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SunFlash – An Entirely New Concept for Building-Integrated PV

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SunFlash – An Entirely New Concept for Building-Integrated PV

TECHNICAL SUMMARY

This report summarizes the feasibility and planning work conducted under our PVBONUS Phase 1 project. Evergreen Solar and its partners, Bechtel, Jefferson Shingleton, and Ascension Technology, have been investigating the development of the SunFlash, an innovative and unique new building product. The SunFlash is unique because it is the first photovoltaic (PV) module which is totally integral. This integral totality will enable simple and cost effective applications that require watertight sealing in a variety of different mountings. This advancement is only possible because of Evergreen's development of an advanced and proprietary backskin material.

Some key features of the SunFlash concept include:

- An integrated module concept whereby the module, backskin, edge seal and mounting method are all a single molded unit of the same material
- An extension of this concept to include the possibility of molded in electrical connections, either pigtail and/or connectors
- A novel encapsulant material with better adhesion, sealing, thermal creep, and UV stability properties than EVA
- A crystalline silicon, glass-front module incorporating our advanced String Ribbon solar cells
- Accessories and features, including a module-integrated inverter, laminated exit wiring, mounting, and raceway wiring, that provide high-performance consistent with building practice

The proposed SunFlash concept is a standardized, cost-effective, long-lasting building product. Our market objective is broad applicability into building applications not adequately served by current PV products. We targeted both residential and commercial buildings, both new and retrofit.

Highlights of our findings include:

- We confirmed broad applicability of The SunFlash and related product concepts to several building applications.
 - ◆ For most of the proposed applications, The SunFlash seems extremely promising: (i) residential slant-roof, new or retrofit, integrated with either asphalt shingles or rigid tiles; (ii) metal buildings, new or retrofit, vertical wall or slant roof; and (iii) specialty applications in commercial buildings, including awnings, window shades, and parking lot shading.
 - ◆ For curtain walls, unfortunately, the total integration concept is actually disadvantageous because it interferes with the complex moisture management systems well developed in curtain wall systems. However, the superior edge seal of our regular frameless module (i.e., without the total integration) will still substantially advance PV's applicability in curtain walls.
 - ◆ We identified additional concepts and applications not hypothesized in the Phase 1 proposal, primarily a shingled tile for residential new-roof construction.
- We successfully collected feedback from buildings and PV experts and iterated our conceptual designs.

- Prototype modules were constructed, both sample size and full-size, and four subsystem mockups were built to demonstrate compatibility with existing building products and practices.
- Selected experiments confirmed no “drop-dead” design factors in several areas relating to sizing, integration, and components.
 - ◆ Preliminary experiments were successful with strip modules (i.e., long, narrow modules) laminated on Evergreen’s continuous, non-vacuum laminator.
 - ◆ Structural integrity testing on the integral mounting was also successful.
 - ◆ Preliminary testing of the backskin, edge seal, and polymer adhesion to the front glass were successfully completed in humidity freeze, thermal cycling, and damp heat.
 - ◆ Flammability testing indicated the new backskin performs at least as well as conventional Tedlar. Prospects for eventual Class A fire ratings appear good.
 - ◆ Micro-inverters were successfully mounted on the new backskin.
 - ◆ Several existing and new plugs were investigated, and preliminary experiments to directly mold wire pigtails or cabinet-mount female plugs into the polymer edge were extremely promising.

INTRODUCTION

Photovoltaics have been incorporated into buildings in many ways, but only a few currently available solutions meet the performance expectations of the buildings sector.

In retrofit construction, the best practices are elegant, low-cost, simple to construct and maintain, safe, and durable. Where they work, they work well, but they have limited applicability and market acceptance. For example, Ascension Technology’s slant-roof roof jacks and flat-roof ballasted trays represent the best of current practice. They use low-cost materials with minimal installation requirements. Dozens of installations utilize these standardized components. Similarly, the roof tile developed by Alpha Real and Newtec of Switzerland facilitates roof integration into tile roofs common in Europe and reduces array installation time by over 70%.

However, these approaches have limited applicability to building types, and have sometimes encountered resistance with real or perceived concerns. For example, roof jacks work on asphalt-shingle roofs, but not easily on tile roofs. Many homeowners or building inspectors have perceived concerns with roof jack lag bolts into the plywood commonly used in asphalt-shingle roofs, despite a stellar field record of structural integrity without roof leaks. The elegant gravity-held mechanical interconnection has also met some market resistance, despite a perfect record in testing and field experience. Regarding the flat-roof, ballasted roof trays, real or perceived concerns with abrasion on rubber roof membranes have blocked some installations. Again, real or perceived concerns with wind loading on ballasted systems have led to some market resistance. One very real limitation occurs in the southwest U.S., likely a critical market for PV, where flat roofs typically will not withstand the weight of ballasted systems because they are not built to accommodate snow loads.

On the other hand, building-integrated products seek to extend PV’s reach to more building types, capture the value of materials and construction costs displaced by integrated PV, and improve aesthetics. Many approaches have been tried, some successfully, but others have encountered performance problems.

