerGuard tile production capacity from 5 MW/year to 8 MW/yr
- established a manufacturing layout master plan for sequential integration of semi-automated and automated component workstations
- defined semi-automation or automation of selected stages of the existing tile fabrication sequence, including PV module preparation, XPS processing, and coating
- advancement of several design improvements to the grid-tied inverter control board including controller redesign, integrated Data Acquisition System (DAS), and communications for audit-worthy verification of PV system performance
- conformed to NEPA, OSHA, and other federal and state regulations applicable to the proposed production process and mitigate potential for waste streams
- initiated of Underwriters Laboratories (UL) listings and international certifications on PowerGuard improvements
- developed of finance packages and integrated warranties
- evaluated commercial demonstrations which incorporated the new design features and manufacturing process.

The following tasks were undertaken during PowerLight’s Phase I effort to achieve the advancements named above:

3.1 Task 1 – Assembly Layout and Integration

PowerLight has engineered a step-by-step approach to integrate cost-effective automation of the PowerGuard tile manufacturing. This master plan specified a plant layout, equipment layout, semi-automated and automated equipment descriptions, labor utilization, and specification for stages of implementation. Phase I work was expected to achieve the following improvements over the manufacturing process which existed prior to PVMaT:

- Increased production capacity from 100 tiles/shift to 200 tiles/shift
- Increased productivity from 4.6 min/tile to 2.3 min/tile
- Decreased number of operators from 10 to between 9 and 6
- Decreased tile cost by 30 – 55%.

All of these goals were achieved, with the exception of the decrease in number of operators (see sections 3.1.4, 3.1.5)

3.1.1 Previous Manufacturing Process

In 1997, prior to this PVMaT subcontract, PowerLight had constructed a 5 MW/yr PowerGuard manufacturing plant with the capacity to produce 100 tiles/shift utilizing 10 operators and 2 supervisors. The description that follows is the manufacturing process that was used at that time to fabricate PowerGuard tiles. This description will be referenced in the sections that follow to offer perspective.

The process:

1) Pre-planed 4' x 8' x 2" sheets of XPS were cut to width and length at a **Panel Saw Station**. Generally, two boards would be cut from one sheet of XPS stock. This was a manually actuated power-saw.
2) Spacer blocks were manually cut at the Panel Saw Station as well, from scrap and XPS stock as necessary to supply the Spacer Attachment Station.
3) A stack of cut boards was manually delivered to an XPS Processing Station.
4) At the **XPS Processing Station**, two of the four 2" tall edges were given a tongue profile and the other two edges were given a groove profile. This was accomplished using handheld routers.
5) Also at the XPS Processing Station, the perimeter of the top face of the board was given a depth profile using a hand held planer.
6) A stack of processed boards was then manually delivered to the beginning of a non-motorized conveyor line.
7) A single board would be placed onto the line and pushed to the Coating Station.
8) A cementitious coating was manually mixed in 5-gallon buckets and hand-carried to the Coating Station.
9) At the **Coating Station**, a masking template was positioned onto the middle of the board, the cementitious coating was manually spread onto the exposed perimeter of the board using a mason's trowel, and the board was pushed to the Spacer Attachment Station.

10) At the **Spacer Attachment Station**, a template was positioned, the spacers were manually glued to the uncoated central portion of the board, and then the board was pushed to the PV Module Placement Station.
11) Elsewhere, PV modules would be removed from their packaging and their undersides were manually wiped clean with alcohol.
12) At the **PV Module Placement Station**, the board with spacers was manually lifted from the conveyor and positioned onto a wooden pallet in a curing rack.
13) Then, the prepared PV module was manually positioned over the board with spacers, and glued onto the spacers, thus completing the fabrication of a PowerGuard tile.
14) Once the pallet in the curing rack was stacked to the desired number of tiles, it would be tension strapped and transported with a fork truck to the packaging station.
15) At the **Packaging Station**, additional packing materials would be added to the pallet and the entire package stretch-wrapped, ready for shipment.

3.1.2 Manufacturing Process Improvements

In accordance with the master plan, PowerLight developed specifications for an automated production line ultimately capable of manufacturing one PowerGuard tile every minute (well over 400 tiles per 8 hour shift). By the end of Phase I, the interim goal of 200 tiles per 8 hour shift was attained.

The manufacturing process implemented in Phase I features the following advancements over the process described in Section 3.1.1:

- a **motorized conveyor**, outfitted with interlocked proximity sensors for automated station to station movements, to eliminate manual movements of components and work-in-progress mentioned in Section 3.1.1, Steps #4 through 10
- a **semi-automated PV module preparation** station (see Task 2)
- a 3-axis, 2 spindle, Computer Numerically Controlled **(CNC) router** to perform simultaneously the routing and planing operations described in Section 3.1.1, Steps #4 and 5 (see Task 3)
- an **automated coating application** station to automate the operations described in Section 3.1.1, Steps #8 and 9 (see Task 4)
- a **semi-automated spacer fabrication and attachment** station to improve the operations mentioned in Section 3.1.1, Steps #2 and 10 (see Task 5)

These individual advancements are described in detail in the sections that follow.

3.1.3 Implementation of the New Manufacturing Process

The previous PowerGuard manufacturing facility was located in Mt. Marion, New York. An exhaustive search for a manufacturing facility local to the corporate headquarters was started in November of 1998, resulting in the lease of a 17,000 square foot factory building in June of 1999. In July of 1999, equipment began arriving at PowerLight's new factory in Berkeley, California.

By the second week of August 1999 the once empty shell of a building was outfitted with new electric service, compressed air, vacuum, and process water. We received, installed, programmed, tested, and started using 100’ of automated conveyor, the CNC router, the automated Coating Station, the PV Module Station, and the Spacer Station. This equipment was utilized during production runs in August and September of 1999. The factory and equipment are shown in Figure 4.

3.1.4 The Final Results

The factory was in full scale production for most of the month of August and the entire month of September 1999. For instance, of the 21 calendar working days in September, the production line was run for 16 days, and 5 days were scheduled for non-production activities such as loading trucks with finished goods, receiving raw material shipments, inventory, equipment inspection and maintenance, extra factory clean-up, and other non-production related work.

We recorded the following results:

- Increased production capacity from 100 tiles/shift to over 200 tiles/shift
- Increased productivity from 4.6 min/tile to 2.3 min/tile
- Achieved a “high water mark” of increased productivity of 1.96 min/tile (5 day average)
- Increased number of operators from 10 to 16
- Decreased tile cost by 30%.

These results were achieved during the month of September, when more than 3000 PowerGuard tiles were fabricated, averaging over 200 per 8 hour shift. The finished goods ready for shipment are shown in Figure 5. The resulting production rate of 2.25 minutes per tile is a 200% increase from the previous method (100 boards per day). Using 52 weeks per year and 160 Wp modules, this rate translates to 10 WM/year production capacity. However, further implementation of the Master Plan and future automation of tasks under PVMaT are necessary for reducing the number of operators from the current level of 16.

We experienced particular success during the last two weeks of September. Training, experience, teamwork, and trouble free operation of equipment resulted in the following production:

Day :	Fri	Mon	Tue	Wed	Thu	Fri	AVG
# Tiles Made :	252	192	204	240	0	288	235

These results typify what can now be expected of a 5 day production run. One day, Thursday, was scheduled to load outbound trucks and receive raw materials for the following week. The best production of the week (288 tiles at just over 1.5 minutes per tile) is difficult to improve upon until the Router Station, Coating Station, and edge trimming bottlenecks described under Tasks 3 and 4 are addressed. The 288 quantity was achieved only because extra routed boards were stockpiled from Monday and Tuesday of that same week.

3.1.5 Difficulties and Solutions

We experienced normal start-up problems during the first two weeks of production.

In our initial production run, we successfully manufactured a 242 tile PowerGuard system in 5 days (8 hours per day) utilizing 16 temporary laborers and 5 PowerLight supervisors. There was tremendous opportunity for improvement. After two weeks time, the 5 managers were reduced to 1 supervisor plus a working lead operator. The managers were needed during the early production runs to learn the equipment, teach the temporary laborers, supervise and organize the labor into a functioning team, and expedite the overall learning curve. Once the production stations had been organized, standard operating procedures developed, and station leaders identified, the number of managers were successfully reduced.

