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DEVELOPMENT OF FLAME RETARDANT PV MODULE ENCAPSULANTS

Volume 1

Final Report

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Executive Summary

Fire retardant ethylene vinyl acetate encapsulant is so far the most promising configuration found to ensure the fire resistance of photovoltaic modules. It can be used in any module construction type, is optically transparent, so is appropriate for use both in front of and behind the solar cells, is substantially lower in cost and weight than competing technologies, and has identical lamination parameters to existing EVA encapsulant. Also, the fire retardant additive package selected meets all environmental criteria worldwide.

The market also exists for such a product line, as evidenced by the survey responses received from our 46 module manufacturer survey participants. A full 63 percent of the respondents reported that STR's conceptualized fire retardant EVA encapsulants would be the proper products to assure the fire retardance of their modules. Moreover, the overall PV module market, which advanced by 42 percent last year, is expected to continue its strong growth, and will in fact be led by those applications seen as most benefiting from fire retardance, building integrated and building mounted PV.

Interest in fire retardant PV is further being spurred by the proposed draft international standard, IEC 1730. This standard, will provide a standard means for rating a module's flammability characteristics, which will allow for product comparison in terms of flammability resistance. This code is expected to assist building code authorities in the establishment of standards for PV modules, and will guide architects, building contractors, and consumers through the product choice and building code compliance tasks.

The sections below highlight the major findings in each of the four Tasks undertaken.

Task 1: Further Problem Definition

The proposal of the draft international standard IEC is intended to standardize the flammability test methods for modules, and will result in the assignment of a flammability rating which may be imprinted on a module's label. The lack of a standard test method has become a concern with the increased popularity of PV, as requirements are dictated by local building authorities, which in many cases rely on nationally recognized standard test methods. These assign a flame resistance rating to the building or roofing materials, and not to the PV modules themselves.

A review of the various encapsulant materials, including silicones, polyvinyl butyral, EVA, liquid encapsulants, ionomer-based encapsulants, and fluoropolymers, found EVA to be the most promising option for achieving module fire retardance. Alternatives tend to be either quite costly, or unable to provide the required performance characteristics.

Task 2: Product Conceptual Design

Conceived on the basis of the findings in Task 1 were three conceptual fire retardant EVA product alternatives that can be combined in five configurations. One of the product alternatives

is an opaque encapsulant, one a transparent encapsulant, and one a low cost flame retardant backsheet. These configurations, and their envisaged performances and costs, provided the basis for our market assessment in Task 3.

Task 3: Market Assessment

Spurring growth in the PV industry are installations in the developing world and remote locations; government and utility initiatives, which provide incentives to the end-user; and cost reductions, which are based on both increased module efficiencies and production economies of scale. Based on these factors, the worldwide PV market is expected advance by 40 percent this year to 165.8 MW, by 43 percent/year over the period 1999-2000, by 19 percent/year over the period 2001-2005, and by 21 percent/year over the period 2006-2010.

We also identified the three major factors prompting the development of the fire retardant PV market: increased attention from regulatory authorities, the growth of building integrated PV, and the attention brought about by the proposed international fire retardant PV standard. The market for fire retardant PV is estimated to be only 4.5 MW for last year and 11.95 MW for this year. However, provided fire retardant EVA is released commercially, it is forecast that the market for fire retardant PV will reach 117.8 MW and account for 35 percent of all module shipments in the year 2000. This share will jump to 42 percent for the period 2001-2005, and then climb to 47 percent for the period 2006-2010.

Eight of our 46 respondents also claimed to be making fire retardant PV modules. However, we believe that only seven are actually capable of achieving a UL 1703 Class A rating or equivalent. Most achieve flammability resistance by shielding the flammable portion of the PV module (the EVA or other proprietary encapsulant) from the heat source. A tempered glass superstrate and substrate can generally achieve a UL 1703 Class A flammability rating, provided proper edge seals are in place. Only one manufacturer employs a flame retardant encapsulant to achieve PV module fire retardance. Specified is a rather expensive, non-flammable fluoropolymer-based material.

An evaluation of competing technologies, and the various methods recommended by our respondents for achieving flame retardance, again highlighted fire retardant EVA as the best performing and most economical option. And, EVA is already firmly entrenched in the market, accounting for over 90 percent of all modules deployed worldwide last year.

Manufacturers also responded with their most desired material characteristics. Flame resistance, transparency, long-term performance, and cost were claimed to be the most desired characteristics, with all being of equal importance. Thin film technology manufacturers required all but transparency, and also rated all to be of equal importance. Also, the manufacturers noted that the fact that there are three UL 1703 Class ratings is of little consequence. The general feeling was if you are going to bother, why not go for a Class A rating? Many manufacturers also said that their modules already conform or would likely conform to UL 1703 Class C.

Provided the conceptualized fire retardant EVA encapsulants are developed and released commercially, it is expected that fire retardant EVA will hold 58 percent of the fire retardant

module market and 19 percent of the overall module market in the year 2000. The year 2001-2005 shares will jump to 71 percent and 27 percent, respectively, and then to 79 percent and 33 percent, respectively, for the period 2006-2010.

Products and applications seen as requiring fire retardant PV over the next few years included:

- Building-related applications such as roof tiles, shingle products, metal and glass roofing products, other roofing materials, roof mounted modules, curtainwall, and facades.
- Offshore drilling platforms.
- Cars.
- Boats.
- Stand-alone installations that are in close proximity to dwellings or other potentially hazardous areas.

Task 4: Business Planning and Formation of Commercial Relationships

Fifty of the 53 module manufacturers contacted agreed to participate in our market forecast, and 46 actually returned completed surveys in time for publication. The responses were highly encouraging, and are prompting us to continue with both our research and market development efforts. In fact, a good portion of the respondents asked for more information, with some even offering to participate in our development efforts at their own expense.

Our intention is to develop a product line that the market both requires and has the means to purchase. Thus, we have worked hard to bring everyone on board early and solicit and incorporate their opinions and suggestions. This is necessary to ensure both the proper product portfolio and an adequate market.

Much of this work was accomplished under Task 3. However, we intend to continue to keep the lines of communication open, through the use of press releases and targeted direct mail, conference and exhibition presentations, and the use of a Development Panel and Project Team. So far, STR has secured Project Team participation commitments from two flame retardant additive producers, three major module manufacturers, and two international regulatory groups.

With a 50 percent share of the worldwide PV market and a 52 percent share of the worldwide EVA encapsulant market, STR intends to use its current, fully-developed marketing channels to bring these primarily drop-in replacement products to market. Fire retardant grades will simply be labeled with the suffix FR.

We expect the fire retardant PV market to be basically divided between fire retardant EVA and constructions of tempered glass superstrate/EVA/tempered glass substrate, however fire retardant

EVA is expected to claim the lion's share. Fluoropolymer and silicone encapsulants, which are inherently fire retardant, will hold only a very slight share due to their high costs.

We see three EVA encapsulant producers eventually challenging STR in the fire retardant arena. However, STR will benefit hugely from its long lead time. We released our "Fast-Cure" EVA encapsulant products commercially in 1986, but only in the past two years have seen the emergence of comparable products. In two to three years time we expect our Asian competitors to catch up, and at this point we will likely lose any Japanese customers we have gained, but our European competitor may not come out with comparable formulations for a good 5-10 years after our introduction.

Finally, STR does have the financial resources and corporate commitment necessary to develop this business. We have already received Board approval to expand EVA encapsulant manufacturing capacity during the year 2000, and have cursorily explored moving to in-house compounding. The latter would become economically desirable once a base level of compounded material required is reached. No staffing changes are anticipated, although additional operators will be required as our overall EVA encapsulant business expands.

1.0 Introduction

1.1 Background and Goals

This Phase I final report covers the work performed by Springborn Testing & Research, Inc. for the period October 1, 1997 to June 30, 1998 under the Department of Energy Cooperative Agreement Number DE-FC36-97GO10255, entitled "Development of Flame Retardant PV Module Encapsulants".

Background: While use of roof-mounted arrays has always been an attractive means of deploying PV, only within recent years have such building integrated concepts (BIPV) found renewed interest among module makers and end-users. Interest has been fostered by such Federal initiatives as PV-BONUS programs, increased funding for energy-related development, and growing recognition by utilities of BIPV's cost-effectiveness. Utilities realize BIPV eliminates many costs involved with transmission and distribution and believe distributed generating systems are more apt to gain early market penetration than large central-station systems.

Design concepts for BIPV can take a number of forms, including vertical curtain walls, awning systems, various rooftop arrays and panels, skylights, atriums, and structural glazing. Such systems must meet a variety of requirements, including solar performance, design, site selection, climate, construction methods, mechanical/electrical needs, maintenance, environment, safety, and flammability. Regardless of the BIPV concept, all require the encapsulation of the solar cells within the module.

Prior to building integrated and rooftop applications, flammability requirements for modules have not been a great industry concern. However, with growing interest in BIPV and the requirement for building code requirements for commercial and industrial structures, flammability issues have become a barrier to entry for many module constructions into this potentially huge domestic market for PV.

Several instances can be cited in which a PV module has contributed to the outbreak of fire at PV installations. Those include the Carriza Solar Photovoltaic Power Plant, Carriza Plains, CA, a PV installation at Lugo, CA, and the PV USA installation at Davis, CA. The Carriza and Lugo fires resulted from hot spots within the PV modules, that caused the encapsulant to ignite. Once ignited the encapsulant burnt holes through the substrate, that allowed flaming droplets of encapsulant to ignite the ground cover. At PV USA, fire resulted from the overheating of a failed bypass diode.

While at least one U.S. based module manufacturer has been able to achieve a UL 1703 Class A flammability rating with their module, one that is encapsulated within a glass superstrate and glass substrate, it is STR's contention that the weight associated with the glass/glass module construction limits its widespread utilization. The lighter weight modules in turn are limited by their lesser flammability ratings. Both situations negatively impact the amount of building opportunities available for PV. This in turn also impacts the level of national energy savings that could be potentially realized through widespread building opportunities for PV.

The overall goal of the 3 phase PV BONUS two project is to develop and commercialize a line of fire retardant encapsulation materials to serve the emerging building integrated and building mounted PV market. The objectives of the Phase 1 effort are limited to concept development and business planning activities.

1.2 Phase 1 Task Descriptions

Task 1: Further Problem Definition - Under this task, STR will review background information and literature on FR systems, especially optically clear ones, fire codes and standards, industry requirements, etc. This effort will be needed to ensure that developed products meet all performance and regulatory requirements.

Task 2: Product Conceptual Design - Under this task, STR will develop fire retarding strategies and estimate costs of these systems versus conventional EVA-based encapsulants. These concepts and costs will provide the basis for market analysis, business planning and product development in Phase 2.