The challenge for a building-integrated PV is to develop standardized products which deliver reliable edge sealing and protection while reducing costs by eliminating redundant building elements. Sealing, in our opinion, is a greater challenge than edge protection. The ultimate source of failure in PV modules is breakdown of the module package,

often caused by polymer degradation and water ingress. Frameless modules have typically not performed as well as framed modules, particularly in harsh (hot and/or humid) environments, because of inadequate edge seal. The building integration successes in Europe will not, we believe, translate as well to the American South or Southwest.

A different approach to integration – polymer-front, flexible modules, particularly with thin films – will have a difficult time matching the stability and longevity of crystalline silicon, glass-front modules. Since product lifetime is a major driver of PV's lifecycle cost, packaging shortcuts are unlikely to be cost-effective. As our Phase 1 market research has shown, longevity in building products is an important precondition of widespread, successful market acceptance.

Electrical connectors are a major issue for building integration. The low efficiency and/or small size of some shingle or tile products can't sustain the high cost of the few high-performance DC plugs, such as Alden or MultiContact. And to our knowledge, none of the low-cost plugs have demonstrated the capability for reliability and long life required for PV products.

Given these issues, we aim to extend the reach and boost the performance of PV building systems. Current retrofit practice works well, but faces limitations in geography, building type, and market acceptance. Current PV building integration practice, on the other hand, faces some cost and performance challenges. Our concept addresses these limitations.

This project team has investigated an innovative and entirely new building product concept, the SunFlash, incorporating a photovoltaic module with integral mounting and sealing for watertight building integration. It can be used as a roof-integrated shingle for slant roofs, for vertical curtain walls, or in other applications. Key features of the SunFlash include the following:

- An integrated module concept whereby the module, backskin, edge seal and mounting and sealing are all a single molded unit of the same material
- An extension of this concept to include the possibility of molded-in electrical connections
- A novel encapsulant material with better adhesion, sealing, thermal creep, and UV stability properties than EVA
- A crystalline silicon, glass-front module incorporating our advanced String Ribbon solar cells
- Accessories and features, including a module-integrated inverter, laminated exit wiring, mounting, and raceway wiring, that provide high-performance consistent with building practice

The objective of the SunFlash is a standardized, cost-effective, long-lasting solution to integrating and water-sealing modules into residential and commercial buildings, both new and retrofit.

CONCEPT DESCRIPTION

The primary design characteristics of the SunFlash are described below. The status of these technology developments is reported later in the report.

- ***High performance backskin for sealing and edge protection.*** Our new backskin is four times thicker and tougher than conventional Tedlar. More importantly, it wraps around the edge of the module to form a polymer low-profile (glass thickness plus 1/8-inch) frame that protects and seals the edge. Because of the unique properties of this novel material, the wrap-around edge, the edge sealing, and the mounting and

water sealing can all be formed into a single integrated unit during the lamination process. By eliminating the conventional aluminum perimeter frame, we can reduce the cost and weight while increasing performance.

- **Long-life encapsulant.** Our new non-EVA encapsulant was designed for longer life, particularly in harsh environments. All indications are that our new encapsulant will be far less likely to 'brown' or delaminate than conventional EVA.
- **Larger, more convenient module size.** We expect to develop a new module size, enabled by our new, continuous, non-vacuum lamination process that facilitates long, narrow modules. We are tending toward long, narrow modules, in the range of 1½-by-6 feet to 2-by-8 feet, to capture the benefits of larger modules but with acceptable ease of handling. Although two people will typically handle these modules, we will aim for the largest module that one person can conveniently carry for short distances, and we expect this aspect ratio to adapt well to architectural applications. Our lamination process will potentially allow us to use a single piece of equipment to laminate most or all of our products in a single machine. This will reduce development and capital costs while improving throughput and maintaining quality.
- **Dependable crystalline silicon.** The module will incorporate Evergreen Solar's String Ribbon crystalline silicon solar cell in a package with tempered-glass front. Thus, the fundamental components retain the efficiency, longevity, stability, and market acceptance of conventional crystalline silicon but without the cost and waste of sawing single-crystal boules or cast blocks.
- **Built-in mounting and water sealing.** Our concept envisions a technique for mounting and sealing a PV module directly into the roof. Detailed drawings and photos are shown in the appendices.
- **Innovative wiring without junction box.** Another of the outstanding features of the backskin is the ability to form it around an exit wire. This may be the first "pigtail" in PV history that has the full performance of a conventional junction box. This feature uniquely allows a wiring raceway to be incorporated into a the cover.
- **Module-integrated inverter.** Evergreen Solar has been collaborating closely with the major developers of AC Modules, including Ascension Technology, Advanced Energy Systems, Trace/OKE, and Alpha Real of Switzerland, and we also have been actively following the development (thus far primarily in Europe) of string inverters. We expect to integrate one or more of these products with the SunFlash. Among the many benefits of module-integrated inverters are the replacement of DC array wiring and DC components with AC components and practices, thereby reducing parts and installation costs and enhancing customer acceptance. System design is simpler and more flexible since the matching of the inverter to the module is already done. Any maintenance or trouble shooting can be made easier by the communications capability built into many AC modules. Most importantly, safety is enhanced because the AC modules will produce no voltage until correctly interconnected to the building power.
- **Simple mounting and sealing system.** A single installation step will both provide mechanical mounting and water sealing. The SunFlash accessories will be designed to maximize consistency with architectural design, accepted building practices and standard building products.