Another area of production requiring improvement was overall cleanliness during production. The production line was run for only about 3 hours of the day as clean-up of the factory after a production run was found to be a labor intensive activity. Dried spills and drips of cementitious material were numerous and required hours of labor to be removed from the equipment, the conveyor, and the floor. Cleanliness of the operation had to improve before the number of operators could be decreased. Improvements to the cementitious material mixing station were proposed to improve cleanliness.

The efficiency at certain workstations also required improvement. In early production runs, the production line had been run at a slow speed in order to allow on-the-job training of the work force. The coating machine and drive mechanism were observed to easily coat 1 or more boards per minute, but assembly of the PV laminate onto the coated board took over 1 minute each, and palletizing of the finished tiles proved to take 2 to 3 minutes per board or more. Simple process modifications and ergonomic aids were proposed at these stations to increase productivity at these stations.

One final inefficiency was encountered. It was found that before the palletizing operation, each tile needed to have all 4 edges of the coated board trimmed of excess coating with a mason’s trowel. The wet coating tended to slump down over the edge of the tile due to the vibrations experienced while traveling down the motorized conveyor. If the coating was left on the tongue and groove profiles to harden, the tiles would not assemble properly during rooftop installation. This unforeseen operation not only required additional labor, but also was observed to be the bottle neck of the operation downstream from the coating station. We will pursue optimization or elimination of this station during a future Phase of this PVMaT subcontract, if possible.

3.2 Task 2 – PV Laminate Preparation

PowerLight has designed and evaluated several automated stations for improving four manufacturing processes related to preparation of PV laminates for assembly into PowerGuard tiles. These processes, before incorporating PVMaT Phase I improvements, were as follows:

1. The assembly of junction boxes (j-boxes) onto the PV laminate. This occurs at the PV manufacturer. The j-box is adhered to the PV laminate and has internal components (terminal block, printed circuit board, etc.) which attach the leads of the laminate.
2. The assembly of the electrical quick connects. The quick connects are assemblies which are purchased by the PV manufacturer and attached to the j-box assembly. They are the cables over which the electricity generated by the solar panel is conveyed.
3. The underside of the completed PV module must be cleaned (“primed”) with alcohol immediately prior to adhesive bonding with the PowerGuard tile.
4. The fully prepared PV module must be electrically tested for proper voltage and current before assembly.

The following sub-tasks were undertaken to investigate the potential cost savings from automating these activities and by removing j-box and electrical quick connect assembly from vendors, thus internalizing those operations in the PowerLight factory.

3.2.1 Sub-Task 2.1 – J-box Attachment Station

PowerLight has produced a design for an in-line, semi-automated j-box attachment workstation. Our goal under this sub-task was to investigate the j-box attachment operation currently implemented by our PV vendors and conceive of a design that would offer the following efficiencies over the existing process:

- Increased productivity from 10 min/lam to 4 – 2 min/lam
- Decreased shipping costs by 30 – 70%

The design which we developed has the PV laminates delivered to a workstation which emphasizes ergonomic placement of the j-box components, the PV laminate itself, and the assembly tools. The assembly tools (screwdriver, glue dispenser, soldering iron) are semi-automatic power tools mounted on tool balances as required.

We simulated the assembly operation through a mock up of the operation by borrowing tools and conveyor from other workstations. The time required to attach j-boxes was reduced from 10 minutes to 8.75 minutes per laminate. In our design, the adhesive application of the j-box remains unchanged, as the PV vendors already use a powered dispenser for glue application. The PC card insertion requires manual dexterity and offers no room for implementation of automation. There are screw connections for which we would use an automatic tool, offering savings of 30 seconds per j-box. Ergonomic improvements account for another 45 seconds of efficiency. The total cost to PowerLight in labor and materials to attach j-boxes is projected to be \$0.038/Wp and \$10,000 to \$20,000 in equipment and tooling. These costs would need to be recovered through savings in shipping costs and price reductions by the PV manufacturers.

In fact, the shipping costs of high-efficiency PV laminates can be reduced from \$0.04/Wp to \$0.01/Wp. A typical case of frameless PV modules (with j-boxes) contains 22 modules. PV laminates (no j-boxes) are packaged 150 to almost the same size case. Though the shipped weight is the same, the shipped volume is decreased by approximately 80%. The shipping costs of low-efficiency PV laminates can be reduced from \$0.06/Wp to \$0.02/Wp.

The costs to assemble are approximately recovered by way of reduced shipping costs. The real incentive to internalize this operation, then, will have to come in the form of PV price reductions from the PV manufacturer. As such, negotiations are underway.

Our investigation determined that without a significant design change to the j-box assembly, a 60% to 80% improvement over the current method employed at the PV manufacturer is not possible. Purchase of the equipment required to implement this design has been put on hold pending: (A) the results of the negotiations for PV price reductions if we assemble the j-box and (B) consideration of design improvements to or alternatives to j-boxes. A solid state approach to exiting the PV laminate may offer simplicity, reliability, and maintenance savings that are not able to be realized with the current j-box assembly design (such an investigation is not currently funded under PVMaT).

3.2.2 Sub-Task 2.2 – Electrical Quick Connects

PowerLight completed extensive research of commercial connector technology. We have selected a particular vendor's electrical connectors due to their ease of use in the field and superior water-tightness. Furthermore, we have designed an automated assembly station for fabricating these electrical connectors into electrical leads. These quick connects can be purchased pre-assembled from the vendor, pre-assembled from a subcontractor, or as unassembled components. Our goal under this sub-task was to internalize this assembly operation and achieve a 50% cost reduction over buying pre-assembled connectors.

Electrical quick connects cost \$0.09/Wp to PowerLight when we buy them pre-assembled. We now make our own quick connects for less than \$0.04/Wp, achieving more than a 50% cost reduction.

Our assembly workstation features a fully automatic wire processing machine which cuts wire to length and strips both ends in a very rapid yet extremely accurate fashion. Secondly, a semi-automatic crimping device is used to fasten the connector onto the wire end. Third, a semi-automatic pulling device is used to assemble the rubber insulating boot onto the connector. Finally, a label dispenser presents the UL label that must be affixed to the finished connector.

We have used these machines to produce close to 20,000 connectors to date. In addition to the cost reduction stated above, we reduced lead times in making our own connectors versus purchasing them outright. PowerLight can now conveniently make our own electrical quick connects with a one-day turnaround for field repairs, R&D, and expedited commercial jobs.

3.2.3 Sub-Task 2.3 – Adhesive Priming Station

PowerLight has designed (but not implemented) a fully automated adhesive priming station whereby the underside of the PV module will be wiped clean using alcohol just prior to the gluing of spacers. Our goal under this sub-task was to reduce the number of operators required for this activity by 50%.

As the PV laminate is conveyed from the beginning of the line to the assembly stations (j-box and spacer attachment), isopropyl alcohol is automatically aspirated onto the areas of the laminate's surface onto which components are about to be glued. The alcohol which remains is automatically evaporated off leaving a surface to which the adhesive will securely attach. Thus, this station shall function with no operators. We expect to build and install this station, but were unable to do so in time for our production runs during Phase I.

Instead, we designed an improved system for adhesive priming for our actual production runs which decreased the actual number of operators by 50% from 1 full-time to 1 part-time operator.

After the PV module is retrieved from the case of PV modules, it is mounted into a jig that specifies the particular areas that require priming. An operator sprays the isopropyl alcohol onto the areas from a spray bottle, wipes the specified areas with a cloth, and proceeds with other tasks related to spacer attachment while automatically blown air expedites the evaporation of the remaining alcohol. The PV laminate remains where it is to receive spacers, thus allowing the same operator to perform adhesive priming and spacer attachment. Previously, the adhesive priming was a separate station requiring a full time operator and additional station to station handling of the PV.

3.2.4 Sub-Task 2.4 – PV Module Quality Control Testing Station

PowerLight has designed and implemented an in-line PV laminate testing station. As it is very costly to isolate and replace a non-functioning PV module in the field after installation of a PowerGuard system, every effort must be made to confirm that PV modules are functioning prior to assembly into a finished PowerGuard tile.

After the PV module has received its j-box, an operator retrieves the electrical quick-connects which extend from the j-box and plugs them into fixed test probes. An artificial light source is applied to the PV laminate. The electrical voltage that results is received by the testing station through the test probes and is visually displayed to the operator confirming that the PV laminate is functional. If the voltage measures is out of specification then the laminate or the connections are faulty. The PV module can then be sent for repair.