Task 3: Market Assessment - Under this task, STR will analyze market potential, affordability, and barriers to market entry - technical and regulatory, etc. This information will provide justification and support for market planning and business development in Phase II.

Task 4: Business Planning/Commercial Alliances - Team with FR makers, U.S. based PV module manufacturers, and national and international architectural organizations. While the PV industry sees BIPV as a way to generate power, the building industry first views BIPV as a building material (i.e.; how does it look, how do you install it, is it strong and impact resistant enough) STR needs to gain their perspective.

2.0 Task Efforts and Activities

The following details the progress made through this nine-month Phase 1 effort.

Task 1: Further Problem Definition

Flammability Rating of PV Modules - Current Methods Identified

Over the course of this investigation it became obvious that there were really no international standards in place that dictate how a PV module should perform with regard to its flammability characteristics. Instead the requirements are dictated by local building codes within the community of which the PV module is to be mounted or integrated. In many cases the degree of flammability resistance is either based on the length of time that is required for a fire department to respond, or the degree of threat for the fire to spread from one building to another.

What is in place in many cases are nationally recognized standard test methods that assign a flame resistance rating to building or roofing materials, as opposed to a PV module. Unfortunately, depending on the country where the building integrated PV module is to be installed, the criteria

for flammability testing can differ from those of the country where the module was fabricated. In response to this dilemma, the IEC is presently drafting international testing standards, that will standardize the flammability test methods, assign a flammability rating based on flammability resistance, and require that rating to be stated on each PV module.

The more prevalent test methods which are in place today are discussed below:

United States

Within the United States PV modules are characterized for flammability under the UL 1703 standard, which cites flammability related test methods under UL 94 and ANSI/UL 790 standards. UL 94 testing is conducted to evaluate the flammability characteristics of the modules' junction boxes. The actual encapsulant related evaluations are conducted on constructed PV modules under the "Spread-of-Flame" and "Burning-Brand" tests as described in the ANSI/UL 790 Standard.

Framed and unframed modules must meet minimum requirements to receive a flammability rating. Testing comprises mounting the PV module on a simulated roof deck, at a 5/12 pitch. Air is blown across the module and deck surface at a rate of 12 miles per hour, creating very conducive burning conditions. Testing conditions vary according to the flammability rating sought, Class A, B, or C.

Receipt of a Class A rating characterizes the PV module as effective against severe fire exposures. Under such exposures, the PV modules are not readily flammable, afford a fairly high degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands.

Class B rated modules are effective against moderate fire exposures. Under such exposures, the PV modules are not readily flammable, afford a moderate degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands.

Class C rated modules are effective against light fire exposures. Under such exposures, the PV modules are not readily flammable, afford a measurable degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands.[1]

According to UL, the module is mounted to the roof deck in accordance with the module manufacturer's recommendations, as mounting characteristics can dramatically affect the module's flammability resistance. Modules mounted flat on the roof deck are considered the worst case. Other factors such as the superstrate glass thickness, tempering, iron content, and rate of thermal transfer can dramatically affect the module's flammability test results. In modules composed of double glass, meaning superstrate and substrate, a non-tempered glass substrate will break as the encapsulant boils, allowing the encapsulant to drip while flaming, and subsequently cause the module to cave in and fail.

[1]Underwriters Laboratories, Inc., UL790 Tests for Fire Resistance of Roof Covering Materials, October 5, 1983

UL 1703 assumes the module is mounted on top of an existing roof. However, in case of building integrated PV, where the modules become part of the roof covering, i.e., photovoltaic roofing tiles, the PV roof covering shall meet the full requirements of UL 790, the Intermittent-Flame, Spread-of-Flame, Burning-Brand, Flying-Brand, Rain, and Weathering Tests.

Europe

It has been rather difficult to pin down the European community with regard to standards for flammability testing of PV modules. All of the European PV producers contacted were oblivious to flammability test standards for PV modules. The general concerns voiced were to insure that their PV module would not be responsible for the ignition of a building from flying sparks or burning debris coming in contact with their modules.

At the present time a European study of building codes and electrical regulations is in progress within the Joule III PRESCRIPT project. Task 1 of that project includes the definition of test procedures and criteria based on existing building codes and standards. A report is due April 30th.

According to contacts at the European Commission, Joint Research Center, at ISPRA, based on the PRESCRIPT draft documents, which are largely confidential, it appears that five countries, Austria, France, Germany, the Netherlands, and the United Kingdom, are actively developing standards for buildings, to which other European countries refer.

Existing European building codes cover the following areas:

- constructive safety: requirements for resistance to fundamental loads (i.e., ensure that the building stands);
- safety: requirements for fire resistance and definition of fire tests;
- health: requirements for protection against noise, water ingress, moisture, rain, condensation, vermin, etc.;
- energy efficiency: requirements for thermal insulation, energy consumption, etc.

From the PRESCRIPT Task 1 report, the regulatory framework for the European Solar Roof Tile project will be prescribed.

According to contacts at ISPRA, it can be difficult to determine if additional fire safety requirements must be specified for roof-mounted PV modules in Europe. In some cases, if modules are mounted on a roof composed of a fire-resistant material, no additional requirements need to be defined for the modules themselves.

The following European fire safety standards have been identified, although they are not specifically written to include PV modules:

Fire safety standards in the Netherlands are NEN 6063, 6065. The material performance requirements against fire propagation are specified in NEN 6082; and the performance requirements for fire resistance are in NEN 6069. The limits for smoke development are specified in NEN 6066.

In Germany, DIN 4102 is the standard for fire behavior of building materials and components. It defines essential fire resistance requirements and is recommended by the Institut für Bautechnik, Berlin. DIN 4102 part 7 and part 7/A1 (amendment) are specific to roofs. Another standard test method cited for external fire exposure to roofs is DIN EN 1187. As the German building code (BauO) requires buildings to have solid roofs, i.e., roofing that is resistant to fire spread by wind and radiant heat, it appears that no additional fire safety requirements are needed for the solar roof tiles.

In the UK, BS 476 defines a number of tests for fire propagation, non-combustibility, etc.

Japan

Although the information on flammability testing sought for Japan proved rather difficult to obtain, the following test methods were suggested to be in place:

JIS A1312 is the standard test "Method of Fire Test for Roof of Building". The specified tests include a "Heating Test" and "Flying Spark Test". These tests are fundamentally similar to the UL 790 "Spread-of-Flame" and "Burning-Brand" tests, respectively.

This standard assigns one of four flammability ratings, 1st Class, 2nd Class, 3rd Class, or 4th Class; 1st Class being the most flame resistant and 3rd Class offering the lowest allowable resistance to the "Heating Test" while still passing the "Flying Spark Test". A roof covering that fails to pass a 3rd Class "Heating Test", yet passes the "Flying Spark Test" is assigned a 4th Class rating. The standard also includes a "Water Pouring Test" that determines a hot roof covering's ability to be doused with water without breakage or damage which may be regarded as detrimental to fire prevention.

In addition to the roof covering requirements, we were informed by multiple Japanese PV module manufacturers of two characterization requirements. The first requirement is for the PV module components, including encapsulant, to be prepared as a block having specific dimensions. The constructed block cannot contribute to a temperature rise (exotherm) of more than 50°C, when heated in a hot air oven for 20 minutes within a temperature range of 740-760°C.

The second test method cited includes a fireproof test for offices and walls. Under this test, a test sample is constructed from PV modules, having overall dimensions of 900 mm by 1800 mm. The sample is subjected to a hot air exposure, where the hot air is applied to the test specimen, held horizontally, from the reverse side, for a duration of 30 minutes. The test specimen's temperature profile is in accordance with 705°C at 10 minutes, 795°C at 20 minutes and 840°C at 30 minutes. There are two criteria for acceptance or passage. The module must not create a flame from above

(the upper surface). Should a flame be created from below (under surface), it must self extinguish within 10 minutes subsequent to the removal of the hot air source.

New International Standards Under Draft - Project: IEC 61730 Ed.1.0, Working Group 02

In order to clarify the flammability resistance of one manufacturer's PV module to another, the IEC is presently drafting an international standard (IEC 1730) that will characterize the fire behavior of PV modules and PV arrays. It allows for the rating of individual modules with regard to fire-ignitability and fire resistance. It provides for the testing of PV modules to be consistent with those tests performed on other building components.

Under this draft standard, a module's fire resistance will be determined in accordance with ISO 834-1 and ISO 834-3 "Fire Resistance Tests - Elements of Building Construction". The module shall be exposed to a prescribed temperature rise as a function of time. The duration of the test shall be until failure occurs under any of the relevant test requirements, i.e., load bearing capacity, insulation and integrity. The maximum exposure is 360 minutes with a furnace temperature elevation of 1,193°C. The test evaluates the module's ability to fulfill for a stated period of time the required stability, integrity and/or thermal insulation specified in the standard fire resistance test.

The module's reaction to fire will be determined in accordance with ISO 5657 "Reaction to Fire Tests - Ignitability of Building Products Using a Radiant Heat Source". This test method provides for the measurement of the module and its components in contributing, by its own decomposition, to a fire to which it is exposed.

The approach of Draft IEC 1730 is not to define the specific requirements for fire-ignitability or fire resistance, but instead provides for a rating of the PV module's flammability characteristics under standard test conditions. Once the module's performance is qualified, each will be assigned its specific flammability ratings, which shall be carried on the module's label. The actual flammability requirements for building integration or deployment will remain the responsibility of the local community building codes.

PV Module Encapsulants

Several different types of encapsulants have been or are presently deployed in PV modules worldwide. The details of each are discussed as follows:

Silicones

In the early days of Photovoltaics, RTV (room temperature vulcanization) silicones were widely utilized as encapsulants. RTV silicones offer excellent light transmission characteristics in the UV, visible and IR regions of the spectrum. They demonstrate excellent moisture resistance, very low outgassing characteristics, and are inherently flame retardant. However, their disadvantages far outweigh their advantages. RTV silicones are high viscosity liquids and, therefore, presented

tremendous difficulty in handling, mixing, deaerating and charging to the module. Further, they are substantially more expensive (10 to 100X) than alternative encapsulant technologies.

Silicones still find application in non-terrestrial applications, specifically Dow Corning's DC 93500, 2-part dimethyl silicone resin. At present, silicone is the only NASA qualified encapsulant for space environments, passing ASTM E 595-93 "Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment".