In summary, the SunFlash will accommodate many building types cost-effectively with adaptable, standardized mechanical, structural, and electrical components.

During Phase 1, we extended the SunFlash to a family of related products, including a shingled tile for residential and commercial applications. While many tiles have been tried over the years, and several are now offered in

limited commercial production (both custom and standard), almost all, in our opinion, suffer from inadequate edge sealing. Particularly for slant-roof applications, where tiles are subjected to standing and running water, ice, and pressurized water from ice dams, edge sealing is absolutely critical to PV tile success.

APPLICATIONS

One of the fundamental benefits of the SunFlash approach will be its potential for a wide range of applications. Three target applications of the SunFlash are described below. Other feasible options are listed as well. The extensive set of drawings and photographs resulting from Phase 1 are contained in the appendices.

- ***Sloped-roof integrated with asphalt shingles.*** The SunFlash enables direct integration onto a residential sloped-roof with asphalt shingles. The Phase 1 prototype demonstrated that the product easily integrates and seals.
- ***SunFlash tile.*** In the SunFlash tile, the top portion of the module has glass encapsulated front and back with the new backskin. Thus the shaded portion of the tile has the endurance of tempered glass, but the plastic coating front and back cushions tile-against-tile motion over time.
- ***Metal buildings: walls and roofs.*** One of the most exciting new developments of Phase 1, not originally described in our Phase 1 proposal, was application to metal buildings. We successfully demonstrated that the SunFlash can be attached to the raised metal ridges simply by fastening a conventional sheet metal screw through the overlapping mounting material into the metal building panel.
- ***Curtain wall.*** One of the key findings of Phase 1 was that the original SunFlash concept is not readily acceptable to architects who remain somewhat skeptical as to its performance. In addition, it is not applicable to some curtain wall systems because it hinders the complex, well-developed system of moisture management in many curtain wall systems. The trimmed SunFlash module, however, is fully applicable, and will be a substantial improvement over existing PV curtain walls because of the superior edge seal and edge protection.
- ***Rack and clip mounts.*** The SunFlash also easily integrates with the full range of rack applications now matched with conventional framed modules. This widely-used design means that SunFlash modules can be manufactured in high volumes rather than simply for niche applications. This will further help reduce costs. Sample applications include sloped roof, awnings, and parking lot covers.

CURRENT TECHNICAL STATUS

This section briefly reports the current status of several of the key enabling technologies.

- The new backskin has been under development for over two years under Evergreen Solar's PVMaT contract. Formulations have been developed, compounded, manufactured into product samples, and engaged in accelerated indoor and outdoor testing. Product development of a family of new products is underway. The first, displayed in at the April 1997 Solar Energy Forum in Washington, DC, is a slide bar that adheres to the frameless module for attachment to Unistrut panel rail. The second, currently being funded by the New York State Energy Research and Development Authority, is a variation targeted at single-module rural electrification systems. We propose extending the backskin applicability to the building-integrated SunFlash family of modules.

- The new encapsulant and its UV stabilization package, also developed under Evergreen Solar's PVMaT contract, are currently undergoing accelerated indoor and outdoor UV exposure tests. Early results indicate that it will have a longer service life than EVA. Furthermore, it has better thermal creep resistance than cross-linked EVA – an important criterion for architectural applications where the module temperatures could reach as high as 90°C. Finally, and also of great importance, it has acid functionality whereas EVA has ester functionality. This means that it will bond more strongly to all adjacent surfaces and thereby facilitate a tighter, better-sealed module with longer service life.
- The long, narrow module development is tied to Evergreen's continuous lamination process, also developed under PVMaT. The process has been demonstrated, and a prototype laminator is now complete and in limited pilot production. The process will eliminate the costly batch manufacturing process of conventional lamination technologies. When fully developed, it will reduce lamination capital and operating costs significantly.
- The backskin sealing and mounting is a new concept and was actually inspired by the PVBONUS RFP. It is made possible only because of the novel properties of Evergreen's new backskin. Early experiments look very promising. The material bonds extremely well to a wide range of materials, including metals, ceramics and other polymers. It molds particularly well, leaving a seamless seal. It is physically tough and creep resistant at temperatures over 200°C.
- An integrated, self-sealing, industrial grade pigtail also looks very promising. Additionally, the backskin will enable Evergreen Solar to form an integrated, sealed module with some of the most likely commercial connectors. This is because many of them, such as the MultiContact connector, are made of Santoprene or its equivalent. Santoprene is what is known as a TPE – ThermoPlastic Elastomer. It consists of a rubber or elastomeric matrix with a fine dispersion of a thermoplastic, in this case polypropylene. The result is a material with the sealing capabilities of rubber and the molding capabilities of a thermoplastic olefin. Evergreen's new backskin material is a modified polyolefin material which can be melted and bonded readily to a TPE such as Santoprene. Thus, integral electrical connectors could be formed when the backskin material is itself molded in place during the lamination process. Furthermore, recent developments in metallocene catalysis for polyethylene and polypropylene have led to materials with narrower molecular weight distribution. This translates into vastly improved physical properties. In fact, Dow and Dupont have recently formed a joint company (Dupont-Dow Elastomers) to exploit elastomer materials based on these new metallocene catalysts. Some of these new TPEs very likely will be attractive candidates for new connectors and new connector possibilities.
- The module inverter development is well underway. Evergreen Solar currently has a TEAM-UP project with AC modules. Evergreen is currently using the UL-listed Advanced Energy Systems inverter, but others are being monitored and tested, as well.