3.3 Task 3 – Extruded Polystyrene Processing

The typically 4' square by 2" thick foam boards onto which the PV modules are mounted are given tongue and groove profiles similar to what one would see in wood flooring. Of the four 2" tall edges of the board, two adjacent edges are milled into tongues and the other two are milled into grooves. Additionally, a 1" wide by 1/8" deep channel is cut into the top face of the entire perimeter of the board using a hand held planer. Before PVMaT improvements, this manner of processing the XPS board was very loud, created enormous volumes of dust, did not offer adaquate precision, and was only as safe as could be expected considering the continuous use of power tools with exposed high-speed cutters.

PowerLight was to design and build an XPS processing station to:

- Increase productivity from 2 min/board to between 1.4 and 0.6 min
- Decrease number of operators from 2 to 1
- Increase dimensional accuracy

Several approaches to this station were identified. Fixed routers through which a moving board could be passed were eliminated from consideration as multiple router heads and stop positions would have to be used, creating many variables. We had a low confidence that such a system would produce parallel sides, perfect 90 degree corners, and tongue and groove profiles that were in perfect Z-axis alignment. On the other hand, our research of CNC router tables found that a fixed board around which computer controlled routers could operate promised tremendous accuracy and repeatability. PowerLight selected a two-headed, 3-axis, CNC router.

From a remote computer, a stored AutoCAD file designates the path which the two router heads follow. Multiple files can be stored for the numerous different PowerGuard sizes. One head performs tongue cutting while the other does the groove, eliminating the need for tooling changes. The rotational speed of the cutters and the linear speed of the router head are both infinitely and independently variable, allowing us to perfectly tune the cutters to the density of the foam material and create smoothly shaped tongue and groove shapes. Repeatability of the router is ± 0.002".

We have processed more than 3000 boards, operating the router 5 days per week, 8 hours per day as part of a single shift manufacturing operation. We have been able to optimize the router speeds and paths while maintaining a quality cut such that one board is processed in 62 seconds. Only one operator is required. We have found the processed boards to be very accurate to our specifications. For instance, the difference in the length of the two cross-diagonals is always less than 0.015". Previously, the average difference was 0.125". The length and width of the processed board is also within 0.015". Previously, the handheld routers were able to process the board within 0.063" of specification. Finally, the tongue and groove profiles are exact reproductions of their AutoCAD drawings. Since the previous method used two different tools (router and planer) to create the edge detail there was always some variability in the shape of the finished edge. Now, with the router bit producing the entire shape, there is virtually no variability.

Some improvements to the router station were required in order to achieve these results. First, placement jigs were added to the router table to make alignment of the board to be routed easier, more precise, and less time consuming. Secondly, the four valves which had to be turned by hand to release the table vacuum (the board is held onto the table during routing by suction through perforations in the table) were replaced by a single electrically operated valve which is activated by a remote switch.

We have been able to process more than 200 boards per day to supply the production line, and the capacity of the router station could be increased further still with modifications to the equipment. The one operator spends at least 30 minutes to 1 hour of unproductive time per day emptying the dust collection system and sweeping up uncollected foam dust from around the router. A larger capacity system or one that could still collect dust while filled bags of dust were being removed would be an improvement. Additionally, the manual movement of boards to and from the router table is time consuming. The operator must wait for the router heads to come to a complete stop before removing the processed board, stack the processed board on a pallet, retrieve the next board to be processed, and position it onto the table. Full or semi-automation of this material handling operation could potentially increase daily production to more than 300 boards per day.

3.4 Task 4 – Automated Coating Station

Under this task, PowerLight designed and built an automated coating station for coating the top surface of the XPS board. During this period, numerous alternatives to the current coating were identified and investigated, including a cementitious coating, plastic or metallic sheet for a roll lamination process, commercially available concrete-based boards, and elastomeric roof coatings. A cementitious coating was selected due to its expected durability and low cost.

Coatings research was undertaken with the assistance of experts in concrete processing. Extensive research was carried out into the formulation of the cementitious coating. Our variables included the different types and proportions of aggregate (sand), aggregate sizes and proportions, types of cement, chemical additives to improve durability, chemical additives to speed or retard curing, chemical additives to improve workability, and proportions of water. Based upon the advice of industry experts, our observations of workability, and our measurements of indicators such as water content and ratios of the various ingredients, a formula was optimized to give 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. A batch of coating samples was sent to NREL for testing using their freeze-thaw chamber and other equipment. Based upon the work accomplished at NREL, PowerLight purchased and installed a freeze-thaw testing chamber at its facility and proceeded to test batches of coating samples. The final tests resulted in a successful mix, as no deterioration was noted after the 200 freeze-thaw cycles required by ASTM C 666 (several freeze-thaw cycles per year can be expected in a high-latitude location).

PowerLight was to design and build an automatic coating station which:

- Increased productivity from 12 min/board to between 4.2 and 1.8 min
- Decreased number of operators from 4 to between 1.6 and 0.8
- Increased uniformity of coating thickness from ±0.125” to ±0.063”

An automated coating, mixing, and application station was designed, built, and used in actual production runs to coat more than 3000 boards of various sizes since the inception of the production line. This custom machinery consists of an in-line coating applicator which replaces the manual troweling operation from the previous method and an automatic mixer which combines the wet and dry ingredients of the cementitious coating and delivers the mix to the applicator. Boards were driven through the coating station at a rate of 1 board per minute or faster for a tremendous improvement over the previous method which achieved 1 board every 12 minutes. This station requires 1.5 operators (1 full time operator and 1 helper who spends 4 hours per shift at the station) for an reduction of 2.5 operators over the previous method. Finally, the coating thickness is very consistent at ±0.063” and does not change with the production line speed.

We have experienced one serious problem with this method of coating. The wet coating tends to slump down over the edge of the board due to the vibrations experienced while traveling down the motorized conveyor. This does not negatively affect the thickness of the coating as coating thickness is measured on the cross-section of a cured tile (post-conveyance) and the coating station is adjusted accordingly to ensure proper thickness of the end product. However, if the coating is then left (on the tongue and groove profiles) to harden, the tiles would not assemble together properly during rooftop installation. Each tile needs to have all 4 edges of the coated board trimmed of excess coating with a mason’s trowel prior to stacking onto pallets as finished goods ready for curing. While we have been able to meet our production goals of 200 tiles per day, this unforeseen operation does require additional labor and is the bottle neck of the operation downstream from the coating station. This operation will certainly be considered for optimization or elimination as part of future manufacturing improvements.

3.5 Task 5 – Automated Spacer Attachment

PowerLight has begun the effort of automating the assembly of spacers into the PowerGuard tile. Automation of this operation shall directly contribute to the increased production capacity expected under Task 1 above. Under Phase I, the existing spacer design was reviewed and alternative spacer materials and designs were researched. Automated equipment for mass-producing the preferred spacer was designed and implemented.

A list of 15 criterion was established against which possible spacers were evaluated. They were: low cost, +30 year life expectancy, PV able to be removed from spacer in-tact after attachment, 50 lb/sqft tension and 200 lb/sqft compression structural performance, enhancement of aerodynamic properties (as per wind tunnel studies), enhancement of low temperature operation of PV laminate (better air-flow under and around the laminate results in lower operating temperature and higher efficiency opreation), flame resistance (must be non-flammable), ability to withstand high temperature, UV resistance, ability to withstand a freeze/thaw environment, ability to adhere to XPS board or to coating of 50 lb/sqft or better, ability to adhere to PV (glass or Tedlar) of 50 lb/sqft of better, ability of design to allow PV attachment in the factory or in the field, ability of design to allow stacking of assembled tiles while coating is still wet, and the ability of the design to allow continuous coating of board.

The following materials (generally commercially available) were evaluated, having already been determined to represent a low cost option: XPS foam blocks, 24 gage mild steel sheet metal “L” shape, 24 gage mild steel sheet “U” shape, UniStrut Prime Angle “L” shape, perforated 24 gage steel sheet “L” shape, JWE metal joist/stud, JWE joist track, Panduit plastic ductwork type “G”, plastic perforated floor drain, other plastic extruded shapes, other fiberglass structural shapes, PVC pipe half-circle, PVC perforated drain pipe, and lightweight concrete blocks.