Polyvinyl Butyral PVB

Polyvinyl Butyral or PVB was the second generation of PV module encapsulants. It was already proven, used for decades as an interlayer in automotive windshields. It offered good optical properties, at substantially lower pricing than silicone. PVB was the encapsulant of choice during the '70's and early '80's. The downside of PVB was that modules employing PVB as encapsulant suffered weathering/moisture related problems that limited their service life. To the extent of our findings there are no PV module producers worldwide presently employing PVB as encapsulants. PVB offers no flammability resistance properties.

Ethylene Vinyl Acetate Based Encapsulants (EVA)

Ethylene Vinyl Acetate copolymer-based encapsulants or more commonly referred to by the PV community as EVA encapsulants, were developed by Springborn Testing & Research, Inc. (formerly Springborn Laboratories, Inc.). The developments were funded under an 11-year Jet Propulsion Laboratories subcontract, DOE/JPL-954527. The commercial development of EVA-based encapsulants provided for low cost, high reliability and dry fabrication of PV modules.

EVA's fate went through a period of uncertainty during the late '80's and early '90's due to field discoloration noted at multiple PV installations. The subsequent characterization and analysis of the causes of discoloration resulted in stabilization strategies and material enhancements to overcome the noted shortcomings. EVA-based encapsulants are sold as "Standard" and "Fast" curing grades. Though lacking in flame retardency, EVA-based encapsulants accounted for greater than 90% of all PV modules deployed worldwide in 1997.

Typical PV module constructions employing EVA-based encapsulants, comprised of a glass superstrate and flexible polymeric substrate (Tedlar or Tedlar/Polyester/Tedlar laminates), have achieved UL 1703 Class C flammability ratings.

Liquid Encapsulants

In addition to EVA-based encapsulants, three PV module manufacturers were identified who utilize liquid encapsulants in at least some percentage of their modules. Two of the manufacturers maintain their liquid encapsulation technology as proprietary. The third claims to employ a liquid polyurethane system, that is cured thermally. The liquid encapsulants are typically high in

viscosity. The encapsulant is typically pumped into the module with edge seals applied between the rigid superstrate and substrate to hold the encapsulant in place during cure.

It is speculated that one of the proprietary encapsulant technologies is based upon acrylate chemistry, the encapsulant is UV cured. The other proprietary encapsulant system undergoes a thermal cured process, and is suspected to be based upon a polyurethane system, requiring overnight cure.

In all three cases the PV modules are constructed to have a glass superstrate and rigid substrate, glass or other. While none of the encapsulants have flammability resistance, the module construction, a glass superstrate and rigid substrate, lends it self toward achieving a UL 1703 Class A rating.

Ionomer-based Encapsulants (Surlyn)

Ionomer-based encapsulants, or as sometimes referred to by the ionomer's commercial name SurlynTM-based encapsulants, were first introduced into PV modules around 1993. These encapsulants are employed by one U.S.-based PV module manufacturer and are protected under their U.S. Patent 5,478,402, issued on December 26, 1995.

The encapsulant's melting temperature is approximately 30°C higher than that of EVA-based encapsulants. Therefore, unlike EVA-based encapsulants, no crosslinking or cure is required. Typical PV module lamination cycles range from 1 hour or longer at approximately 200°C.

PV modules constructed with ionomer-based encapsulants employ glass superstrates and substrates. Edge sealing is necessary to prevent moisture migration into the module, as the ionomer-based encapsulant is more hygroscopic than other encapsulant technologies. While the clear ionomer-based encapsulant offers no flammability resistance, it is possible to afford some flammability resistance by incorporation of flame retardant additives into the encapsulant layer behind the solar cells. The glass/glass module construction lends itself toward better performance under UL 1703 flammability testing.

Fluoropolymer Based Encapsulants

The idea of fluoropolymer-based encapsulants has been considered for 10 years or more. Resulting from its inert nature, it offers superior chemical and electrical resistance, UV stability, and is inherently flame retardant. The downside has been the cost, with similar pricing to that of silicone resin. There is, however, one European PV module manufacturer employing a fluoropolymer based encapsulant into their PV panels for building-integrated roofing applications, with a demonstration community in Germany. The encapsulant is believed to be based on polytetrafluoroethylene copolymer.

Components of a PV Module

The composition of a PV module is dictated by the module producer, module qualification tests, the end-use application, local building codes and end-user requirements.

Superstrates

The module superstrate must be highly transparent, weatherable, hard, smooth, resistant to soiling and preferably, have the ability to screen out ultraviolet light below 340 nanometers. The superstrate provides the module's first line of defense from degradation and corrosion caused by environmental factors. It provides electrical isolation of the circuit, and it may or may not function to provide mechanical strength to the module. A superstrate must be sufficiently transparent across the spectrum of 340-1200 nanometers to allow at least 90% of the available light to transmit to the solar cells.

A number of superstrates are commonly employed in PV modules. A non-inclusive listing is detailed below:

Tempered Glass (UV Screening)
Tefzel
Tedlar

Tempered Glass (Non-UV Screening)
Polycarbonate

Substrates

While the module substrate has similar demands as the superstrate, it does not normally require the same light transmittance. The substrate provides electrical isolation of the circuit, provides environmental isolation, physical protection (cuts, abrasion, tears, etc.) and infrared emission to lower the module operating temperature. It should be bondable, tough and weatherable. The substrate may or may not function to provide mechanical strength to the module.

A number of substrates have been employed in PV modules. A non-inclusive listing is detailed below:

Float Glass
Tedlar
Tedlar-Aluminum-Tedlar
Tedlar-Polyester-4% EVA Copolymer
Aluminum
Concrete
Epoxy Fiberglass

Tempered Glass
Tedlar-Polyester-Tedlar Laminates
Tedlar-Aluminum-Polyester-Tedlar
Stainless Steel
Rigid Plastic Sheeting
Slate
PVC Foam

Encapsulant

The PV module's encapsulant is a transparent organic material that demonstrates elastomeric properties. There is a significant difference between the thermal-expansion coefficients of

polymeric materials and the solar cells and metallic interconnects. Stresses developed from the daily thermal cycles can result in fractured cells, broken interconnects or cracks and separation in the encapsulant material. To avoid these problems, the encapsulant must adhere to all contacted surfaces, it must accommodate the differential expansion of the various module materials without over-stressing the cell and interconnects and must be resistant to fracture. The encapsulant must be a low-modulus, elastomeric material (e.g., less than 3000 psi).[2]

A number of encapsulants have been employed in PV modules. A non-inclusive listing is detailed below:

Dry Encapsulants

EVA-based
Ionomer-based
Fluoropolymer
Polyvinyl Butyral

Wet Encapsulants

Proprietary Liquid Encapsulants
Silicone
Polyurethane

Fabrication of a PV Module

While there are several novel techniques used in the lamination of PV modules, regardless of composition, they are all fundamental to the same principle. The thorough evacuation of air from the interior of the module and its displacement with a protective encapsulant. Typical examples of the PV module's laminate composition are detailed below:

Typical PV Module Constructions

Crystalline & Polycrystalline PV Modules - Excluding Frames

Flexible Superstrate and Substrate

[2]Cuddihy, E., Coulbert, C., Gupta, A., Liang, R., Electricity for Photovoltaic Solar Cells Flat-Plate Solar Array Project Final Report, Volume VII: Module Encapsulation, JPL Publication 86-31, October 1986

Thin Film PV Modules - Excluding Frames

Of course, the actual module fabrication process is dependent on the physical nature of the encapsulant employed, whether it is dry or wet. In the cases of dry lamination, the encapsulant is first laid up into the module's construction in a flexible sheet form. The actual encapsulation of the module involves evacuating the air from within the module, simultaneously melting the encapsulant, followed by compression of the area between the superstrate and substrate. The compression forces the molten encapsulant to flow, filling all voids between the superstrate and substrate. The prevalent lamination process employs a vacuum laminator.

A vacuum laminator consists of a double sectioned "picture frame" enclosed on the top with a metal plate and a heated platen on the bottom. A flexible diaphragm separates the upper and lower chambers. Both chambers are equipped for controlled air evacuation and return to atmospheric conditions. While the top chamber is permanently fixed, the bottom chamber is formed on closure of the laminator, i.e., the bottom portion of the picture frame contacts the heated platen over a silicone rubber gasket to form an airtight seal. It is within this bottom chamber that PV module lamination occurs. Typical dry lamination consists of the following sequence:

1. Loading of the preassembled, stacked PV module components into the lower chamber.
2. Evacuation of the air from both the top and bottom chambers.
3. Heating of the PV module assembly, thus initiating melting of the encapsulant.
4. Once sufficiently deaerated to 1 Torr or less pressure, and the encapsulant is sufficiently softened, the top chamber is repressurized by releasing the vacuum, thus causing the diaphragm to place a load on the PV module assembly.
5. The PV module assembly is heated until the time and temperature exposures are sufficient to result in complete curing when applicable.
6. Once completed in the case of cured encapsulants, the module can be immediately removed from the laminator. In some cases, the module may be laminated (deaerated and melted) then removed from the laminator and post-cured in an oven.

The operation permits the PV module assembly to be continuously evacuated throughout the entire lamination process for removal of air and volatiles. The repressurization of the upper chamber in step 4 places a load on the module to prevent bubble formation and encapsulant movement.[3]

Encapsulant Costs

While the relative cost of one encapsulant system to another has already been addressed, it is important to note the percentage of module cost attributed to the encapsulant. In the case of an EVA-based encapsulant employed in crystalline and polycrystalline silicone modules, the encapsulant cost is approximately 1.75-2.5% of the overall module cost.

Task 2: Product Conceptual Design

As a result of the Task 1 efforts, STR has conceptualized the development of three PV module construction components which will provide significantly greater flammability resistance to PV modules. Two products are alternative PV module encapsulants that are flame retardant. The first will offer good light transmission characteristics from 340-1200 nanometers, i.e., will be optically transparent. The second will be opaque, for employment behind the solar cells. The third product is the invention of a very low cost flame retardant backsheet, for substitution of the more expensive substrates presently employed by PV modules, many of which burn. These concepts address the problem that existing encapsulant systems provide a fuel source during combustion.

Five generic configurations for implementation of improved flame retardancy for photovoltaic solar modules are conceived. Four add varying degrees of cost to module fabrication, while the fifth reduces cost. However, it's possible that through slight downgauging of products associated with the other four configurations or through the re-engineering of manufacturing procedures, others of the five could offer the same cost savings. Full assessment of the cost efficacy and improved performance of the other four configurations represents considerable effort, and will be addressed in the Phase 2 effort.

CONFIGURATION 1. Utilization of the optically transparent FR encapsulant, employing conventional superstrates and substrates. The encapsulant will be appropriate for use both in front of and behind the solar cells within a module. Its usage will likely be limited to crystalline and polycrystalline modules as the optical quality of the encapsulant in front of the cells is critical. *(Most thin film modules utilize a single layer of encapsulant behind the cells; therefore, optical transmission of the encapsulant is not important.)*

It is projected that the optically transparent FR encapsulant will sell for approximately \$1.00 per square foot on average. This construction, while expected to impart a UL 1703 Class A rated flammability resistance, will increase a finished module's cost by approximately 3 %.