COMPATIBILITY AND DEMONSTRATED ADVANTAGE

The proposed product will be integrated into a wide variety of residential, commercial, and industrial buildings for both new construction and retrofit applications. This section discusses several considerations common to all of the applications, including aesthetics, structural and electrical codes, and consistency with good engineering practice.

One of the most important issues is aesthetics and enhancing, or at least acceptable, integration of the PV system with the architectural features of the building. For example, aesthetics considerations played a very important role in Bechtel's design of the array structure for NREL's Solar Energy Research Facility building. From a commercial point of view, it is also important to develop the most cost-effective means of installing the modules, where this

includes both the mechanical means of securing the modules to the building and the labor involved in the installation process. Overriding considerations are safety and structural integrity of the building when a PV system is added.

System designs are governed by a several structural codes, including Uniform Building Code, Standard or Southern Building Code, Basic Building Code, and National Building Code. The roof design process generally involves calculation of the building and roof structures' ability to safely transfer loads (and combinations of loads) to the foundations or other permanent supports of the building. Adding a PV array structure will increase stress levels on the building, including the roof and/or walls. For retrofit applications, it must be determined whether the increased stresses fall within allowable stresses. The design analyses for commercial and industrial buildings tend to be unique to each building. The level of effort required by permitting authorities may also increase with building occupancy (e.g., requirements for a school building may be more extensive than for a warehouse).

The most important roof loads include the dead, live, snow, wind, and seismic loads; and, for facades, wind and seismic loads are key. Dead loads comprise the weight of the roof itself and the weight of the PV system (modules and array support structure). Typically, the PV dead load is relatively small compared to snow and wind loads. Live loads include roof-top equipment, building machinery, ponding of rainwater, maintenance personnel, and similar items. They would also include stacking and storage of PV system components on a roof during the installation process. Snow loads may dominate in some areas of the U.S. In other areas of the country, wind loads dominate. Designing structures to resist wind and snow loading is a complex engineering task. When a PV system is added to a roof or facade, wind patterns may change and the resulting wind loads on the arrays and roof structure may be even more difficult to determine.

Generally, the NEC (National Electric Code) is the governing set of rules which local officials use to insure that electrical system designs and installations are safe and will operate as intended. UL (Underwriters Laboratories) is the listing agency most often used in the U.S. to indicate equipment's adequacy in terms of safety. Ascension Technology has a great deal of experience designing PV systems that meet all applicable electrical codes and were among the first to field grid-tied PV systems which met all NEC requirements. Ascension engineers have participated in the electric code making process. Personnel at both Evergreen and Ascension have experience with and detailed understanding of UL requirements and have participated in the process of getting equipment listed.

PHASE 1 RESULTS

Results from the Phase 1 scoping study are reported here for the four key tasks:

- ◆ Product Conceptual Design
- ◆ Manufacturing and Production Planning
- ◆ Market Assessment
- ◆ Business Planning

Task 1: Product Conceptual Design

This task was the heart of the Phase 1 effort. We did three things:

- ◆ Prepared sketches, drawings, prototypes, and an interview guide to prepare for interviews
- ◆ Conducted personal interviews to explore current building practice and elicit feedback on our preliminary concepts

- ◆ Based on feedback from interviews and other research, revised and extended the set of conceptual designs, both on paper and with prototypes

Regarding preliminary sketches, drawings, and prototypes, we began the investigation with the SunFlash concept: a PV module whose polymer backskin allowed for a totally integral building unit. Drawings were prepared to demonstrate how this concept might work in several building applications. In addition, a new concept was developed, the shingled tile, that is similar in some regards to other rigid PV tiles, but takes advantage of the unique backskin characteristics for what we expect to be the highest performance PV tile in the industry. Prototype modules were developed of both the SunFlash and shingled tile.

