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SolarTile: A ROOFTOP INTEGRATED PHOTOVOLTAIC SYSTEM

Phase I Final Report

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1. Introduction

1.1. Background

AstroPower, Royal Group Technologies, and Solar Design Associates are jointly developing an integrated photovoltaic roofing system for residential and light commercial building applications. This family of products will rely heavily on the technological development of a roofing tile made from recycled plastic and innovative module fabrication and encapsulation processes in conjunction with an advanced Silicon-Film™ solar cell product. This solar power generating roofing product is presently being referred to as the SolarTile. A conceptual drawing of the solar roofing tile is shown in Figure 1. The SolarTile will be integrated with non-solar tiles in a single roof installation permitting ease of assembly and the ability to use conventional roofing techniques at ridges, valleys, and eaves.

Figure 1. Section of roof and detail of single photovoltaic tile.

Prototype products that attempt to replace shingles and tiles are being developed by other manufacturers. However, there does not exist an integrated commercial system of structural components and supporting infrastructure for the installation of any residential and commercial building photovoltaic system. These problems can be uniquely addressed by the AstroPower, Royal Group Technologies, Solar Design joint venture. Distribution systems are in place for AstroPower photovoltaic and Royal Group Technologies building materials customers as well as existing buildings with integrated photovoltaics designed by Solar Design. These companies possess a significant knowledge of their own customers needs and when coordinated will successfully penetrate this new and emerging market.

During the Phase II program, AstroPower, Royal Group Technologies, and Solar Design Associates will work together to develop a product demonstration with progression towards commercialization of this technology. It is the intent of AstroPower, Royal Group Technologies,

and Solar Design Associates to meet the requirements of the program to build knowledge and manufacturing expertise in the US. Although Royal Group Technologies is a Canadian company, Royal Sierra, a wholly owned subsidiary incorporated in the US, will serve as the subcontractor for this effort. Eventually, the *SolarTile* will be manufactured at Royal Sierra or another Royal plant in the US. AstroPower will be the prime contractor and will be responsible for the solar cell and associated array components, Royal will be responsible for the development of the tile and the marketing and sales infrastructure, and in conjunction with AstroPower the integration of the tile and wiring components. Compatibility with standard structure will be insured by designing panels that can readily replace and function as roofing with conventional fastening methods.

When fully developed, the solar cell component of the large module will be up to a 12-inch x 36-inch Silicon-Film™ Product III cell with an operating voltage of 48 volts and integrated bypass diodes. This high voltage solar cell will allow each SolarTile unit to be wired in parallel rather than series stringing a number of tiles. This monolithic interconnection relates to lower I^2R losses, integrated blocking diodes, easier installation, and fewer hand wired connections, as well as, lessening the deleterious effect on electrical generation by partial roof shading. Prior to introduction of the Silicon-Film™ Product III solar cell that will probably occur after Phase III, AstroPower will use large area Silicon-Film™ Product I solar cells and integrate the necessary interconnects at the cell level for integration into the proposed SolarTile product for the Phase II and Phase III demonstrations.

SolarTile roofing systems will be assembled of four functionally different components. These are: photovoltaic arrays, photovoltaic receptor tiles, non-photovoltaic tiles, and end connector tiles for through-roof wiring. All of the components will be dimensionally and cosmetically compatible with only the photovoltaic component having an embedded solar cell and being approximately three times wider than the other components. The solar cell component will be assembled separately and after the completion of the roofing installation will be set into a socket in the receptor tiles. Wiring, and interconnections will be embedded in the receptor tile as it is formed. This embedding will afford protection from physical damage and weathering. Individual SolarTile units will connect together eliminating tile to tile hand wiring. The end connector component will have wires that can pass through a hole in the roof for connecting to the electrical system inside the building. Both the solar cells and the roofing tiles can have different colors and can be made architecturally pleasing. Figure 2 shows the four SolarTile components.

Figure 2. SolarTile components: a) photovoltaic element, b) photovoltaic receptor tile, c) end connector tile, and d) plain tile.