The spacer material chosen was XPS foam blocks. The key advantages were the very low cost, ease of manufacture in the PowerLight factory, potential for use of scrap material (from the XPS board cutting operation), excellent compressive and tensile strength (exceeding 50 lb/sqft by more that 50 lbs/sqft), excellent pull-out resistance when embedded in cementitious material, and ability of finished tiles to be stacked upon each other while the cementitious material is curing. Moreover, the very important trait of pullout resistance is not degraded at all due to freeze/thaw cycling. These advantages were overwhelming, but not without some drawbacks. First, as the XPS foam is an insulator, the PV area in contact with the XPS runs slightly hotter than the area with no XPS attached. Secondly, the XPS foam does degrade if exposed to direct sunlight. This is not a problem for the PowerGuard tile backerboard as all exposed surfaces are covered in the cementitious coating which blocks the UV rays. Thus, the spacers must be located far enough in-board of the edges of the tile so as to be shaded from the sun by the PV module. Fortunately, this location was found to be adequate structurally and did not impact wind tunnel performance.

We have manufactured more than 10,000 spacers utilizing a spacer fabrication station. This station is quite simple, consisting of a power saw suspended on rails above a motorized conveyor. XPS board stock is advanced forward to a fixed stop, the saw is actuated pneumatically, and a spacer of the desired width is cut. One operator can produce 4 spacers in 2 minutes, resulting in almost 1000 spacers per day. This station works very well even with fixed stops and is quite sufficient to supply the production line with enough spacers (4 per tile x 150 tiles from router per day = 600 spacers per day immediate requirement). However, loading of the board stock onto the conveyor and collection of the cut spacers from under the station and off of the floor consumes much of the operator’s time. Optimizations in material handling such as automatic positioning of the board stock, retractable stops, automatic actuation of the saw, and automatic stacking of the cut spacers would offer additional efficiencies and will be considered in the future.

3.6 Task 6 – Inverter Controller Improvements

Under this task, PowerLight identified Trace Technologies as the inverter manufacturer to modify the inverter to incorporate a data acquisition system (DAS), incorporate dial-up communication capability, replace analog circuitry with digital circuitry, and eliminate non-PV related functionality currently part of the controller modification. Significant progress was made this period. The Solar Control Unit (SCU) is now PV specific, the parts count has been reduced by 25%, MTBF has been increased by over 33%, and DAS capabilities have been incorporated. Test results are expected in February 2000, with a first commercial installation in March, 2000.

3.7 Task 7 – Manufacturing Design Improvements

Under this task, PowerLight has initiated several design advancements to the PowerGuard product in advance of defining manufacturing methods:

1. Mounting of the PV module on the XPS board in a sloped fashion.
2. Substitute an amorphous-silicon (a-Si) PV module for the current crystalline PV module.
3. Modifications to PowerCurb, the current securement method for PowerGuard systems

3.7.1 Sub-Task 7.1 – Sloped-Tile Assembly

PowerGuard tiles consist of a flat, frameless PV module mounted onto a flat backerboard. PowerGuard tiles are installed only on flat or nearly flat roofs. Thus, the face of the PV is in a plane parallel with the rooftop. While this is a convenient configuration for manufacturing, shipping, and installation, the PV is not oriented towards the path of the sun and will not attain peak performance (except in low latitudes).

PowerGuard has been tested and deployed in tile slopes up to 20 degrees. Sloped-tile systems are shown in Figure 6. However, the cost per tile increase is significant, the design life 5 years short, and the shipping volume is more than two times that of the same size flat tile.

Under this sub-task, PowerLight was to refine the design of a low-cost, simplified sloped PowerGuard tile, and a more readily manufacturable spacer assembly which not only attaches the PV module to the XPS board but enables the tile to ship flat and be erected into the sloped position in the field. The targeted improvements were:

- Increased design life from 5 years to 30 years
- Decreased cost per tile by 20 - 50%
- Decreased shipping height from 10” to between 7.5” and 5”

Prototypes of an improved sloped-tile assembly that attempts to reduce cost, reduce shipping density, and simplify manufacturing were created and evaluated. Four prototypes were fabricated including a prototype which ships flat and “pops up” in the field, one which is shipped fixed in the slope position, a “field assembly” version (allowing the PV to be shipped separately), and a hybrid version that is partially fixed and partially assembled in the field. A prototype is shown in Figure 7. Despite our research into alternate materials and creative fabrication options, the nature of a “pop-up” design is expensive, requiring several structural moving parts and multiple fasteners. Instead of decreasing the cost for a sloped tile option over a flat tile, we were considering increasing or doubling the previous cost in order to incorporate the selected hinges and locking mechanisms.

As such, the hybrid version was chosen as the best design and was implemented for a New York Power Authority (NYPA) installation. This design centered on relatively inexpensive angular XPS foam spacers that tilt over onto the backerboard for shipping and must be positioned and glued into place in the field. When collapsed, the tile is less than 4.5" tall. Additionally, we are familiar with these materials and expect a 30-year life. The manufacturing process, overall quality of this design, and costs to install were evaluated following the completion of this project, resulting in recommendations for further design modifications. While we were able to meet the cost objectives and quality requirements for this small project, our evaluation centered upon the inherent difficulties of maintaining quality when assembling tiles in the field (on a rooftop, without a workstation, in a variety of weather conditions, with different laborers every time). A "pop-up" design was still highly desirable.

An extensive product design effort led to a production prototype for a "pop-up" sloped-tile design. We have been able to utilize custom sheet metal parts in place of much more expensive hinges and mechanisms. Wind tunnel testing proved that these parts, with some modifications, could be counted upon structurally. The collapsed tile is less than 4.5" tall. We expect a 30-year life. We are approaching the cost objective, but desire to investigate further design options. This effort shall be continued with the aid of a product design consultant in Phase II of this PVMaT contract.

3.7.2 Sub-Task 7.2 – Amorphous-Silicon (a-Si) Tile Packaging

One marketing aspect of the PowerGuard system is its low profile. Unable to be seen from ground level, a system can be installed with minimal impact to the aesthetics of a customer's building. Even so, a PowerGuard tile is approximately 5.25" tall making it an obvious deviation from the make-up of the existing rooftop. A shorter tile would certainly offer a sleeker, more integrated appearance while enabling greater packing density for lower shipping costs.

More than 50% of the height of a PowerGuard tile is due to the spacer blocks which offset the frameless PV module from the coated backerboard. This offset enables airflow under the crystalline PV laminate to keep it cool during operation. The hotter a crystalline laminate gets, the less its efficiency. An amorphous-silicon (a-Si) PV laminate, on the other hand, operates with a lower temperature coefficient.

Under this sub-task, PowerLight was to design an a-Si PowerGuard tile meeting the following criteria:

- Decreased tile height from 5.25"
- Decreased tile cost of 10 – 20%
- Maximum PV laminate temperature of 90 °C (194 °F)

Several prototype tiles were constructed using a-Si laminates mounted upon spacers of various heights. These tiles were installed at two Northern California sites and monitored for temperature and performance characteristics from July to October of 1999. While the spacers can 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 is 3.25" tall, a full 2" shorter. Shipping density has improved as PowerGuard tiles may be stacked 16 to a pallet instead of the usual 12 per pallet. This increase in shipping density results in shipping cost reductions of 15 to 20%. The cost of the actual tile will see minimal improvements which will not achieve the 10 – 20% expected.

3.7.3 Sub-Task 7.3 – Retrofit PowerCurb

One of the advantages of PowerGuard over other PV products is that no penetrations need be made to the roof in order to install and operate the system. The PowerGuard tiles are not bolted down or otherwise fastened to the roof. However, the PowerGuard tiles, assembled next to each other in the middle of a flat roof like an "island", are exposed to high winds, heavy rain, and building vibrations. In order to prevent movement of the PowerGuard system, the entire perimeter of the PowerGuard system is fitted with PowerCurb. PowerCurb prevents movement of the system due to its weight and the interlocking connection which it makes among all of the perimeter PowerGuard tiles, causing the system to act as one large unit instead of smaller, lighter individual tiles.

PowerCurb consists of two main components: ballast and a housing for the ballast. Previously, concrete blocks (the ballast) were laid into long sheet metal trays and the trays, in turn, pinched the PowerGuard tiles onto the roof. Additional sheet metal parts (with a Kynar painted finish for weather resistance) were assembled to cover the blocks and form a sheet metal housing with an aerodynamic and aesthetically pleasing shape. This is an expensive design as PowerLight has no sheet metal processing equipment and must have the parts made at a custom sheet metal shop. The completed parts were then transported to PowerLight for packaging and shipment. This sequence requires custom fabrication on a per job basis incurring additional costs associated with shipping, communication, shop labor, and scheduling coordination. Furthermore, this design allows for slight variations in repetitive shapes, introducing installation difficulties.