We conducted personal interviews with a range of professionals, including specialists in architecture, civil and structural engineering, CAD, buildings practice, electrical engineering, and PV systems. The following is a summary of key conclusions from the interviews.

- The SunFlash and shingled tile prototypes look quite promising for a range of building types.
 - ◆ In the residential sector, the SunFlash should work well for new or retrofit, and the shingled tile meshes well with existing roof products for new construction in conjunction with composite tile roofing.
 - ◆ In the commercial sector, metal buildings and precast concrete wall construction may be well suited for the SunFlash – both new and retrofit.
 - ◆ The SunFlash may be intriguing in new innovative “rainshield” curtain wall applications.
 - ◆ The SunFlash seems applicable in a wide range of architectural specialty applications in commercial buildings, including awnings, window shades, and parking lot shading.
 - ◆ Opportunities to utilize the SunFlash in flat roof applications, not yet explored, should be evaluated.
- On the other hand, conventional commercial building curtain wall applications pose special challenges.
 - ◆ The SunFlash does not demonstrate significant advantages, and in fact poses distinct disadvantages, as its design interferes with the highly developed moisture management system inherent in most curtain wall systems.
 - ◆ However, Evergreen’s basic frameless module, with its wrap-around polymer edge but without the fully integrated mounting and sealing, may provide the superior edge seal and edge protection required for curtain wall applications. This will become increasingly important, since curtain wall applications look for extremely long product lifetimes, e.g. 50 years.
 - ◆ Curtain wall applications pose particular challenges for any PV supplier. Condensation, icing, grounding and long-term durability are critical design issues for curtain wall applications. Suitability may be restricted by limited product size, color, and thickness. Curtain wall manufacturers may not be good potential partners because of the custom nature of most curtain wall applications; not only are each building’s specs different, but the glass typically gets thicker for higher floors within the same building. Finally, this is viewed as one of the most conservative building sectors, particularly in the U.S.
- Fire code requirements must be further investigated for the SunFlash applications in commercial buildings. The possibility and expense achieving UL Class A fire rating for residential roof applications should be evaluated.

- Glass companies are key players in most building sectors, even if glass isn't used directly in the systems SunFlash is targeting, e.g., slant-roof residential systems or metal commercial buildings.
- Architects must be consulted in every phase of the SunFlash development program, and must be satisfied with product aesthetics, particularly in commercial building applications.

The results of the interviews and related research are summarized in the Product / Application Matrix in Exhibit X.

Exhibit 1. Product / Application Matrix

<i>Application</i>	<i>Product</i>
Residential slant-roof, retrofit or new construction, roof-integrated with asphalt shingles	SunFlash on wood strapping overlaid onto existing asphalt shingle (retrofit) or exposed roof joists (new)
Residential slant-roof, retrofit or new construction, with composite tiles	SunFlash tile on exposed roof joists
Metal building: vertical wall or slant roof	SunFlash attached directly to the sheet metal ridges with sealing tapping screws with sheet metal screws
Curtain wall	Frameless module with wrap-around polymer edge seal/protection
Specialty applications in commercial buildings, including awnings, window shades, and parking lot shading	SunFlash attached to rack mount with screws through the edge mounting material or with edge clips

These applications encompass important extensions of the building set for which the PV industry has developed promising, low-cost solutions:

- While roof-jacks are versatile, elegant, and inexpensive for stand-off slant-roof asphalt shingle mounting, no good solution exists for building integration with asphalt shingles. The SunFlash seems promising for this – both retrofit and new construction. While one supplier's flexible shingle has commanded substantial attention, we believe the SunFlash's tempered glass, crystalline solar cells, integrated weatherable wiring, and superb edge seal will yield a product of substantially longer life.
- The SunFlash concept also looks extremely promising for metal buildings, an unglamorous but extremely widespread building concept. Applicable to both facades and slant roofs, SunFlash installation on metal buildings may possibly become the lowest cost PV-on-buildings approach anywhere: even less than roofjacks.
- While several suppliers have offered rigid solar tiles compatible with wood shakes and roofing tiles of several compositions, we believe the SunFlash's edge seal will again make it a product of superior life. The industry's limited experience with simply removing the frame of conventional power modules has not been good. Edge delamination leads to premature module failures.
- As noted earlier, simply adding the polymer edge seal to Evergreen's conventional module may provide the best and longest-lived product for curtain wall applications. While early curtain wall demonstrations

appear promising in Europe's temperate climate, we are not confident that frameless EVA-Tedlar laminates will fare well in the South and Southwest U.S.

Task 2: Manufacturing and Production Planning

Task 2 included three efforts: the construction of a prototype modules; an assessment of the balance-of-systems (BOS) components; and a cost analysis for the SunFlash system in both a commercial and residential system.

Prototype modules were made for both the SunFlash and the shingled tile. Thickness and backskin treatment and processing were developed sufficiently to get repeatable results with nearly perfect manufacturing yields.