[3]STR Photocap Solar Cell Encapsulants Technical Guide, July 1997

CONFIGURATION 2. The utilization of an opaque FR encapsulant behind the solar cells, employing conventional module superstrates and substrates. The envisaged encapsulant will be appropriate for use behind the solar cells of thin film, crystalline and polycrystalline modules. Assuming a conventional flammable encapsulant is employed in front of the cells, we foresee the rear encapsulant containing the flammable encapsulant between itself and the superstrate on exposure to fire.

It is projected that the opaque FR encapsulant will sell for approximately \$0.60 per square foot on average. This construction, while expected to impart substantially improved flammability resistance, will increase a finished module's cost by approximately 1 percent.

CONFIGURATION 3. The utilization of the optically transparent FR encapsulants from Configuration 1 in conjunction with the envisioned low cost flame retardant backsheet or substrate. This flame retardant encapsulant system including backsheet can be used in crystalline and polycrystalline modules both in front of and behind the solar cells. The FR backsheet will serve as the module's substrate. It is anticipated that this construction, which most resembles conventional module fabrication, will provide for achievement of a UL 1703 Class A flammability rating.

Pricing for the optically transparent FR encapsulant will average approximately \$1.00 per square foot, while a 5 mil thick FR backsheet will sell for approximately \$0.10 per square foot. This construction with its excellent flammability resistance, will likely increase the finished module's cost by approximately 1.4 percent.

CONFIGURATION 4. The utilization of an optically transparent FR encapsulant in front of the solar cells, with an opaque FR encapsulant employed behind the cells. The opaque encapsulant will be laminated to a 5 mil FR backsheet. Normal superstrates are employed. This is actually the ultimate version for flame retardancy. A UL 1703 Class A rating is certainly anticipated.

Pricing for the optically transparent FR encapsulant will be approximately \$1.00 per square foot; the opaque encapsulant approximately \$0.60 per square foot; and the 5 mil thick FR backsheet approximately \$0.10 per square foot. This construction with its excellent flammability resistance, will likely increase the finished module's cost by approximately 0.6 percent.

CONFIGURATION 5. The utilization of a glass superstrate and normal top layer of encapsulant above the solar cells. The opaque FR encapsulant will be employed behind the solar cells laminated to a 5 mil FR backsheet. A minimum UL 1703 Class B rating is certainly anticipated, but it is more likely a Class A rating will be achieved.

Pricing for the opaque encapsulant will be approximately \$0.60 per square foot and the 5 mil thick FR backsheet, approximately \$0.10 per square foot. This module's construction with its improved flammability resistance, should actually decrease the finished module's cost by approximately 0.6 percent.

These five configurations are illustrated in Figure 1.

A techno-economic assessment of these options is provided in Table 1.

Cost comparisons in Configurations 1 through 4 are predicated, for the moment, on use of FR modified EVA films equivalent in thickness to that current in use. It may be possible to modify thickness and achieve further manufacturing economies.

<p align="center">Table 1. Techno-economic Assessment</p>				
Configuration	Modifications to Current System(s)	Envisaged Module Performance	Envisaged Costs	Comments
1	Optically clear FR EVA employed in front of and behind solar cells	will be high in flammability resistance may be deficient in light transmission to the cells	\$1.00 on average, per square foot; increases total crystalline PV module cost ~3%	Appropriate for employment behind glass or flexible superstrates. For use in crystalline and polycrystalline PV modules
2	Opaque FR encapsulant employed behind solar cells	will be high in flammability resistance may be deficient in achieving Class A rating	\$0.60 on average per square foot; increases total crystalline PV module cost ~ 1%	Appropriate for employment behind solar cells. For use in thin film, crystalline and polycrystalline modules
3	Optically clear FR EVA encapsulant plus FR backsheet	will be high in flammability resistance and resemblance to traditional PV modules may be deficient in light transmission to the cells	\$1.00 on average per square foot of encapsulant; \$0.10 on average per square foot of 5 mil backsheet increases total crystalline PV module cost ~1.4%	Should qualify for a UL 1703 Class A flammability resistance rating
4	Optically clear FR EVA frontsheet, opaque FR backsheet laminated to FR backsheet	will be high in flammability resistance and cost performance may be deficient in light transmission to the cells	Increases the total crystalline PV module cost by ~ 0.6%	A cost-effective PV module construction for achieving a UL 1703 Class A flammability resistance rating
5	Opaque FR encapsulant with FR backsheet	will be high in flammability resistance and cost performance may be deficient in achieving a Class A flammability resistance rating	Decreases the total crystalline PV Module cost by ~ 0.6%.	The most cost-effective PV module construction. May or may not achieve a UL 1703 Class A rating, but certainly a Class B rating should be achievable

Reasonable expectations for an improved flame retardant PV system are outlined in Table 2.

<p align="center">Table 2. Expectations of the Improved Flame Retardant PV System</p>		
Attribute	Minimum Level of Performance	Target Level of Performance
ignitability	UL 94V-2	UL 94 V0 or 5V
flame spread	UL 94V-2	UL 94 V0 or 5V
quantity of smoke generation	will not be specified	will not be specified
optical density (obscurity) of generated smoke	will not be specified	will not be specified
toxicity or corrosivity of generated smoke	will not be specified	will not be specified
processability	slight to moderate increase in difficulty of plastics processing	no change in plastics processing
mechanical properties of FR polymer	slightly embrittled or slightly prone to blooming with long-term service, especially at elevated temperatures	no embrittlement or blooming on long-term service
permanence or durability of FR modified material	slight propensities to hydrolytic or thermal degradation, or slight blooming of additives, or slight delamination with time (especially at higher temps) of FR modified polymer	no degradation of FR performance or adherability of FR modified materials with time or with variations in product moisture content
heat generation during combustion	heat release rate is reduced from that of the non-FR polymers	heat release rate is greatly reduced from that of the non-FR polymers
interlaminar adhesion characteristics for FR modified module	minimal degradation of adhesion with high temperature and/or high humidity exposure of PV module, as measured by visible delamination	no degradation of adhesion with high temperature and/or high humidity exposure of PV module, as measured by visible delamination

Polymers can often be flame retarded through addition of either halogenated or non-halogenated species. STR contends, considering product requirements, there need not be restrictions on considering use of halogenated additives or species for achieving the desired higher level of flame retardancy. Many, if not most, cost-effective polymeric flame retardant products currently in the market utilize halogenated species, and their associated proven technologies, for achieving or improving flame retardancy. While FR product development based on wholly halogen-free constituents is a worthy objective, there are significant difficulties associated with implementation in a manner that satisfies all requirements.

Task 3: Market Assessment

In order to determine the market potential for fire retardant photovoltaic modules, and eventually the market potential for fire retardant ethylene vinyl acetate encapsulated photovoltaic modules, we first undertook a review of the current worldwide PV module market and its drivers. Our research in Task 1 showed that several manufacturers were indeed making fire retardant PV modules, and we opined that at least through the year 2010, fire retardant PV will continue to claim not the overall market, but a growing percentage of it. Thus, we felt it vital to determine

expected shipments for the full PV market through the year 2010. This review is covered below under "I. Current PV Market Situation Analysis" and "II. PV Module Market Forecast."

Next, we compiled a list of 53 active or soon-to-be active module manufacturers worldwide, and contacted each. All were asked to confirm any previously reported production figures and intentions, and for their current and anticipated fire retardant module production figures. This dialogue, which in many cases introduced a topic that had not been considered before, provided the material for the bulk of our analysis. In brief, this task confirms current production figures, provides future expected production figures for PV modules and fire retardant PV modules, examines the market potential for fire retardant EVA and any competing technologies, and notes those end-uses which hold the most potential for fire retardant PV.

I. Current PV Market Situation Analysis

A. Present and Historical World Production

World PV cell/module shipments advanced by a huge 42 percent last year to 125.8 megawatts, according to Photovoltaic News. Credited were huge increases in new plant capacities, and the expanded grid-connected markets in Japan and Europe. Shipments were up by 31 percent in the United States, 65 percent in Japan, and 60 percent in Europe. The Rest of World shipments declined from 9.8 MW in 1996 to 9.4 MW in 1997⁴.

Table 3. World Photovoltaic Cell/Module Shipments (MW)⁵							
	1991	1992	1993	1994	1995	1996	1997
U.S.	17.1	18.1	22.4	25.6	34.8	38.9	51
Japan	19.9	18.8	16.7	16.5	16.4	21.2	35
Europe	13.4	16.4	16.6	21.7	20.1	18.8	30.4
Rest of World	5	4.6	4.4	5.6	6.3	9.8	9.4
Total	55.4	57.9	60.1	69.4	77.6	88.6	125.8

However, when the 7.1 MW of amorphous silicon cells produced for the consumer products market, and all of the consumer-oriented cadmium telluride cells are removed from the 1997 total, 118.7 MW of terrestrial power cells remain⁶.

B. Growth Factors

But what factors are prompting this strong growth?

⁴Paul D. Maycock, "World PV News," Photovoltaic News, Vol. 17, No. 2 (February 1998), pp. 1-6.

⁵Ibid.

⁶Ibid.

In its on-line literature, Spire Corporation, a manufacturer of PV manufacturing equipment, notes, world PV market growth is driven by needs for telecommunications and village power. It is forecasting gains of 15-25 percent annually for the indefinite future. "PV will be a billion-dollar industry in 1997 and perhaps a \$10 billion industry by 2005 if U.S. utility-driven initiatives take hold⁷."

We have identified three major industry growth drivers, two of which were touched upon by Spire Corporation: the developing world; government and utility initiatives; and module and system cost reductions.

The Developing World

According to PV systems supplier and installer Northern Arizona Wind & Sun, "It [photovoltaic power] makes sense for remote sites that are too far from power, or where the power is too unreliable. Costs for power lines range from \$8,000 to \$45,000 per mile. As a general rule, if you are more than 1/2 mile from a line, solar is probably the best alternative." "It may also make sense in areas that have grid power, but where the cost of tearing up the streets and/or other construction are expensive. Examples are bus stop shelters, storage yard lighting, rail signals, and cell phone transmitters." However, "It does not make sense in a typical residence or business that is connected to regular grid power. The installation costs are far too high, and the payback is 15 to 25 years, assuming no maintenance⁸."