Under this sub-task, PowerLight was to develop and alternative PowerCurb design that could be manufactured in the PowerLight factory while achieving the following:

- Decreased cost by 40 – 60%
- Decreased number of parts from 6 to 3

We have achieved a 50% cost reduction, and decrease in the number of parts from 6 to 2.

Many alternative materials were investigated to serve as housings for ballast. Besides the cost considerations, the selected design had to be structurally sound to resist wind loading, compact enough for easy shipping, superior in UV and rot resistance, non-flammable, amenable to common ballast material, and attractive in color and finish. Molded plastic shapes (including recycled plastic products), extruded plastic shapes, extruded metal shapes, and simplified sheet metal designs were evaluated.

The final design is composed of 2 parts: a galvanized sheet petal pan and a custom shaped concrete curb. We expect that we can manufacture our own unique concrete curbs using either a wet cast process or an extrusion process. The curbs would replace the blocks as ballast. The curbs will 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. With this design, we can change the curb profile as we desire to accommodate design changes. For instance, the a-Si PowerGuard tile discussed in sub-task 7.2 would require a curb 2” shorter in height than the current design. We expect a cost reduction of at least 50%, depending on our ability to manufacture the curbs in-house or if we buy them pre-made. Such an evaluation shall be undertaken as a part of our Phase II effort.

3.8 Task 8 – Component Testing, Certification, and Safety

PowerLight is committed to worker safety and considers environmental stewardship synonymous with its purpose. Explicit time has been allocated to evaluate each manufactured component and process for environmental, safety, and health impacts. This includes potential for waste streams and hazardous substances, and using recycled materials where appropriate.

Product safety, from installation through 30 years operation, has been ensured throughout PowerLight’s history through strict attention to testing and recognized programs for certification. The PowerGuard system has completed Underwriters Laboratories (UL) testing as both a building product and integrated PV assembly.

However, the product improvements made, and the new factory built as a result of our Phase I effort, necessitates the following additional work:

1. Incorporation of federal and state environment, health, and safety regulations
2. Wind tunnel testing of the design modifications to the PowerGuard system
3. UL testing of modified and new components
4. Attainment of certifications required in the international marketplace

The following sub-tasks were undertaken in order to assure continued compliance and acceptance of our unique product in domestic and international markets.

3.8.1 Sub-Task 8.1 – Environment, Health, and Safety

Certain federal and state regulations governing the manufacturing, installation and operation of PowerGuard PV roof tiles have been reviewed. An assessment was conducted to identify those regulations within federal and state codes that generally apply to PowerLight’s activities, and therefore have a bearing on process and equipment design.

The following aspects of PowerGuard were specifically reviewed for incorporation of relevant standards and regulations:

1. Production equipment design
2. Production operation specifications
3. Factory worker training programs

4. Installer training programs
5. Installation manuals
6. Operations and maintenance training programs
7. Operations and maintenance manuals

Upon review of federal and state regulations, PowerLight has determined which regulations apply to current processes and has implemented systems to insure compliance where necessary. In addition, various regulations have been called out which have a direct bearing on processes and equipment now in development under PVMaT. In some cases, the regulations will aid in determining the direction in which PowerLight engineers will take in enhancing manufacturing and installation processes.

For instance, PowerLight's manufacturing process involves the processing of extruded polystyrene foam board stock including mechanical cutting operations, which in management's opinion produce source noise levels that may exceed maximum levels mandated by Occupational Safety and Hazard Act (OSHA) requirements. Elsewhere, materials and processes employed to produce, apply and dispose of the cementitious mix products are governed by Federal EPA regulations. Finally, general workplace safety regulations apply in the areas of emergency plans, use of forklifts, installation and use of overhead conveyance devices.

PowerLight has also determined that certain sections of the Code of Federal Regulations, The Clean Water Act, The Occupational Safety and Health Act (OSHA) apply to production operations. Similarly certain sections of the State of California OSHA requirements apply to production operations. Within Title 40, Chapter I, U.S. EPA regulations are defined. The parts most relevant to PowerLight's production processes were determined.

Since PowerLight will be operating in several states it is proposed to adopt a more conservative approach towards occupational health and safety issues. The regulations mandated by the State of California, Division of Occupational Safety & Health (CAL/OSHA) appear to fulfill or exceed regulations of other states as well as many of the federal regulations. In the case where regulations overlap, PowerLight will apply the more conservative of the regulations to insure compliance with all pertinent agencies.

In accordance with CAL/OSHA regulation, an Injury and Illness Prevention Program has been in place at PowerLight facilities for some time (T8 CCR, Section 3203). There are also emergency and fire plans in place in compliance with Title 8, sections 3220 and 3221. In addition to these programs, a factory worker training program will be 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 is also being established in accordance with GISO 5194. However, it should be noted that PowerLight's use of hazardous or toxic chemicals is extremely limited as determined by the EPA'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 the regulations referred to above as a reference for its design staff. Copies of these regulations are available upon request.

As new processes are developed under PVMaT, PowerLight's training programs will evolve accordingly.

3.8.2 Sub-Task 8.2 – Wind Testing: Computational Fluid Dynamic Modeling

Wind-induced system failures are of prime concern in any roof-mounted PV system, including PowerGuard systems. PowerGuard is aerodynamically unique compared to other roof-mounted building products in several ways: it consists of several material layers with an air cavity; it uses a permeable tongue and groove connection; and it features a unique ballasted perimeter securement. Unfortunately, wind related building codes and standards such as the Uniform Building Code (UBC) and the American Society of Civil Engineers (ASCE) are overly conservative when applied to semi-permeable roof cladding such as the PowerGuard tile. However, these codes allow, and even encourage the use of wind tunnel testing and evaluation of building products in expected wind conditions. For these reasons, wind tunnel testing and analysis is the only reasonable approach in investigating PowerGuard's wind resistance.

Under this task, PowerLight has undertaken an effort to understand the effects of wind on PowerGuard RT (retrofit curb) systems. PowerLight has previously conducted wind tunnel tests on PowerGuard LG (using Light Guard pavers as the means of securement), drawing on the world's leading experts in fluid dynamics and utilizing state of the art wind tunnel test facilities at Colorado State University (CSU). It is essential that any product modifications implemented as a result of this PVMaT contract be validated through additional wind testing. This data is also essential in extending PowerLight's development of standardized engineering design tables which relate PowerGuard system performance to UBC and ASCE wind classifications. Such summary test data shall enable project engineers to verify and approve the design features of a proposed system in only a few minutes.

During Phase I, PowerLight, at CSU, conducted testing on aerodynamically accurate (1:32 scale) 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 was 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.

We were able to determine that the design changes implemented during PVMaT have not degraded or improved PowerGuard's ability to withstand 140 mph winds on most buildings. An example of a final table created from data collected in Phase I is shown in Figure 8. Further testing of the PowerGuard product shall continue in Phase II of this PVMaT contact, resulting in final wind design tables for PowerGuard systems.

3.8.3 Sub-Task 8.3 – Underwriter's Laboratories Listing

Independent testing services are key to validating product safety and enhancing consumer and financier confidence. Such services are of heightened value in the PV industry due to its relative infancy and to the lack of awareness regarding PV products by most code officials and the public. As the industry matures and the range of PV base products expands it is imperative that product integrity be preserved through objective testing. Underwriters Laboratories, Inc. (UL) is widely regarded as the preeminent independent testing service in the United States for fire and safety testing. Other recognized testing laboratories exist choose to use UL standards as well.

As such, PowerLight has included into all design and manufacturing modifications features that will assure PowerGuard to pass all necessary UL testing for product listing by that organization. For instance, the UL requirements for electrical quick-connects were determined in order to evaluate the chosen quick-connect (see Task 2) for PowerGuard. PowerLight has submitted PowerGuard prototypes to UL for testing and listing which include five different frameless PV modules, an a-Si PowerGuard tile, the selected electrical quick-connects for PowerGuard tiles, new field combiner box, and PowerGuard RT system specifications. Results of UL evaluations are expected under PVMaT Phase II and additional UL submissions shall continue at that time.