Utilizing the separate component approach for the roof tile and the solar array encompasses a number of benefits: 1) safety – the roofer is not exposed to electrical hazards during the roofing process, 2) ease of maintenance – the solar cell modules can be replaced without affecting the integrity of the roof or the roof tiles can be replaced without replacing the more costly solar array, 3) product development cost – the manufacture of two separate components will have a lower overall development cost than trying to develop a single integrated product with the same attributes.

2. Progress

The Phase I effort included tasks aimed at the development of the proposed product concept; product manufacturing or fabrication, and installation cost estimates; business planning; and a market assessment of the proposed product, including target selling prices, target market sectors, size estimates for each market sector, and planned distribution mechanisms for market penetration. Technical goals as stated in the Phase I proposal and relevant progress are reported in the following.

2.1. Business Relationship

During the Phase I program a significant effort has been invested to develop a business relationship and assess the technological opportunities afforded by the BIPV effort among the partners. AstroPower, Solar Design Associates, and Royal Group Technologies have agreed to support this product development effort and have identified key personnel to lead the effort. AstroPower has agreed to manufacture the photovoltaic component for use in making the SolarTile and recognizes that the success of this product in the marketplace will be strongly driven by economics. Further, AstroPower agrees to provide Royal preferential solar cell pricing to help establish and grow this market. Royal's efforts in the marketing and sale of the new SolarTile in the US market and elsewhere will be supported by AstroPower and Solar Design Associates.

All team members are in agreement to:

- ✓ provide cost-sharing to support the R&D effort
- ✓ manufacture an AstroPower Silicon-Film™ solar cell product for the SolarTile
- ✓ manufacture the Royal roof slate for use in making the SolarTile
- ✓ integrate the photovoltaic element with the roof slate to produce the SolarTile
- ✓ manufacture SolarTile in the US at the Royal subsidiary or another US location such as a new facility
- ✓ market and sell the new SolarTile in the US market and elsewhere

Royal Group Technologies has selected an existing subsidiary, Royal Sierra, incorporated in the US to serve as the key representative of Royal during the DOE-supported contract product R&D effort. During this effort Royal agrees to develop a new Royal roof slate compatible with the conventional Royal roof slates which will receive the photovoltaic element.

2.2. *Product Design and Attributes*

The SolarTile product has been conceptualized and agreed upon by all parties. This was accomplished at a series of meetings involving high level strategic personnel from all companies. The design of the roofing system was shown previously in Figure 1.

Solar cells were provided by AstroPower to Royal Group Technologies for feasibility testing with the tile forming process and a design concept SolarTile was constructed. The concept hardware is shown in Figure 2.

Figure 2. Concept demonstration SolarTile prepared in Phase I.

Early experimental attempts attempting to mold the solar cell component with the tile failed due to a number of mechanical considerations. After reviewing the data and after lengthy discussions it was decided that there was more benefit to be derived from separating the photovoltaic and roofing components. Utilizing the separate component approach for the roof tile and the solar array encompasses a number of benefits: 1) safety – the roofer is not exposed to electrical hazards during the roofing process, 2) ease of maintenance – the solar cell modules can be replaced without affecting the integrity of the roof or the roof tiles can be replaced without replacing the more costly solar array, 3) product development cost – the manufacture of two separate components will have a lower overall development cost than trying to develop a single integrated product with the same attributes.

Based on this new scenario, specifications of the SolarTile product have been drafted. Draft specifications include the physical size, configuration, tile substrate, AstroPower photovoltaic element and the method of bonding the photovoltaic element to the substrate. Options for electrical interconnection and termination have also been evaluated.

The physical size of the tile system has been chosen. Photovoltaic tiles will be nominally 18" high x 36" wide with non-photovoltaic and end-connector tiles at 18" high x 12" wide. This will allow for a near conventional looking roof and the ability to integrate into any roof design that can utilize standard roofing shingles or slates. The photovoltaic tile will initially consist of a string of five AstroPower AP-225 solar cells with an output voltage of about 3 volts. This Silicon-Film™ solar cell technology will be used for demonstration purposes and will be replaced by the advanced monolithically interconnected Silicon-Film™ solar cell when appropriate. Physical size of either solar cell product will be essentially the same and highly interchangeable.