The American Solar Energy Society reported that there are 2 billion people around the world that lack electric power. This is 70 percent of the population in the developing world. As such, the World Bank expects that the developing countries will invest \$1 trillion in new power systems by the year 2000⁹.

Commented the Solar Energy Industries Association (SEIA), the U.S. trade association representing commercial enterprises involved in solar energy, "If photovoltaics (solar cells) were used for just 10% of new electricity generation outside the U.S., industry revenue would amount to approximately \$13 billion per year." And, "There will be over 900,000 megawatts in new energy needs in countries where solar could compete over the next 15-20 years. Capturing just 2% of this market would create \$20 billion in projects¹⁰."

The Utility Photovoltaic Group (UPVG) agrees. "After studying market potential in 84 developing countries, UPVG estimated that these countries represent an aggregate market of 300-320 megawatts just over the next five years--a total market value of \$900-\$960 million at \$3 a watt. The biggest markets for PV are in Asia and Latin America, according to James E.

⁷Spire Corporation Web Site, <http://www.spirecorp.com/pv.htm>, pp. 1-2.

⁸Northern Arizona Wind & Sun Web Site, http://www.windsun.com/PV_Stuff/solar_FAQ.htm, p. 2.

⁹The American Solar Energy Society Web Site, <http://www.sni.net/solar/fbmao.htm>, p. 2.

¹⁰Solar Energy Industries Association Web Site, <http://www.seia.org/sf/sfintl.htm>, p. 1.

Rannels, director of DOE's National Photovoltaic Program. China, India, Indonesia, Vietnam, Mexico, and Brazil have large market potential, as do Kenya and South Africa¹¹."

Government and Utility Initiatives

In its "1997 World PV Cell/Module Shipments Survey," Photovoltaic News claimed that the 42 percent gain in shipments for 1997 "was shared equally between the normal off-grid applications and the emerging, heavily subsidized grid connected and building integrated markets in Japan." This was the second year in a row that all of the Japanese manufacturing capacity growth was used to serve the subsidized "70,000 roofs" and "Institutional/Schools/Local Government" programs¹².

A brief overview of programs underway or proposed for each country follows.

Brazil--CEPEL has committed to a long-term, multi-MW national PV rural electrification program. Awards were to be made in 1997¹³.

Denmark--The Danish environment ministry is to offer subsidies of up to 30 percent on the costs incurred by industry and business in the installation of solar power cells. About \$143 million has been allocated, mainly from energy tax revenues¹⁴.

Germany--Germany's national budget for PV in 1996 was \$55 million¹⁵. Cities across the country are also offering rate-based incentives of 2 DM/kWh for all PV power fed back into the grid. The program, begun in earnest in 1996, is funded by a 1 percent surcharge on electricity bills. It "is expected to create 10 MWp of photovoltaic market volume by year-end 1998"¹⁶.

India--The Indian government is upping production and intends to become a major world producer of PV modules. It is planning to power 100,000 villages with renewable energy, primarily PV modules, and will install solar powered telephones in every one of its 500,000 villages¹⁷. Indian producers claimed 5.2 MW of production for 1997¹⁸.

Japan--The country's PV budget has been increased by at least 15 percent/year since 1992, and at \$130 million for 1996 its budget was over twice that of the U.S.¹⁹. The country's Ministry of

¹¹John J. Berger, Ph.D., CHARGING AHEAD: The Business of Renewable Energy and What it Means for America, (Henry Holt and Company, May 1997), BCC Web Site, <http://www.buscom.com/enerzine/html/solar.html>, p. 1.

¹²Maycock, op. cit., pp. 1, 5.

¹³Applied Power Corporation Web Site, http://www.appliedpower.com/support/GSA_center/international.htm, p. 1.

¹⁴"Solar cell subsidies/production hikes," European Chemical News, February 9-15, 1998, p. 24.

¹⁵Solar Energy Industries Association Web Site, <http://www.seia.org/sf/sfpv.htm>, p. 1.

¹⁶Applied Power Corporation Web Site, loc. cit.

¹⁷The American Solar Energy Society Web Site, op. cit., p. 4.

¹⁸Maycock, op. cit., p. 6.

¹⁹Solar Energy Industries Association Web Site, <http://www.seia.org/sf/sfpv.htm>, p. 1.

International Trade and Industry has also developed the largest PV program in history, offering subsidies of up to 50 percent of the total installed cost for a residential rooftop PV system. A total of 12 MW were installed during 1996, and 33 MW were planned for installation last year²⁰. However, only about half the total planned installations for 1997 were accomplished²¹.

Mexico--Mexico plans to electrify 60,000 villages using PV by the year 2000²².

Netherlands--In the central Dutch town of Amersfoort, authorities are initiating a new housing project that will install 1.5 MW of capacity, or 15,000 panels. The first houses were to go up in March 1998²³.

Switzerland--The utility EWZ has begun a solar stock exchange program where customers volunteer to buy a block of PV power. The contributions are aggregated, and the PV systems put out to bid. Installations are expected to amount to 0.5 MW over the first 18 months of the program²⁴.

Also, the Swiss government's "Energy 2000" project, which is being funded at \$200 million/year through the year 2000, takes in PV and wind-powered pilot projects. Some \$40 million is available per year to finance these alternative power projects²⁵.

United Kingdom--The United Kingdom's "Scholar Programme" is a series of research and development programs designed to lead to PV installations on 100 schools and colleges across the country. Participating schools have to raise 35 percent of the cost of one of three styles of grid-connected PV systems: a canopied walkway, an entrance atrium, or a standard structure on a wall or roof. The £2.5 million program is receiving £1 million in support from the government's "Technology Foresight Challenge"²⁶.

United States--For 1996, California's Sacramento Municipal Utility District (SMUD) expected to acquire an additional 750 kilowatts of PV, of which "somewhere between 100 and 200 kilowatts will be from building-integrated systems"²⁷.

²⁰Applied Power Corporation Web Site, loc. cit.

²¹Paul D. Maycock, "Japanese PV Capital Expansion Plans Top 200 MW By 2000," Photovoltaic News, Vol. 17, No. 1 (January 1998), pp. 5-6.

²²The American Solar Energy Society Web Site, op. cit., p. 4.

²³Philip Blenkinsop, "Shell takes initial steps into solar dawn," Nando Times, December 22, 1997, Nando Times Web Site, http://wedge.nando.net/newsroom/ntn/health/122297/health22_15467_body.html, p. 2.

²⁴Applied Power Corporation Web Site, loc. cit.

²⁵Werner E. Wiedmer, "Switzerland: Renewable Energy Equipment Market," May 1997, Web Site, http://www.cleanenergy.de/News_archive/01_06_97/130697_4.html, p. 1.

²⁶"The United Kingdom's first solar...", The UPVG Record, Spring 1997, Web Site, <http://www.ttcorp.com/upvg/record/rc197par.htm>, p. 2.

²⁷Judith Anne Gunther, "Who needs a roof? Cover your house with solar cells instead., Web Site, <http://juniper.tamu.edu/HOMEPAGE/JFOY/psmay96.htm>, pp. 4-5.

The 82-member UPVG has also launched an industry-government collaboration, known as "Project TEAM-UP." The program is to provide \$500 million to utilities over a six-year period to purchase 50 MW of solar generating capacity²⁸.

Most recently, President Clinton introduced the "Million Solar Roofs Initiative." This is a national plan to put solar electric systems on one million American roofs by 2010. According to PV system integrator the Applied Power Corporation, "The proposal is founded on four key components: leveraging existing government programs to place solar on federal buildings; low-interest financing for homeowners and businesses; advocacy of net metering laws to allow homeowners to feed solar power back into the grid and essentially run their meter backwards by selling the power back to the utility at retail rates; and the potential formation of a national renewable energy trust providing 'greenback' incentives to solar customers²⁹." The federal commitment is to install solar electric and solar thermal energy systems on 20,000 federal buildings by 2010³⁰.

Global Environment Facility--This joint funding program of the United Nations and the World Bank has set aside \$400 million in loans and grants for solar and other renewable energy. It is expected to translate into \$2-\$4 billion in projects over the next few years³¹.

PV Module and System Cost Reductions

Equally important to the success of PV energy, but of a longer-term nature, is the impact the decreasing price of modules has on overall demand. Costs have been reduced by increased module efficiencies and production economies of scale. However, they are being negatively impacted by unsecured silicon supplies.

The UPVG estimated, "industrywide, each time cell sales double, costs fall by 20-25 percent. ... During the technology's short history--despite vacillating government support--PV module costs have already plummeted from \$1,000 per peak watt in the 1950s to about \$4 per peak watt in 1996. Costs of \$3 per peak watt had been expected this year [1997] but a short-term shortage in solar-grade silicon supplies has caused a slight reversal in cell costs in 1997³²."

"The UPVG regards \$3 per peak watt as a probable threshold for PV to enter new markets. According to a UPVG study, 'Photovoltaics: On the verge of Commercialization,' at \$3 per peak watt, the potential exists for nearly 9,000 megawatts in near-term domestic PV sales in some 10 specific U.S. markets and represents potential revenues of \$27 billion³³."

²⁸Berger, op. cit., p. 2.

²⁹Applied Power Corporation Web Site,

http://www.appliedpower.com/support/GSA_center/U.S._nat_prog.htm, p. 1.

³⁰U.S. Department of Energy Web Site, <http://www.eren.doe.gov/millionroofs/faq.html>, p. 5.

³¹Solar Energy Industries Association Web Site, <http://www.seia.org/sf/sfintl.htm>, p. 1.

³²Berger, op. cit., p. 1.

³³Ibid.

Northern Arizona Wind & Sun reported that costs have been dropping about 2-4 percent/year (adjusted for inflation). "Solar panels represent about 50% of the installed original cost for a system, but batteries represent about 50-60% of the long term costs (20 years). Skimping on batteries and charge controls will reduce up front costs, but increase the long term costs. With the improved batteries and controls available now, the long term costs are about 20% less than 5 years ago, due mainly to longer life and less maintenance³⁴."

Looking at PV modules, the main cost is in the production of pure silicon for the cells. "If a method is found to drastically reduce these costs, then you might see a 10 to 20% reduction, continues Northern Arizona Wind & Sun³⁵." "Each 10 by 10 centimeter cell costs about \$3, some 35-40 percent of the final cost³⁶."

Shell Solar's president, Gosse Boxhoorn, said the main problem is that silicon wafer producers currently use scrap material from the semiconductor industry. "The quality is needlessly high, but they still have to compete with the computer sector. 'There is no solar-grade silicon, because there is no market, so we have to pay the semiconductor prices,' he says." He believes silicon production for the solar sector is at least three to four years off, but said when it does arrive it could cut silicon prices by 30-40 percent³⁷. Prices for solar-grade silicon rose by as much as 400 percent for some contracts between 1993 and 1996³⁸.