3.8.4 Sub-Task 8.4 – International Certifications

Furnishing PV systems in foreign markets requires compliance with the respective national codes and standards. Unfortunately, such directives vary significantly throughout the world, representing a wide range of testing and certification issues across target markets. Under this sub-task, PowerLight has initiated a program to identify and execute code/standard compliance requirements in the global market.

In order to simplify the code and standard identification process, we have utilized the International Compliance Services (ICS) division of UL. PowerLight has investigated the receipt of 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 Task 9 – Integrated Warranties

Previous to this PVMaT contract, PowerLight provided its customers with a series of pass-through warranties, which can be confusing and inefficient. Under this task, PowerLight has developed a PowerGuard comprehensive system-warranty, integrating warranties from the PV manufacturers, inverter manufacturers, and other system components. Additionally, a service and maintenance option was established.

3.10 Task 10 – Assessment of Commercial Demonstrations

PowerLight places great emphasis in assessing the performance of its systems. Under this task, PowerLight was to put methods in place to enhance its ability to evaluate the performance of commercially installed systems. Additionally, as the design and manufacturing improvements implemented under this Phase 1 PVMaT contract are implemented into fabricated and installed systems, these systems shall undergo evaluation of the improvements made. It was hoped that during Phase I, PowerLight would manufacture and install at least one commercial system of at least 40 kW which could then be evaluated for performance and additional design and manufacturing modifications.

Ten identical 6 kWp systems (60 kWp total) were manufactured for the New York Power Authority. These installations, completed in October of 1998, allowed evaluation of the improvements to the product that had been implemented at that time. It was discovered that the new tongue and groove profile improved the ease of installation. The coating was found to be robust. Two key components were determined to require further advancement: the sloped tile assembly and the PT PowerCurbs. These advancements are discussed in Tasks 7.1 and 7.3.

A 7.7 kWp system was installed in at the State University of New York, New Paultz, also in October of 1998.

A 28 kWp system was installed for the Western Area Power Administration in Elverta, CA. This system was assessed at over 29 kWp. We learned from this system that laminate strength is a major issue for a-Si tile development. In the months subsequent to installation and commissioning of this system, over 115 a-Si laminates needed to be replaced due to cracking. This problem was primarily due to a manufacturing flaw at the PV vendor which is now being addressed.

In August and September 1999, we manufactured several commercial projects. These include 3 projects at 100 kWp or larger and several more at 25 kWp or larger. As these projects are installed during Phase II of this PVMaT contract, they will offer the perfect opportunity to refine or design and manufacturing process.