- For the SunFlash, most of the work was performed on small (1 ft²) modules, but full size (8 ft²) modules were also made by the end of Phase 1 (see photographs included in the Appendix).
- For the shingled tile, prototypes were made in two sizes, corresponding exactly to the dimensions of two commercially available roofing tiles from a major tile manufacturer. The smaller was approximately 1.5 ft² and the larger approximate 4 ft².
- Preliminary experiments were also conducted with "strip" modules, i.e., laminates with long, narrow dimensions, laminated on Evergreen's continuous, non-vacuum laminator. This concept takes advantage of a low-cost lamination technique, enabled only by Evergreen's proprietary non-EVA encapsulant. More importantly, it seems highly consistent with installation and wiring economics for many building applications. As champions of Mobil Solar's large-area module for many years before forming Evergreen Solar, we are believers in the benefits of large area, but became familiar with the unwieldiness of large near-square rectangles.

While Phase 1 did not permit extensive testing, several preliminary tests were performed to look for "drop-dead" issues.

- One of the key issues for the SunFlash will be the structural integrity of the mounting technique. The static loading test sequence of IEEE1262 was performed and passed easily.
- The shingled tile was submitted to accelerated testing for humidity freeze, thermal cycling, and damp heat. The testing was not completed by the end of Phase 1, although at the time of reporting no issues were found regarding the backskin, the wrapped polymer edge, or the adhesion of the front polymer edge to the glass. This is consistent with extensive testing performed on Evergreen's frameless power modules.
- Preliminary flammability evaluation was performed. In the Burning Brand and Spread of Flame tests, the new backskin material performed at least as well as the EVA/Tedlar construction.

Most of the Phase 1 BOS work focused on structural and mechanical issues:

- Preliminary designs were completed for the following systems: (i) asphalt shingle, sloped roof, (ii) shingled tile, sloped roof, (iii) metal buildings, either vertical walls or sloped roof, (iv) curtain wall facades, and (v) rack- and clip-mounted panels, which could be used on such applications as awnings and parking lot covers. Compatibility was demonstrated with existing standard building materials, although neither exhaustive nor optimized analysis were completed.
- The designs and compatibility assessments were sufficiently promising that mockup subsystems were constructed for four of the five systems noted above (see photos): (i) asphalt shingle, sloped roof,

(ii) shingled tile, sloped roof, (iii) metal buildings, either vertical walls or sloped roof, and (iv) rack- and clip-mounted panels. Only the curtain wall was not built for lack of time in the brief Phase 1. Working modules were used for some; laminates without solar cells for others.

Only preliminary work was possible on related BOS issues. Again, the focus was consideration of preliminary feasibility or early-warning "drop-dead" issues:

- Micro-inverters being used in Evergreen's standard AC Module (i.e., with framed Tedlar modules) were mounted onto the new frameless modules' backskins.
- Several existing and new plugs were investigated, and preliminary experiments to directly mold wire pigtails or cabinet-mount female plugs into the polymer edge were extremely promising. These successful experiments further validated the highly attractive attributes of Evergreen's new backskin, which is a moldable thermoplastic with excellent adhesion to a range of relevant materials.

Preliminary cost analysis of the SunFlash and shingled tile modules confirmed our expectations that these modules will be less expensive than conventional framed, Tedlar modules. Excluding the cost of the solar cells, the module-related costs in fact are expected to decrease on the order of 20% relative to conventional framed, Tedlar modules.

BOS cost analysis was not performed, because (as noted above) preliminary evaluation confirmed that existing building products will be directly useable with the SunFlash and shingled tile. Thus the potential issue of high-cost, low-volume specialty products or components to assure compatibility seems not to be an issue.

Task 3: Market Assessment

Only a qualitative market assessment was performed because the range of product/application possibilities in fact increased rather than narrowed during Phase 1. This is an extremely encouraging conclusion by itself.

As may be remembered from our Phase 1 proposal, we share the widespread enthusiasm about the match of PV with the building sector. The industry has largely abandoned the cover-the-deserts power plant approach to PV of the 1970s in favor of the buildings view of the 1990s.

Buildings have much in their favor. Relative to ground-mounted systems, buildings already provide the structural mounts. Building PV is located close to load use, which minimized utility transmission and distribution investment, operations, maintenance, and load losses and also increases system reliability. Displacing building materials helps close the cost gap between PV power and conventional electricity. To many, PV on buildings is aesthetically appealing. Distributed PV is moving in the direction of the evolving utility industry: toward dispersed systems physically close customers to and economically adding value to customers.

However, the unfulfilled challenge is that, to date, not many cost-effective systems have been developed to put PV on buildings. We earlier note the elegant simplicity and low cost of the roof jacks and commercial flat roof pans pioneered by Ascension Technology. However, these products have limited applicability. For example, the evidence is increasing that ballasted systems are not suitable for the vast majority of flat commercial roofs in the U.S. We remember the major lesson from our team's experiences at Mobil Solar with a flat-roof system secured through the roof membrane to a building's structural steel. The BOS and cost was prohibitive, even if the PV were free. We remember SMUD's original procurement requirement that residential systems be put on shake and tile roofs predominant in their service territory; now, many years later, virtually all of the residential systems have been installed on asphalt shingle roofs because the other roofing systems are too costly thus far.