Thus, getting a grip on the silicon problem and embracing automation could bring prices down to 30-40 cents per kWh, according to Boxhoorn³⁹.

A quick review of world PV module price and shipment trends highlights the effect of price reductions on shipments.

Growth Factor Market Dynamics

Each of the above discussed Growth Factors is expected to continue playing a major role in the development of the world PV market, at least through the year 2010. While The Developing World holds great promise and opportunity for installations, Government and Utility Initiatives have in the past had and will continue to have the most impact on the developed countries. In fact, the latter has resulted in much of today's "artificial market." But, it is the last Growth Factor, PV Module and System Cost Reductions, which will have the greatest impact on the market's long-term success. Government and Utility Initiatives are necessary for the development of solar power and for it to gain a major foothold, but will not sustain the market over the long haul. Inevitably, this immature industry will need to secure the necessary raw material supplies and embrace the technologies which raise the competitiveness of solar power.

³⁴Northern Arizona Wind & Sun Web Site, op. cit., p. 3.

³⁵Ibid.

³⁶Blenkinsop, loc. cit.

³⁷Ibid., pp. 2-3.

³⁸Berger, op. cit., p. 5.

³⁹Blenkinsop, op. cit., p. 3.

Table 4⁴⁰.

Price Table

Shipment Table

II. PV Module Production Forecast for 2000, 2005, 2010

A. Industry Expectations

Industry growth forecasts range from 15-30 percent per year--estimates not totally out of the ballpark considering that world shipments were up by 42 percent last year, and by 15.5 percent from 1995 to 1996⁴¹. Shipments are used as a basis for demand/consumption, as modules are generally made to order.

In a paper presented at the UPVG Utility PV Experience Conference, held in Lakewood, Colorado, in October 1996, D. Osborn and D. Collier noted, "Conventional business-as-usual market forecasts to 2010 estimate 830 MWp annual photovoltaic sales (including only 60 MWp for on-grid central stations) resulting in world-wide sales of \$8-10 billion⁴²."

Shell Solar also recently noted it is looking to take 10 percent of the solar cell market, which it estimates is set to grow by 15 percent/year⁴³.

Similarly, Bayer Solar sees the world PV market growing by about 20 percent/year. It is spending \$19.5 million to increase production of silicon wafers at its Freiberg, Germany, plant to 16M/year

⁴⁰Glenn Hasek, "Solar Shines Brighter," Industry Week, April, 20, 1998, p. 26 (table credited to Paul D. Maycock, Photovoltaic News).

⁴¹Paul D. Maycock, "1996 World PV Cell Shipments Up 15.5% To 89.6 MW," Photovoltaic News, Vol. 16, No. 2 (February 1997), p. 1.

⁴²D. Osborn and D. Collier, "Utility grid-connected photovoltaic distributed power systems," UPVG Utility PV Experience Conference, Lakewood, Colorado, USA, October 1996.

⁴³Blenkinsop, op. cit., p. 1.

by the year 2000. Current production at the facility is 6M/year, and Bayer holds 10 percent of the world market⁴⁴.

By region, Solar Europe is forecasting that European PV cell production could exceed 100 MW/year by the year 2000⁴⁵. And, the publication PV Activities in Japan expects capital expansion plans in Japan to reach 200 MW by 2000⁴⁶. In the U.S., "The proposed tax credit [Al Gore's], coupled with 'Green Pricing,' pro-renewable programs in some state utility deregulation programs, and the potential cost reductions resulting from new thin film plants would virtually assure an American 100 MW+ per year market for grid-connected domestic PV rooftop systems in the next 3-5 years. Even without the proposed tax credit, these market sectors could soon be the largest PV market sector in the United States⁴⁷."

B. Forecast Methodology

We decided that the best way to determine future production intentions and confirm current and past figures was to ask the manufacturers. Beginning with PV News' producer list and production figures, we added manufacturers from Gridwatch.com's "Global Power Directory" of PV module manufacturers⁴⁸, from a smaller list of module manufacturers retrieved from the Internet⁴⁹, and from our in-house files. Next, we inserted any production figures and expansion plan mentions that we had run across during our initial literature search, and had our in-house experts narrow down the list to current and anticipated manufacturers. Our final list included 53 manufacturers.

With list in hand, we then developed a two-page survey, an introductory letter explaining our project and the factors prompting it, and literature on our five conceptualized EVA encapsulant products and their economics. The personalized surveys asked each to verify their current production figures and any noted expansion plans. Also, we asked for company shipment forecasts for the years 1998, 2000, 2005, and 2010, and inquired as to whether any current production meets UL 1703 Class A or JIS A132 fire resistance standards.

Then, we asked about each company's future fire retardant PV production intentions, solicited suggestions on how to achieve module fire retardance, asked about the types of end-uses which would most benefit from fire retardant PV, and finally inquired about their interest in fire retardant EVA encapsulants. Each company was initially contacted by telephone so that the project could be explained, and the name and contact numbers for the proper recipient gathered. Then the nine-page survey packet was faxed to each intended recipient's attention.

⁴⁴"Bayer Solar is shining," European Chemical News, February 9-15, 1998, p. 29.

⁴⁵Paul D. Maycock, "European PV Production To Exceed 100 MW/Year By 2000," Photovoltaic News, Vol. 17, No. 1 (January 1998), p. 5.

⁴⁶Paul D. Maycock, "Japanese PV Capital Expansion Plans Top 200 MW By 2000," Photovoltaic News, Vol. 17, No. 1 (January 1998), pp. 5-6.

⁴⁷Paul D. Maycock, "Gore Announces Solar Tax Credits," Photovoltaic News, Vol. 17, No. 3 (March 1998), p. 1.

⁴⁸Gridwise Engineering Company Web Site, <http://www.gridwatch.com/guide/solar/manufacturers.html>, pp. 1-9.

⁴⁹Georgia Tech Web Site, <http://www.ece.gatech.edu/users/2648/ModManuf.html>, p. 1.

Approximately one week after making our initial phone and fax calls, follow up calls were made and faxes sent. This contact continued until a formal response was received. The final response tally was 49, with only three of the 49 declining to participate. The remaining four manufacturers had agreed to participate, but their responses were not received in time to make the final report. None of the non-respondents are or are expected to become substantial producers in the near-term.

Manufacturer responses were next compiled into a report for review by our in-house experts. Numbers were examined for basic feasibility, and verified and adjusted accordingly where necessary. Also, any missing statistics were input at this time, and incomplete forecasts were carried out through the year 2010. For incomplete areas, a percentage of growth method was used.

One notable finding at this time was that a number of manufacturers voluntarily reduced their historical production figures, which resulted in a lowering of regional and worldwide production from the volumes reported by Paul Maycock in Photovoltaic News. We opted not to adjust the Photovoltaic News table appearing under "I. Current PV Market Situation Analysis, A. Present and Historical World Production," as Mr. Maycock's annual reports have long been accepted and endorsed by most industry players, and reasonably reflect industry production trends. However, our "Current and Anticipated Module Shipments (MW)" table on the next page does reflect these changes.

Once all of these adjusted statistics were in place, we tallied up the numbers for each region, and the world. These numbers were then reexamined by our in-house experts for feasibility, and in many cases revised downward. The general feeling was that in several cases manufacturers were confusing capacity with production, and that in some the forecasts were simply wishful thinking. The downward adjustment was as high as 40 percent in some regions, particularly for the later periods.

C. PV Module Shipments and Market Forecast

Contacted Were:

U.S. - ASE Americas/ASE GmbH; AstroPower, Inc.; Atlantis Energy, Inc.; Ebara Solar, Inc.; Energy Photovoltaics; Evergreen Solar, Inc.; Iowa Thin Film Technologies, Inc.; Photocomm/Golden Genesis; Siemens Solar Industries; Solar Cells, Inc.; Solarex Corp.; Solec International; United Solar Systems Corp.

Europe - Antec-Solar (Germany); Atersa (Spain); bmc Solar Industrie GmbH (Germany); BP Solar (United Kingdom); Dunasolar Photovoltaics, Inc. (Hungary); E.N.E., S.A. (Belgium); Eurosolare S.p.A. (Italy); Gallivare Photovoltaic (Sweden); Helios Technology S.r.l. (Italy); ICEC AG (Switzerland); Intersolar Group Ltd. (United Kingdom); Isofoton S.A. (Spain); Koncar Solar Cells (Croatia); NAPS Solartron Manufacturing Co. Ltd. (Finland); Photowatt International S.A. (France); Pilkington Solar GmbH (Germany); Rap Mikrosysteme GmbH (Germany); Shell Solar Energy B.V. (The Netherlands); Solarnova Solartechnik GmbH & Co., KG (Germany);

Solar Power Ltd. (Malta); Solartec s.r.o. (Czech Republic); Solon AG (Germany); Vegla Vereinigte Glaswerke GmbH (Germany); Webasto Systemkomponenten GmbH & Co. KG (Germany).

Japan - Canon Business Machines, Inc.; Daido Hoxan Inc.; Fuji Electric; Kaneka Corporation; Kyocera Corporation; Mitsubishi Electric; Sanyo Electric Co., Ltd.; Sekisui Engineering Co., Ltd.; Sharp Corporation; Showa Shell Sekiyu K.K.

Rest of World - China Photovoltaic Technology Development Centre (China); Ever Step Development Ltd. (Hong Kong); LG Industrial Systems Co., Ltd. (Korea); Samsung Advanced Institute of Technology (Korea); Sinomar (Taiwan); Star Power International Ltd. (Hong Kong).

Please also note that we placed each company under the region heading in which it is headquartered. Therefore, regional totals are not necessarily based on actual production in a region, but refer to the production totals for the companies headquartered in that region.

Table 5. Current and Anticipated Module Shipments (MW)							
	1995	1996	1997	1998	2000	2005	2010
U.S.	27.5	29.3	41.6	58.2	105.7	277.1	691.9
Europe	17.7	18.7	35.4	49.6	104.7	252.7	587.6
Japan	15.9	20	32.2	45.1	110.4	255.6	754.1
Rest of World	5.5	9.5	9.2	12.9	17	34.3	68.9
World Total	66.6	77.5	118.4	165.8	337.8	819.7	2,102.5

Estimated worldwide gains are: 40 percent for this year, followed by a 43 percent/year gain for the period 1999-2000, then a 19 percent/year increase for the period 2001-2005. The years 2006-2010 will see an average annual gain of 21 percent/year. Average annual growth over the period 1998-2010 will be around 25 percent/year.

Regionally, manufacturers in each of the world's regions will see a 40 percent gain this year. It appears that all are taking last year's huge 42 percent worldwide gain, as reported by Paul Maycock in Photovoltaic News, to heart.