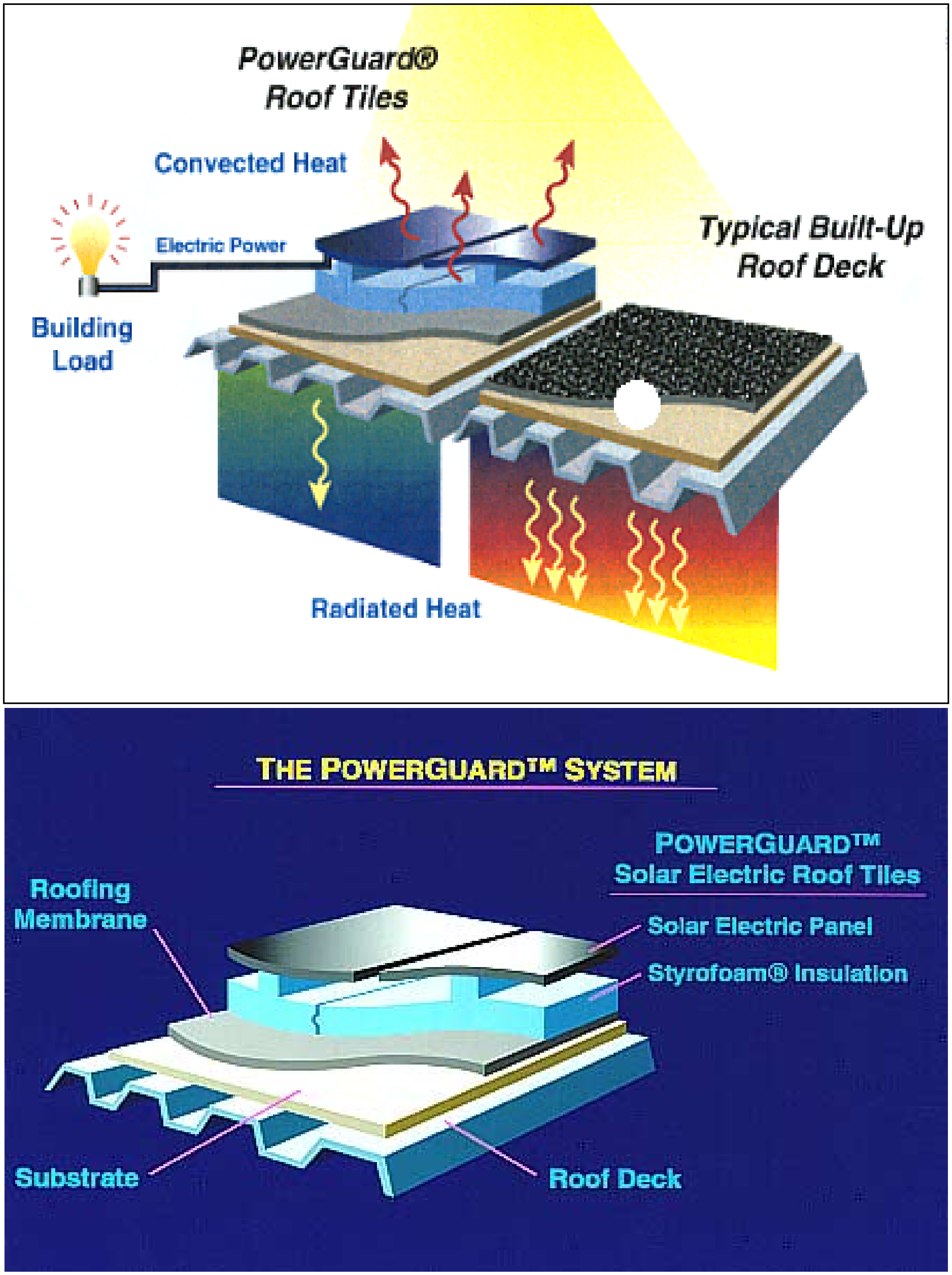


Figure 1 - PowerGuard® Tile Schematics

Figure 2 - Two PowerGuard® Tiles

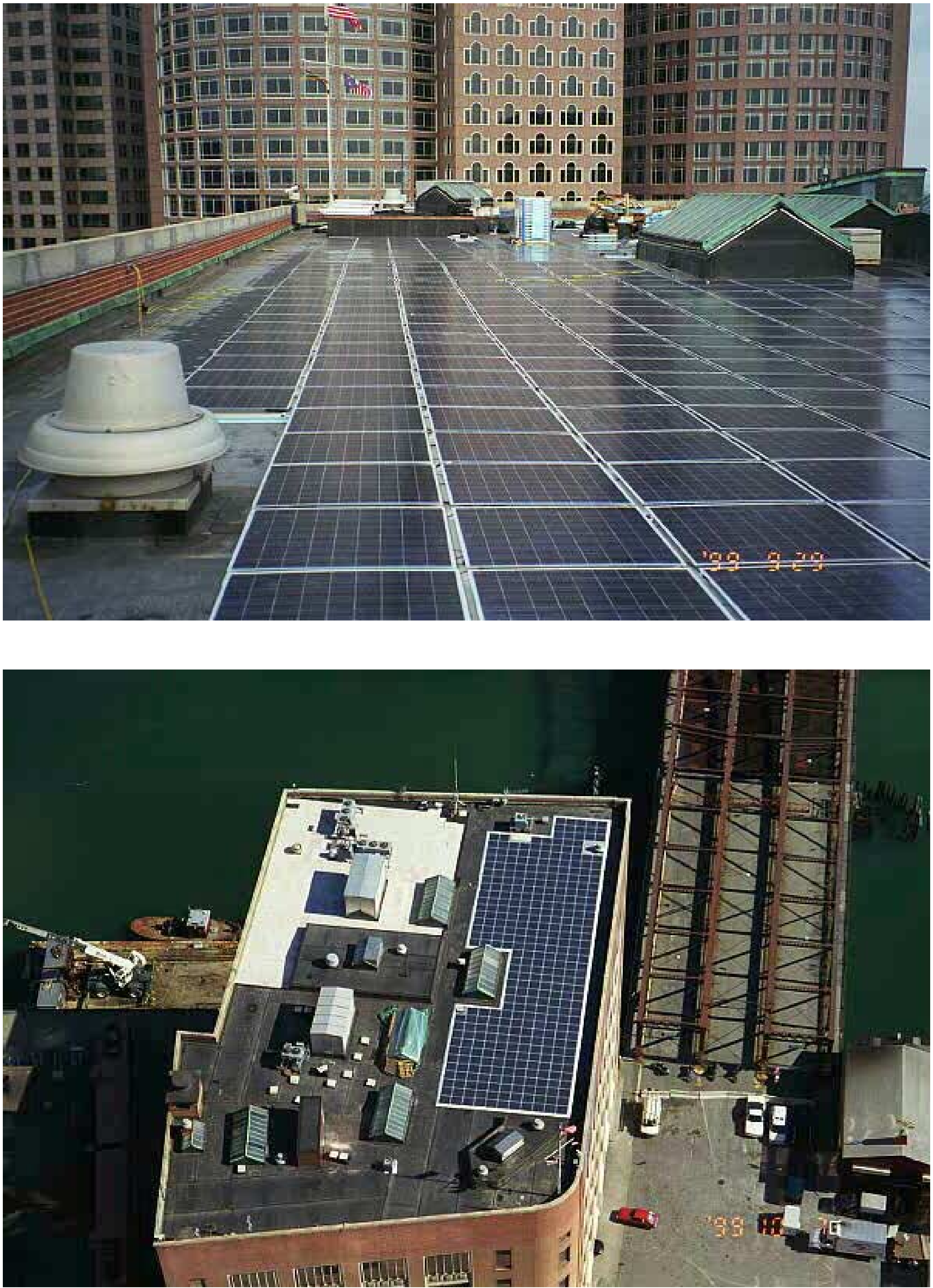


Figure 3 - Installed PowerGuard® System

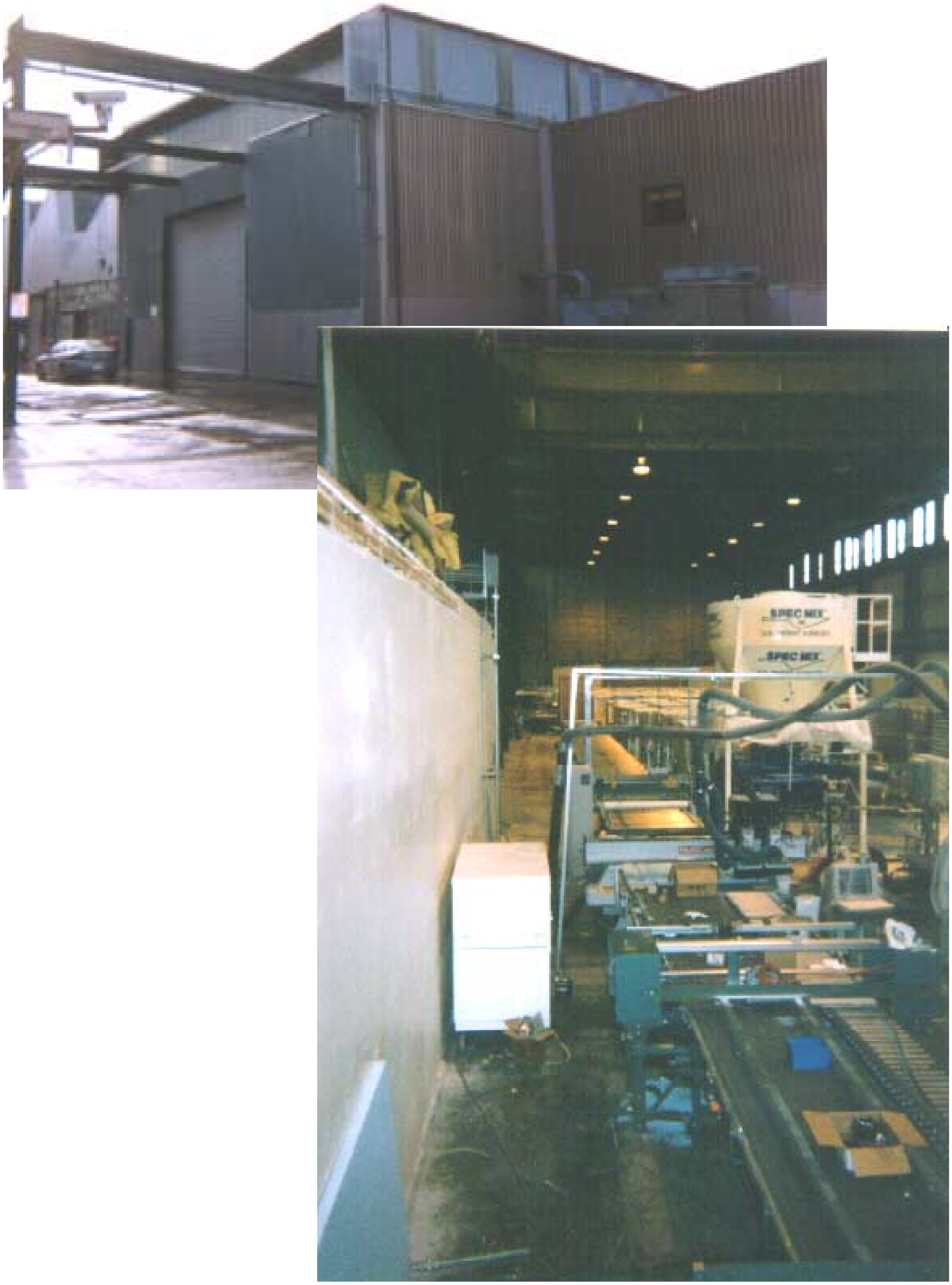


Figure 4 - PowerLight Factory - Berkeley, CA

Figure 5 - Pallets of Finished PowerGuard Tiles

Figure 6 - Sloped PowerGuard® Systems

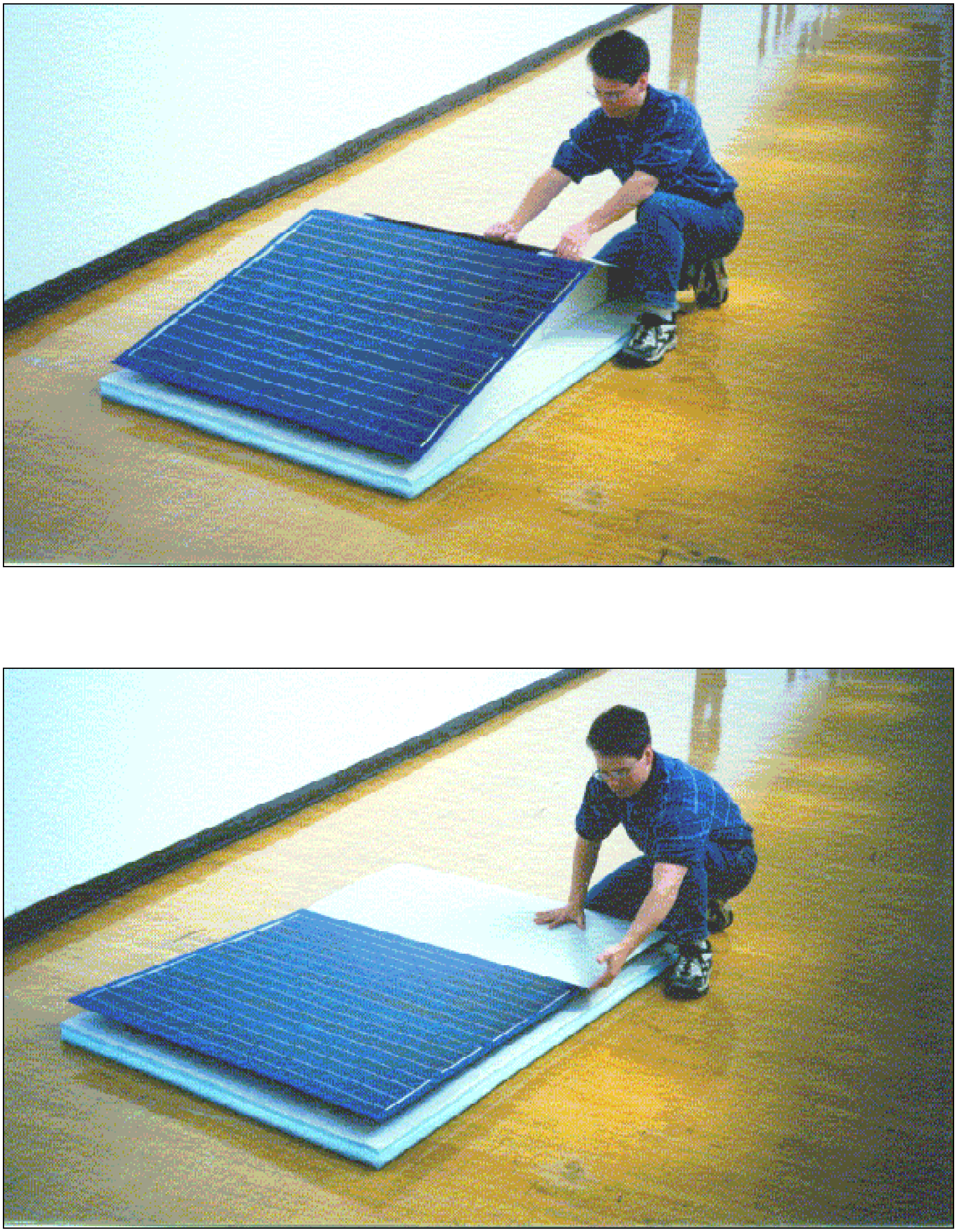
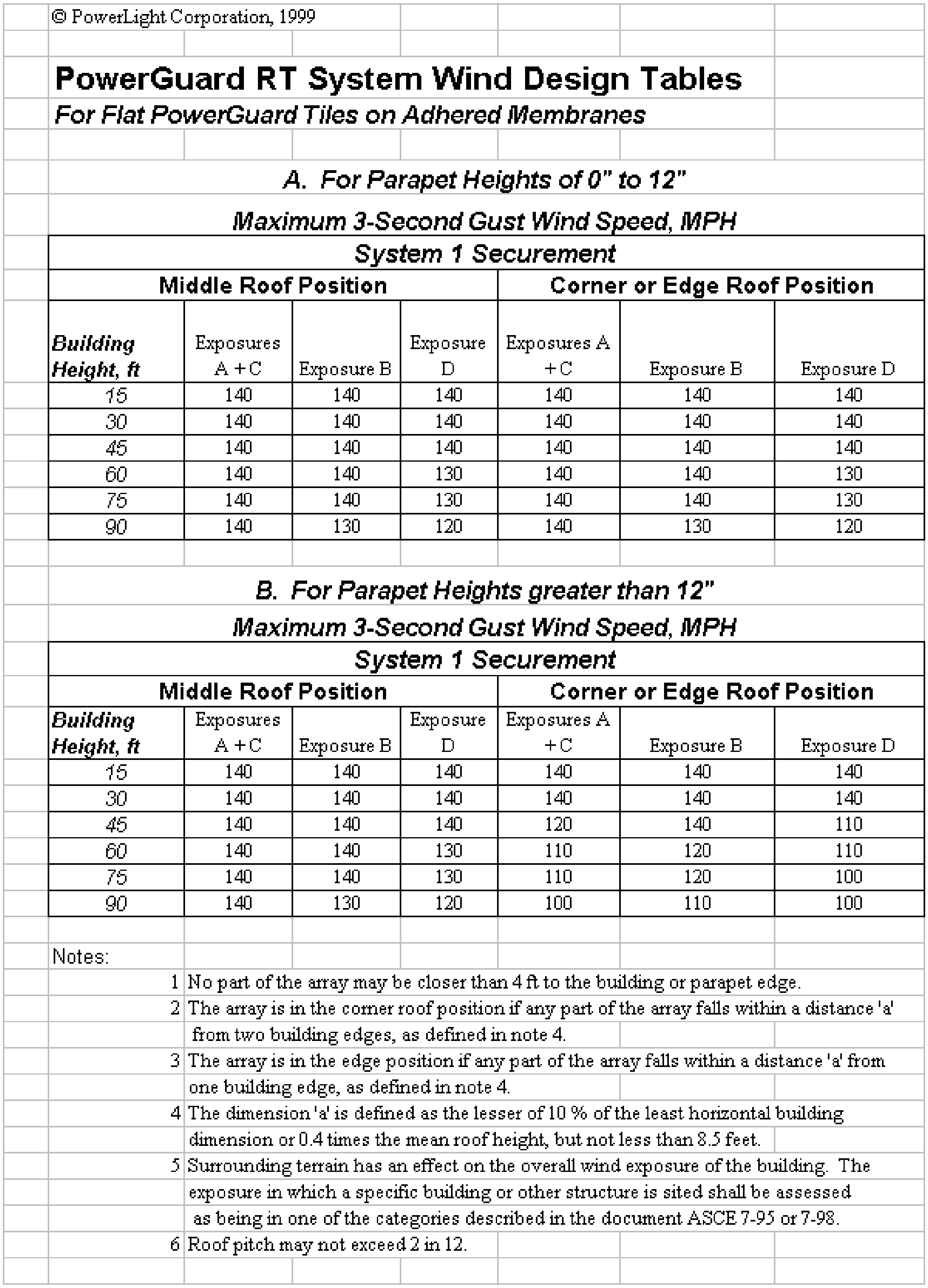


Figure 7 - Sloped-Tile Prototype



PowerGuard RT System Wind Design Tables

For Flat PowerGuard Tiles on Adhered Membranes

A. For Parapet Heights of 0" to 12"

Maximum 3-Second Gust Wind Speed, MPH

System 1 Securement						
	Middle Roof Position			**Corner or Edge Roof Position**		
Building Height, ft	Exposures A + C	Exposure B	Exposure D	Exposures A + C	Exposure B	Exposure D
15	140	140	140	140	140	140
30	140	140	140	140	140	140
45	140	140	140	140	140	140
60	140	140	130	140	140	130
75	140	140	130	140	140	130
90	140	130	120	140	130	120

B. For Parapet Heights greater than 12"

Maximum 3-Second Gust Wind Speed, MPH

System 1 Securement						
	Middle Roof Position			**Corner or Edge Roof Position**		
Building Height, ft	Exposures A + C	Exposure B	Exposure D	Exposures A + C	Exposure B	Exposure D
15	140	140	140	140	140	140
30	140	140	140	140	140	140
45	140	140	140	120	140	110
60	140	140	130	110	120	110
75	140	140	130	110	120	100
90	140	130	120	100	110	100

Notes:

1 No part of the array may be closer than 4 ft to the building or parapet edge.

2 The array is in the corner roof position if any part of the array falls within a distance 'a' from two building edges, as defined in note 4.

3 The array is in the edge position if any part of the array falls within a distance 'a' from one building edge, as defined in note 4.