Our team views the market challenge, therefore, as *extending the range of applicability* of low-cost building deployment. As long as PV deployment is approximately equivalent in cost to conventional building practices, we are substantially advancing PV commercialization. Because we think we're on the path to doing this for a number of important buildings sectors that have thus far too expensive – metal buildings, shake and tile slant roofs, asphalt shingle roof-integrated, we chose to devote more of Phase 1's resources to conceptual design and technical feasibility rather than detailed market assessment.

Task 4: Business Planning

The existing team – Evergreen, Bechtel, Ascension Technology, and Jefferson Shingleton, P.E. – has substantial experience manufacturing, qualifying, and selling PV systems. Of the current team, only Bechtel has substantial experience in the buildings sector.

We recognize, therefore, that a critical part of this project's success will be forming business relationships with companies that design and build buildings, and manufacture and market buildings products. (Task 3, below, discusses the Phase 1 activities in team formation.) Our goal is to merge PVBONUS products with the mainstream buildings industry.

In Phase 1 we engaged in exploratory discussions with a number of potential partners. Companies that were sufficiently interested to visit Evergreen Solar, see our prototypes, and discuss potential collaboration include:

- Three major glass companies: two that make bulk glass as well as fabricated glass (i.e., cutting, coating, tempering, laminating, and sealing multi-pane products); and one that makes specialty glass
- A major manufacturer of pre-fabricated homes
- A major manufacturer of industrial facilities and steel structures
- An energy services company that designs and implements energy conservation programs for new home construction

While no formal arrangement were completed, several of these and other potential relationships made substantial progress. With most of the above companies, we had multiple (as many as seven) meetings. All of the above companies (except the energy services company) have multinational operations.

Appendix 1: Interview Results

INTRODUCTION

As part of the market research, a series of interviews were conducted with representatives from Bechtel R&D, Sacramento Municipal Utility District (SMUD), and PVUSA, for the purposes of gathering product design and marketing information. This appendix describes the results of those interviews, which were conducted in accordance with the Interview Guide presented below. Professionals both within and outside of the PV field were interviewed.

In-person interviews were conducted by Jefferson Shingleton with representatives of the following three organizations:

- Bechtel is a partner in this PVBONUS project. The Bechtel role is to lead the assessment of building design and construction practice and contribute to concept development for the components. Joe Perkowski arranged all of the interviews within Bechtel.
- SMUD is a utility with an active program supporting the installation of roof-mounted photovoltaics in residential grid-interactive applications. An interview was conducted with Dave Collier at SMUD in order to gather design information to contribute to the conceptual design effort.
- PVUSA is a test site where several utility-interactive residential, commercial, and industrial photovoltaic systems are installed and monitored. The total installed capacity at PVUSA is nearly 1 MW. Many systems have been in place for nearly 10 years, and provide valuable data on the performance of various designs and materials. PVUSA, now operated by SMUD, has installed several prototype residential roof-top PV arrays in a new Small Systems Test Facility, where long term testing can be conducted and side-by-side comparisons can be made of system performance.

In addition to the interviews, detailed site studies were made of representative PV systems at PVUSA and SMUD. Although most of the PVUSA systems are ground-mounted, many of these systems embody innovations in module design, multi-module panel construction, and electrical conductors. Photographs were taken that were used in the comparative design efforts.

CONCLUSIONS

The following is a summary of key conclusions from the interviews.

- The SunFlash and shingled tile prototypes look quite promising for a range of building types.
 - ◆ In the residential sector, the SunFlash should work well for new or retrofit, and the shingled tile meshes well with existing roof products for new construction in conjunction with composite tile roofing.
 - ◆ In the commercial sector, metal buildings and precast concrete wall construction may be well suited for the SunFlash – both new and retrofit.
 - ◆ The SunFlash may be intriguing in new innovative “rainshield” curtain wall applications.
 - ◆ The SunFlash seems applicable in a wide range of architectural specialty applications in commercial buildings, including awnings, window shades, and parking lot shading.
 - ◆ Opportunities to utilize the SunFlash in flat roof applications, not yet explored, should be evaluated.