Then over the period 1999-2000, Japanese manufacturers will see shipments advance by 56 percent/year, while European shipments will grow by 45 percent/year. U.S. shipments will follow at 35 percent/year, and Rest of World shipments at 15 percent/year.

For the years 2001-2005, U.S. manufacturers will grow shipments by 21 percent/year, followed by European manufacturers at 19 percent/year, Japanese manufacturers at 18 percent/year, and Rest of World manufacturers at 15 percent/year.

Then for the period 2006-2010, Japanese manufacturers will boost production by 24 percent/year, U.S. manufacturers by 20 percent/year, European manufacturers by 18 percent/year, and Rest of World manufacturers by 15 percent/year.

III. Fire Retardant PV Module Production Forecast for 2000, 2005, 2010

A. Why Flame Retardant PV?

The increased popularity of PV systems, spurred by government and utility incentives and reduced system costs, has resulted in increased attention from regulatory authorities. Specifically, concern has been raised as to the fire resistance of building integrated and building mounted modules. And, as attention begets attention, this increased awareness has led to proposed international fire retardant standards for PV modules, which in turn have boosted awareness.

Federal, State/Province, and Local Building Codes

A number of jurisdictions already have in place regulations regarding the fire resistance of building integrated and/or building mounted PV modules. As expected, these locales are those having higher product penetration, and/or historical problems with fire. For example, Japan requires that building integrated and roof hugging modules meet JIS A132 "Method of Fire Test for Roof of Building." Similarly, many cities in the state of California require modules for such uses to be UL 1703 Class A rated.

Such rating requirements currently preclude the use of traditional modules somewhat to completely in these areas. Also, those modules that are acceptable tend to be either quite costly or substantially heavier than traditional modules.

Government/Utility PV Incentive Program Standards

A second reason for compliance with fire retardant standards is access to rebates or incentives offered by governments, utilities, and other organizations. In many cases, the overseeing organization or agency requires the selected system to meet certain performance standards. However, the mandatory requirement in these cases has tended to be to the lesser Class C rating offered by UL. Class C rated modules can withstand light fire exposure, evidencing only minor resistance to fire exposure.

Growth of Building Integrated PV

The growth of the building integrated PV (BIPV) market has also had a huge impact on the need for fire retardant modules. BIPV is where the PV elements actually become an integral part of the building. A strict definition also requires the elements to replace some other building material, as in say roof tiles or glazing. However, the U.S. Department of Energy in its "Solar Buildings" literature also includes PV modules that are mounted on an existing building's exterior⁵⁰. For the

⁵⁰U.S. Department of Energy Web Site, <http://www.eren.doe.gov/solarbuildings/integrated.html>, p. 1.

purpose of this study, we will adhere to the strict definition of BIPV, but do assess the overall market and market potential for BIPV as well as building mounted PV. It is our determination that growth as well as technological advances in both these markets prompted international efforts to address the flammability issues associated with PV modules. Now under formal review is the draft international standard IEC 1730.

BIPV has the major advantages of cost savings and architectural aesthetics. According to Alan Paradis and Daniel Shugar in "Photovoltaic Building Materials," which appeared in *Solar Today*, "The solar industry has long envisioned the integration of solar photovoltaic (PV) panels into building design as an elegant way to deliver electrical energy to buildings. The appeal of integrating PV into building materials is that the structure itself becomes an energy producer, providing some or all of the building's electrical energy requirements. The cost of the PV panels is at least partially offset by the savings realized from not purchasing the building materials that the PV replaces⁵¹."

Mike Nicklas of Innovative Design in Raleigh, North Carolina, quantified the savings in Judith Anne Gunther's "Who needs a roof? Cover your house with solar cells instead." He noted, "If you were to set a photovoltaic module out in a field, and build a support system, you might get something like a 25-year payback. If you were to take that same system and integrate it into the roof, you could knock that down to about 12- to 15-year payback.' And by gleaning heat from the photovoltaic panels, Nicklas estimates he can cut the payback down to about four years⁵²."

But despite these advantages, BIPV, and even building mounted PV, is not for everyone. Both the local climate and a building's location must be conducive to solar energy generation, and even the timing of peak energy requirements is important if storage batteries are excluded. The bypassing of storage batteries is often the case with BIPV, as most uses are for structures connected to a utility's grid, and are designed to displace the customer's use of utility-generated electricity⁵³. Also, local energy costs are important for determining payback periods. For example, despite Switzerland's commitment to renewable energy, the country's PV "guru," Professor Jeanneret, does not foresee an economically viable application of solar cells in Switzerland for the next 40-50 years⁵⁴.

Typical BIPV applications include curtain walls, skylights, atrium roofs, awnings, roof tiles, and semi-transparent windows. Specific PV module applications expected to benefit from fire retardance over the next few years are discussed in section V. of this task.

With regards to the overall market, though, a report which analyzes market opportunities for BIPV in Australia relates regional target installations of around 1,300 MW by the year 2010 for

⁵¹Alan Paradis and Daniel Shugar, "Photovoltaic Building Materials," *Solar Today*, May/June 1994, pp. 34-37, Web Site <http://www.ecw.org/projects/bipvpubs.html>, pp. 1-2.

⁵²Gunther, op. cit., p. 3.

⁵³U.S. Department of Energy Web Site, <http://www.eren.doe.gov/solarbuildings/integrated.html>, p. 1.

⁵⁴Wiedmer, loc. cit.

Europe; 4,600 MW, also by the year 2010, for Japan; and highlights the U.S.'s planned 1 million rooftop program. Current total world PV installations are put at around 580 MW⁵⁵.

Proposed International FR PV Standards

Finally, the draft international standard IEC 1730 is itself increasing awareness, as is the dialogue prompted by this Department of Energy project. The draft standard addresses the flammability issues associated with BIPV and building mounted PV, by providing a standard means for rating a PV module's flammability characteristics. Qualification to the final standard will result in the assignment of a specific flammability rating, which may be printed on the module's label. The idea is not to define module fire resistance requirements, but to allow for product comparison in terms of flammability. As such, the code is expected to assist building code authorities in the establishment of standards for PV modules, and guide architects, building contractors, and consumers through both the product choice and building code compliance tasks.

However, it is the proposal for such a standard that is of interest here. It appears that the acknowledgment of the need for such a standard, and the resulting draft proposal, have served to further raise awareness of the problem.

B. Current Production Meeting UL 1703 Class A or Japanese Standards

As of this May, only eight of the 46 survey participants claimed to be manufacturing fire retardant modules. Three of the companies are based in the U.S., and five in Europe. Collectively, they claimed to currently produce over 9.7 MW/year of fire retardant modules, with U.S. producers accounting for approximately 5.7 MW/year, and European producers for over 4 MW/year. This amounts to around 6 percent/year of current worldwide production. No Japanese or Rest of World participants claimed fire retardant module capacity.

The lack of Japanese manufacturers in the fire retardant arena seemed strange, given JIS A132, "Method of Fire Test for Building." However, one Japanese manufacturer noted that JIS A132 is to be revised under "the Building Standards Act." The respondent noted, "PV and building industries are working hard to develop a roof integrated or mounted PV product that conforms to 'the revised Act.' The effort will make it possible for PV manufacturers to fabricate FR PV products before long." Perhaps, while the technology is available, producers are holding off until the new, more flexible, standard is in place.

How Is Fire Retardance Achieved?

Out of the 46 worldwide PV module manufacturers participating in our study, eight claim to currently manufacture fire retardant PV modules. Based on the intelligence gathered before and during this program, we conclude that there are probably seven manufacturers constructing flame retardant modules. Generally, most manufacturers do not consider a UL 1703 Class C classified

⁵⁵M. Watt, R.J. Kaye, D. Travers and I. MacGill, "An Analysis of the Australian Market for Building Integrated PV," Photovoltaic Special Research Centre, School of Electrical Engineering, University of NSW, p. 1.

module as fire retardant, though we suspect one or two of the eight claimants did. The overall industry perspective was that actual fire retardance is achieved through conformance to UL 1703 Class A, or a similar rating.

Of those manufacturers thought to achieve a UL 1703 Class A or similar rating, the flammability resistance is most commonly attained by shielding the flammable portion of the PV module (the EVA or other proprietary encapsulants) from the heat source. PV modules constructed of a dual glass composition (a tempered glass superstrate and substrate) can generally achieve a UL 1703 Class A flammability rating, provided proper edge seals are in place. Proper edge sealing is attained for flame retardant applications by completely encasing the encapsulant within the PV module.

The substitution of non-tempered glass for tempered glass will cause the PV module to fail the flammability test. The non-tempered glass, upon cracking, collapses away to leave the encapsulant totally exposed to the heat source. Tempered glass will crack, but remains in place.

Other flame retardant module constructions achieve their flammability rating by similar means. Manufacturers have replaced tempered glass with rigid, non-flammable materials such as cement board, and other like materials that function to shield the encapsulant from the heat source.

Only one PV module manufacturer identified employs flame retardant encapsulant to accomplish PV module flame retardance. The encapsulant is a rather expensive, non-flammable fluoropolymer-based material.

Revised Current FR PV Module Production

As such, we opted to alter the fire retardant PV module production figures that had been supplied to us. Production for 1997 was put at 4.5 MW worldwide, with the majority being produced by U.S. manufacturers. However, the European manufacturers are expected to make great gains in fire retardance this year, which will help boost the worldwide total to 12.0 MW.

C. Competing Technologies

As this investigation is aimed at determining the market potential for fire retardant modules, and not just specifically fire retardant EVA encapsulant, we did ask each manufacturer to note any other methods they would recommend for achieving module fire retardance. Following each suggestion is a discussion of the basic pros and cons of each.

Recommended were:

- "Standard EVA between two pieces of glass should be sufficient for the majority of applications." (U.S. manufacturer)

Glass superstrate/EVA/glass substrate--Standard EVA between two pieces of glass should be sufficient to ensure fire retardance for the majority of applications. This is the predominant method employed today to achieve a UL 1703 Class A rating. However, not just any glass may

be used. Tempered glass will shatter, but generally hold together, whereas non-tempered glass will crack and fall apart to leave the encapsulant exposed to the flame source.

This method is also only suggested for applications where weight is not a concern, as glass/glass modules tend to be nearly twice as heavy as the single glass modules.

- "Thicker glass? Flame retardant backsheet." (U.S. manufacturer)

Glass superstrate/EVA/fire retardant backsheet--One manufacturer claimed to be using this technology to produce fire retardant modules, but with a thicker glass superstrate. Our experts were not sure what merit a thicker glass superstrate offers, but fire retardant backsheet is one of our proposed approaches. The Tedlar-based backsheets employed today are fire retardant, but the high cost of Tedlar has kept laminate thickness down. Thus, the thin backsheets tend to crack upon exposure to fire, and cracking allows the flammable encapsulant to drip out and catch fire.