A novel, high speed continuous lamination process will be developed by AstroPower in the Phase II effort. The benefits of continuous lamination can have far reaching effects beyond the PVBONUS program objectives. Conventional lamination methods are not amenable to the deployment of high volumes of small, shingle sized arrays. In order to reduce cost and meet the expected volume demands of the solar rooftop market, it will be necessary to develop this technology.

The photovoltaic element will be bonded to the substrate by adhesive means. Presently, the adhesive attachment method has not yet been identified and will be addressed in the Phase II effort. However, a number of innovations have been discussed. For instance, the tile can be designed with caulk channels and a trough to accept the photovoltaic element. This is shown schematically in Figure 3.

Figure 3. Cross-sectional and top views of SolarTile photovoltaic section.

Interconnect wiring is expected to be embedded in the body of the tile during its formation and will terminate in the trough and at a tile-to-tile connector. This wiring may be different depending on the bus voltage of the system and the solar cell technology employed. In the case of the AP-225, a number of tiles will need to be series interconnected. Whereas, when the advanced monolithically interconnected solar cell product is used, it will be specified at the bus voltage and all tiles will be connected in parallel greatly simplifying layout and adding another level of flexibility to this innovative system design.

The composition of the tile itself can be formulated from a blend using both recycled plastic and sand. This blend will be chosen to match the coefficient of expansion of silicon in the temperature range of interest. By achieving this expansion match, thermal cycle degradation will not occur within normal terrestrial ambient conditions.

The tile-to-tile interconnect is presently being defined. It is preferable to have a hard connection at the tile edge rather than wires that emerge from the tile. Constraints that are being considered in designing this connector are: the tile must have some rotational movement to accommodate roof variations; and the connector must be readily fastened and form a tight connection that is resistant to environmental degradation. Because of this, a coaxial connector configuration is being assessed and will be considered in Phase II.

Additionally, the SolarTile product must be able to meet the following requirements:

- ✓ minimum life span of 50 years for both functionality as a roofing product and for fail safe electrical functions of the wiring, connections, and solar cells in a variety of extreme climates
- ✓ maximum output of electrical energy without more than 20% deterioration over a life span of 50 years
- ✓ Mechanical resistance and electrical functionality in extreme climatic conditions such as wind, hail, snow, rain, heat, etc.
- ✓ Easy to install and replace
- ✓ able to withstand walking
- ✓ total integration and interchangeability with Royal Ecoproducts line of composite roofing products

2.3. Develop initial cost estimates to produce the new SolarTile product

In order to estimate the cost of a proposed product, it is first necessary to consider the product spectrum and available pricing options. As can be seen in the table, the price of the Royal Ecoproducts roofing tile compares favorably with its competition. It is readily apparent that even though the cost is higher than asphalt, the value in life span is much greater. Also the installation of the Royal Ecoproducts is simpler and requires less preparation than slate, clay, or concrete, further reducing the cost of ownership.

STYLE	PRICE TO DISTRIBUTOR (PER ROOFING SQUARE)	INSTALLATION COST (PER ROOFING SQUARE)	PRODUCT WEIGHT (LBS PER SQUARE)	COMMENTS (WARRANTY/LIFE SPAN IN YEARS)
Asphalt shingles	\$21-80	\$30-50	210-255	15-30
Slate	\$320-1200	\$110-150	980	50-100
Concrete- Heavy Light	\$400 \$500	\$200-250 \$200-250	variable	50-100
Clay Tile	\$140-850	\$120-200	variable	50-100
Metal (steel)	\$155-310	variable	50-270	20-50
Synthetic Slate	\$220-230	\$70-100	385-470.	50
Wood (cedar) Medium- Heavy-	\$105 \$135	\$67-135	300-400	15-30
Plastic Roofing	\$250-325	\$100-125	62	50
Royal Ecoproducts Roofing Systems	\$225-250	\$150 approx.	300	50

The cost of the SolarTile product is much more complex and cannot be evaluated at this time. Further development of the product and the Phase II demonstration should provide sufficient means to make a judgment, however, the cost of an integrated product will certainly be less than the cost of a roof and a conventional solar installation.