4 The dimension 'a' is defined as the lesser of 10 % of the least horizontal building dimension or 0.4 times the mean roof height, but not less than 8.5 feet.

5 Surrounding terrain has an effect on the overall wind exposure of the building. The exposure in which a specific building or other structure is sited shall be assessed as being in one of the categories described in the document ASCE 7-95 or 7-98.

6 Roof pitch may not exceed 2 in 12.

Figure 8 - Example Wind Table

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13. ABSTRACT *(Maximum 200 words)*

During Phase I of "PowerGuard® Advanced Manufacturing," PowerLight Corporation accomplished the following advancements:

- Decreased system cost by 15%
- Increased PowerGuard tile production capacity from 5 MW/year to 8 MW/yr
- Established a manufacturing layout master plan for sequential integration of semi-automated and automated component workstations
- Defined semi-automation or automation of selected stages of the existing tile fabrication sequence, including PV module preparation, XPS processing, and coating
- Completed the advancement of several design improvements to the grid-tied inverter control board, including controller redesign, integrated data acquisition system (DAS), and communications for audit-worthy verification of PV system performance
- Conformed to NEPA, OSHA, and other federal and state regulations applicable to the proposed production process and mitigated potential for waste streams
- Initiated Underwriters Laboratories listings and international certifications on PowerGuard improvements
- Developed finance packages and integrated warranties
- Evaluated commercial demonstrations that incorporated the new design features and manufacturing process.

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