- On the other hand, conventional commercial building curtain wall applications pose special challenges.
 - ◆ The self-flashing does not demonstrate significant advantages, and in fact poses distinct disadvantages, as the flashing interferes with the highly developed moisture management system inherent in most curtain wall systems.
 - ◆ However, Evergreen's frameless module, with its wrap-around polymer edge but without the extra flashing, may provide the superior edge seal and edge protection required for curtain wall applications. This will become increasingly important, since curtain wall applications look for extremely long product lifetimes, e.g. 50 years.
 - ◆ Curtain wall applications pose particular challenges for any PV supplier. Condensation, icing, grounding and long-term durability are critical design issues for curtain wall applications. Suitability may be restricted by limited product size, color, and thickness. Curtain wall manufacturers may not be good potential partners because of the custom nature of most curtain wall applications; not only are each building's specs different, but the glass typically gets thicker for higher floors within the same building. Finally, this is viewed as one of the most conservative building sectors, particularly in the U.S.
- Fire code requirements must be further investigated for SunFlash applications in commercial buildings. The possibility and expense achieving UL Class A fire rating for residential roof applications should be evaluated.
- Glass companies are key players in most building sectors, even if glass isn't used directly in the systems the SunFlash is targeting, e.g., slant-roof residential systems or metal commercial buildings.
- Architects must be consulted in every phase of the SunFlash development program, and must be satisfied with product aesthetics, particularly in commercial building applications.

INTERVIEW GUIDE

1) Conduct Introductions

2) Record Personal Information

3) Show Pre-prototype SunFlash and Shingled Tile Modules

4) Explain Initial Concepts

SunFlash commercial curtain wall
 SunFlash residential roof mount
 SunFlash rack mount
 Shingled tile prototype

5) Detailed Questions

Review Current Practices

On this first exposure to the SunFlash concept, where do you initially believe will be the best fit for SunFlash products in residential and/or commercial building applications?

What do you see as product concept characteristics that might limit the suitability of the SunFlash concept to a broader range of applications?

What references or personal perspectives can you offer to assist in the development of a more complete understanding of current building practices for residential and commercial construction?

Practical On-Site Issues

What references or personal perspectives can you offer to identify practical on-site issues in the construction of commercial and residential buildings that may relate to the conceptual design of SunFlash products?

Code Issues

What do you believe will be the primary codes issues for the design of SunFlash products?

Design Criteria: Structural, Electrical, Aesthetics, Flammability Requirements

What design criteria, standards, and test methods are applicable to the design and certification of SunFlash products, e.g. fire resistivity; water penetration; deflections, etc.

What minimum fire rating must SunFlash products attain in order to gain acceptance for commercial and residential applications?

Purchase Factors

What other purchase factors must be addressed in the design of SunFlash products?

Market Potential

What information, recommendations, or references can you offer that will help to develop estimates of market potential?

Marketing and Sales Implementation

What will be the most appropriate role for your company in the Phase 2 project?

What kind of partners should Evergreen consider for the Phase 2 project? e.g. A&E firms; manufacturers; builders; etc.

What specific partnering recommendations can you make to Evergreen for the Phase 2 project?

Appendix 2: Photographs of Results

SunFlash Modules Integrated in Residential Pitched Roof

SunFlash module with flashing screwed to horizontal nailers. Unlike PV devices which replace asphalt shingles, the SunFlash replaces sheathing and allows for improved cooling thereby enhancing performance and lowering cost.

Sealing tape improves the weather-tight performance of SunFlash modules and may be pre-applied in the factory.

SunFlash Modules Integrated in Residential Pitched Roof (continued)

Two SunFlash modules, integrated with standard asphalt-shingle-over-plywood construction.

SunFlash modules shown with optional batten and cover wiring raceway, which mates easily to conduit.

SunFlash Modules Integrated in Residential Pitched Roof (continued)

Detail showing installation of optional batten.

Detail showing installation of optional wireway.

SunFlash Modules Mounted to Standard Rack

Standard racks like this are currently widely used for ground or flat-roof mounting as well as stand-off racks for pitched roofs.

SunFlash modules are easily installed using self-tapping screws.

SunFlash Modules Mounted to Standard Rack (continued)

Detail showing installation of optional batten and cover electrical raceway.

Detail showing mounting on SunFlash modules using self-tapping screws.

SunFlash Modules Clip-Mounted to Standard Rack

Trimmed SunFlash modules can be easily installed on conventional racks using a simple clip design. These racks are currently used in ground-mounted, flat-roof and stand-off pitched-roof applications.

Detail showing clip mounting.

SunFlash Modules with Molded-In Pigtails and Connectors

Close-up of front and back of molded in pigtail

Close-up of molded-in connector.

SunFlash Modules Mounted on Metal Standing Seam Construction

SunFlash modules mounted using the metal roof as a means of wire concealment and mechanical protection.

Detail showing installation with self-sealing screws directly on standing seams.

Detail showing installation of optional batten.

Detail showing installation of optional wiring raceway.

SunFlash Modules Mounted on Metal Standing Seam Construction (continued)

Detail showing optional matching wiring raceway on pitched roof.

Detail showing optional matching raceway on vertical wall.

SunFlash Modules Mounted on Metal Standing Seam Construction (continued)

Trimmed SunFlash modules mounted to pitched metal standing seam roof using mounting clips

Detail showing mounting clip.

SunFlash Modules Mounted on Metal Standing Seam Construction (continued)

SunFlash modules mounted to vertical metal standing seam wall with optional matching batten and cover.

Detail showing optional matching batten and cover.