2.4. Perform a detailed market assessment of the new SolarTile product including: identification of target market sectors, estimation of the size of these market sectors planned distribution mechanisms for full market penetration, and the estimated selling prices

An initial estimate of market potential for the new SolarTile product, including identification of target market sectors, estimation of the size of these market sectors, and proposed distribution mechanisms for full market penetration have been identified and discussed.

The total roofing products in the United States in 1996 was \$8.625 billion dollars and is projected to rise to \$14.2 billion by the year 2000. The residential market currently accounts for 60% of the total roofing products demand on a volume basis or 146 million squares (one square

equals 100 square feet of finished roof) in 1996 with projections to 199 million squares in 2006. Residential roofing is broken down into two segments: new construction and re-roofing. In 1996, new construction represented 25.6% of the total roofing market, and is expected to *decline* by the year 2006, to 21.6%. Re-roofing represented 74.7% of the total roofing market in 1996, and is projected to *rise* to 78.4% by 2006.

As noted above strong growth is expected in the residential replacements and improvements market. As homes constructed during the boom housing starts market of the mid/latter 1970s and mid 1980s have reached or will reach shortly an age when replacement roofs are required (every 15-20 years for conventional asphalt shingles that were mainly used during this construction phase). Also, population dynamics and low interest rates are creating a healthy environment for the trade-up housing market with good prospects for residential improvements and maintenance projects. This, along with a prospering economy, will allow a larger market of homeowners to purchase higher-end roofing materials to add value, prestige, and individuality to their homes.

The roofing market in the United States is broken down into roofing sales by region. The following represents the market segment percentages of sales in 1996.

Figure 4. Roofing market by region.

Northeast: This region comprising of New England and the Middle Atlantic States saw \$1.335 Billion or 15.5% of the total roofing market in 1996. Projections for the year 2006 will see a rise in sales to 2.075 Billion or 14.6% of the total projected roofing market.

Midwest: This region comprising of East North Central and West North Central States saw sales of \$1.930 Billion or 22.4% of the total roofing market in 1996. Projections for the year 2006 will see a rise in sales to \$3.075 Billion or 21.7% of the total roofing market.

South: This region comprising the South Atlantic, East South Central and West South Central States saw sales of \$3.440 Billion or 39.9% of the total roofing market in 1996. Projections for the year 2006 will see a rise in sales to \$5.775 Billion or 40.7% of the total roofing market.

West: This region comprising of the Mountain and Pacific States including Alaska and Hawaii saw sales of \$1.920 Billion or 23.3% of the total roofing market in 1996. Projections for the year 2006 will see a rise in sales to \$3.275 Billion or 23.1% of the total roofing market.

It is believed that the "Residential Replacement and Improvements Roofing Market" is the target market with the largest potential for growth and market share. In following this logic, the Southern United States would potentially create the best success for sales volume for Royal Ecoproducts Roofing Systems. This is shown in Figure 5 and the accompanying tables.

Figure 5. Roofing market size.

	New Residential Roofing Market (Year 2001)	Residential Replacement and Improvements Roofing Market (Year 2001)
Total (Million Squares)	40.0	134.0
Asphalt Shingles	24.0	108.8
Roll Roofing	10.0	14.3
Built-up Roofing	0.7	2.3
Modified Bitumen Roofing	0.4	0.9
Elastomeric Roofing	0.3	0.6
Metal Roofing	0.3	0.8
Wood Shingles and Shakes	0.8	1.7
Plastic Roofing	0.3	0.3
Roof Tile	2.8	3.7
Other Roofing	0.4	0.6

Royal Ecoproducts Roofing Systems as they are launched will be initially offered to existing Royal Group Technologies customers. As these products become commercialized and current customers are introduced to the line, other additional avenues of sales and distribution will be sought out. These options might include but are not limited to: sales agents, distribution companies, private labeling, and joint venture offshore marketing partners or other avenues Royal might see fit.

The Royal Building System™ is a revolutionary construction technology that incorporates the use of leading edge polymer composites and concrete, to create durable, attractive and low maintenance structures. The Royal Building System™ is being used with increasing frequency in over 50 countries worldwide for a wide variety of construction applications, including residential, light commercial, institutional and industrial structures. The Royal Building System™ is manufactured in Canada, Mexico, Colombia, Argentina and China, with additional plants under development in Poland and the Philippines.

The roof of The Royal Building System™ is made from the same durable polymer components as the walls, and is used in combination with standard steel reinforcement to provide structural stability to the buildings. A patented, optional, polymer based "Spanish" roof tile can be connected to the roof panels to provide for a finished roofing system.

An alternate option to the standard Royal Building System™ roof allows for the application of a third party roof using conventional building materials. Using the latter option, standard roofing materials must be applied as the Royal "Spanish" roof tile has of yet not been adapted for conventional roof structures.

The Royal Building System™ and the SolarTile share a number of conceptual similarities, and therefore would be considered ideal complimentary products.

- ✓ Common vision of preserving the environment through recycling and more efficient use of existing natural resources
- ✓ Promoting the use of more cost effective building methods and materials
- ✓ Promoting greater use of leading edge technologies in the building materials industry
- ✓ Strong commitment to providing a high level of customer satisfaction by offering quality, value-added products
- ✓ Promoting materials with improved performance characteristics from a building science perspective

In addition to the above, the SolarTile allows The Royal Building System™ to exploit a number of key marketing strategies:

- ✓ The Royal Building System™ currently commands significant market acceptance in warm climates such as the Caribbean and South America, where there is abundant access to solar radiation
- ✓ The Royal Building System™ is gaining market share in countries where access to a reliable source of power is inadequate (i.e. Caribbean, Russia, China), or the cost of power generation is high (i.e. Caribbean and Japan)
- ✓ The Royal Building System™ recently received BOCA building code approval in the USA, a precursor to the successful commercialization of the technology in the largest market in the world
- ✓ Royal Building Systems (Cdn) Ltd. has entered into a number of strategic marketing alliances with Fortune 500 companies such as Shell Oil and Home Depot. The use of the SolarTile with The Royal Building System™ reinforces Royal's commitment as a leading global manufacturer and supplier of building materials and technologies
- ✓ Provides a viable alternate roofing solution that can be marketed with structures built using The Royal Building System™ technology and a third party conventional roof

For the purposes of this report, the following assumptions are inferred:

1. The use of the SolarTile is limited to residential and light commercial applications
2. Total roof area for The Royal Building System™ is calculated based on output of the technology in all current manufacturing centres worldwide in 1998, with additional capacity coming on-line starting in 1999 from Poland and the Philippines operations
3. Assumes all capacity dedicated to providing housing units with roof installation conforming to the target market
4. A conservative growth rate of 15% representing the increasing use of the SolarTile in combination with The Royal Building System™ technology worldwide

5. Capacities have been modified for situations where the Royal roof system will not be supplied (i.e. industrial and commercial applications involving a flat roof)

The market potential for the use of the SolarTile in combination with The Royal Building System™ technology can be quantified as 17,100,000 sq. ft. in 1998, and increasing to a total of 29,900,000 sq. ft. by the year 2002, using a conservative 15% growth rate per annum.

3. Conclusion

AstroPower, Royal Group Technologies, and Solar Design Associates represent a uniquely qualified team to bring the SolarTile to market. The design of the product has been guided by volume manufacturing methods used by the building products company as well as the photovoltaics company. The inclusion of an architectural design company will insure that the tile is amenable visually and can be integrated with buildings thereby assisting with market acceptance. The technology can be developed and a pilot production facility can be enabled in the desired time frame, resulting in field demonstrations before or near the completion of the program. Both AstroPower and Royal Group Technologies will finance the commercialization of the SolarTile product at the conclusion of the PVBONUS contractual period.