- "Resin encapsulation technology." (European manufacturer)

Glass superstrate/acrylic encapsulant/glass substrate--While modules produced in this manner are indeed flame retardant, our in-house experts felt flame retardance was completely attributable to the glass superstrate and substrate, not the encapsulation system. It is suspected that the proprietary UV cured encapsulant system is flammable.

- "Possible other materials like substitutes for glass or back protection foils." (European manufacturer)

Glass superstrate/encapsulant/glass or metal foil backsheet--We think that this manufacturer is referring to the replacement of Tedlar-based backsheets with either glass or metal foils, i.e., aluminum. While such construction would likely result in a flame retardant module, the use of metal backsheets is undesirable, due to the possibility of an electrical short circuit or shock hazard, and hi-pot failures.

- "We are searching for new FR or non-flammable encapsulant except EVA." (Japanese manufacturer)
- "Fluoropolymer." (European manufacturer)

Silicone or fluoropolymer encapsulant--The only alternative fire retardant encapsulant technologies now available are silicones (liquid) and fluoropolymers (dry film). Both possess the necessary optical clarity. However, both are extremely expensive in comparison to EVA.

- "Maybe a liquid encapsulant for very large modules." (European manufacturer)

Glass superstrate/liquid encapsulant/glass substrate--Flame retardance has become associated with liquid encapsulants, but the achieved flame retardance is actually the result of employing a glass

superstrate and substrate. Additionally, weight is a concern, due to the need for a glass superstrate and glass substrate, and processing difficulties are common.

- "Up to now, EVA is the suitable product for the encapsulation of PV modules. I suppose if it is possible to add some new fire retardant matter during the production of EVA or during the encapsulation, it would improve the FR performance. That seems cost-effective." (Rest of World manufacturer)

Fire retardant EVA encapsulant--Fire retardant EVA encapsulant is so far the most promising configuration found. It can be used in any module construction type, is optically transparent so is appropriate for use both in front of and behind the solar cells, and is substantially lower in cost than silicones and fluoropolymers. It is also easy to process (dry lamination process), has identical lamination parameters to existing EVA encapsulant, is lightweight and flexible, and has no hazards associated with its handling or processing. Finally, the fire retardant additive meets all environmental criteria worldwide.

On the negative side is the fire retardant encapsulant's cost, which is estimated to be 2-3 times more than standard EVA for the top transparent grade, and about 50 percent more for the opaque encapsulant used behind the cells. However, one conceptualized product is a flame retardant low cost backsheets, which would actually reduce a module's overall manufacturing cost by 0.6 percent. The former products would raise a module's overall manufacturing cost by approximately 3 percent and 1 percent, respectively.

Here, we also note that during our investigation we found no technical or regulatory barriers that would hamper the acceptance of fire retardant EVA encapsulated modules. Based on input from a number of flame retardant additive producers, the technologies under consideration for rendering EVA encapsulants flame retardant are currently utilized worldwide.

D. Required Fire Retardant Material Characteristics

Based on input from the worldwide PV module manufacturing community surveyed, we found the following fire retardant encapsulant attributes of equal importance in fulfilling PV module manufacturers' requirements.

Crystalline and Polycrystalline PV Modules

Flame Resistance--Obviously, the lack of flammability resistance would disqualify an encapsulant from further consideration in fire retardant applications.

Transparency--It is desired to convert as much available sunlight into electricity as possible. Therefore, it would be undesirable to employ an encapsulant that filters or limits the amount of available sunlight transmittable to the solar cell. A transparency level of 92 percent or greater is the generally accepted level.

Long-Term Performance--Encapsulants are expected to survive out-of-doors for a minimum of 25 years in order to render a PV module installation economically advantageous. Thus, an encapsulant must be capable of maintaining a PV module's integrity for 25 years, and is generally expected to last for 30 years or more. Lack of long-term performance will render an encapsulant unsuitable.

Cost--Price is as important as the above three characteristics. Alternative encapsulants such as silicones and fluoropolymers are available, and boast excellent flame resistance, transparency, and long-term performance, but have failed to gain any notable market share due to their high costs.

Thin Film Technologies

Flame Resistance, Long-Term Performance, and Cost--For thin film PV modules, the encapsulant is frequently employed behind the solar cell. In these constructions, transparency is thus not a concern, but all of the other above criteria are still weighted equally.

Also during this investigation, we found that the fact that there are three UL 1703 Class ratings is of little consequence to module manufacturers. The general feeling seemed to be if you are going to bother, why not go for a Class A rating. Many manufacturers also commented that their modules already conform to UL 1703 Class C or its equivalent. Thus, Class C is seen as no big achievement, and Class B as not a real consideration.

This finding, however, is vital to this project, as it means that fire retardance will probably prove to be a black and white issue. Or in other words, a module will be either fire retardant, and aimed at the building integrated and roof top mounted market, or it will not, and will be either fielded or targeted at areas where fire retardance is not of consequence. Thus, there will be no demand for varying degrees of fire retardance.

E. FR PV Module Market Forecast

<p align="center">Table 6. Current and Anticipated FR Module Shipments (MW)</p>							
	<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1998</u>	<u>2000</u>	<u>2005</u>	<u>2010</u>
U.S.	0	0	4	8.2	35.4	105	291.1
Europe	0	0	0.5	3.8	22.4	60.6	127.1
Japan	0	0	0	0	59.1	174.4	561.8
Rest of World	0	0	0	0	0.9	1.7	3.4
World Total	0	0	4.5	12	117.8	341.7	983.4

STR forecasts that worldwide shipments of fire retardant modules will grow from 4.5 MW last year to 12.0 MW this year, an increase of some 166 percent. However, an even bigger gain is expected for the period 1999-2000, growth equaling 210 percent/year. From the period 2001 to 2005, the increase will be a more modest 24 percent/year, which will continue through the period 2006-2010. The average annual gain for the period 1998-2010 will be 51 percent/year.

With regards to regions, Japan is expected to take off as a fire retardant module producer in the year 2000, and will maintain its dominance through 2010. Early adopter, the U.S., will be second in production, followed by the European manufacturers. The Rest of World producers will have some fire retardant module production beginning in the year 2000, but fire retardance is not expected to have much attraction for developing countries.

Versus non-fire retardant module shipments, fire retardant module shipments are expected to take off around the year 2000. The following table compares the two.

Table 7. Current and Anticipated FR Module Shipments Versus Non-FR Module Shipments (MW)							
	1995	1996	1997	1998	2000	2005	2010
<u>U.S.</u>							
Module Shipments	27.5	29.3	41.6	58.2	105.7	277.1	91.9
FR Module Shipments	0	0	4	8.2	35.4	105	91.1
<u>Europe</u>							
Module Shipments	17.7	18.7	35.4	49.6	104.7	252.7	87.6
FR Module Shipments	0	0	0.5	3.8	22.4	60.6	27.1
<u>Japan</u>							
Module Shipments	15.9	20	32.2	45.1	110.4	255.6	54.1
FR Module Shipments	0	0	0	0	59.1	174.4	61.8
<u>Rest of World</u>							
Module Shipments	5.5	9.5	9.2	12.9	17	34.3	68.9
FR Module Shipments	0	0	0	0	0.9	1.7	3.4
<u>World Total</u>							
Module Shipments	66.6	77.5	118.4	165.8	337.8	819.7	102.5
FR Module Shipments	0	0	4.5	12	117.8	341.7	83.4

Note that 1998 fire retardant module shipments are expected to account for just 7 percent of overall shipments, while year 2000 fire retardant module shipments will equal 35 percent of shipments. The fire retardant percentage will then rise to 42 percent by 2005, and 47 percent by 2010.

IV. Fire Retardant EVA Market Forecast for 2000, 2005, 2010

A. Product Factors

Section "D. Required Fire Retardant Material Characteristics" under "III. Fire Retardant PV Module Production Forecast for 2000, 2005, 2010" of this Task discusses the characteristics that were found to be most important to module manufacturers. To summarize, they are: flame resistance, transparency, long-term performance, and cost. We also found that all are interrelated, and are of equal importance to module manufacturers. Thus, we can conclude that any material that meets the required characteristics would gain a huge percentage of the available fire retardant module market.

It is STR's contention, and the finding of its laboratory staff, that the conceptualized flame retardant EVA encapsulants have the potential to do just that. They will be transparent, cost effective, fire retardant, and have identical lamination parameters and life expectancy to traditional EVA encapsulants.

B. Market Factors

Given the availability of an acceptable fire retardant encapsulant material, we see the market easily adapting to its use. Competing technologies are few and far between, and EVA is already entrenched, accounting for over 90 percent of all modules deployed worldwide last year. Thus, provided fire retardance becomes a key market requirement as expected, and is a feature that end-users are willing to pay a slight premium for, fire retardant EVA encapsulant products are expected to gain a substantial percentage of the worldwide PV module market.

C. Forecast to 2000, 2005, 2010

Table 8. Anticipated FR EVA Shipments (MW)							
	1995	1996	1997	1998	2000	2005	2010
U.S.	0	0	0	0	20.5	74.7	229.8
Europe	0	0	0	0	17.1	44.1	96.3
Japan	0	0	0	0	39	114.4	379.2
Rest of World	0	0	0	0	0.9	1.7	3.4
World Total	0	0	0	0	77.5	234.9	708.7

As is highlighted in the table below, shipments of fire retardant EVA encapsulated modules are forecast to account for approximately 66 percent of world fire retardant module shipments in the year 2000, and around 23 percent of worldwide module shipments, provided fire retardant EVA products are available. If not developed, overall fire retardant module shipments will be substantially reduced, as the industry will not adopt silicone and/or fluoropolymer encapsulants

due to their high cost. Some manufacturers may opt for glass/glass configurations, but not the majority.

Table 9. Anticipated FR EVA Shipments Versus FR Shipments and Non-FR Module Shipments (MW)							
	<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1998</u>	<u>2000</u>	<u>2005</u>	<u>2010</u>
<u>U.S.</u>							
Module Shipments	27.5	29.3	41.6	58.2	105.7	277.1	91.9
FR Module Shipments	0	0	4	8.2	35.4	105	91.1
FR EVA Mod. Ships.	0	0	0	0	20.5	74.7	29.8
<u>Europe</u>							
Module Shipments	17.7	18.7	35.4	49.6	104.7	252.7	87.6
FR Module Shipments	0	0	0.5	3.8	22.4	60.6	27.1
FR EVA Mod. Ships.	0	0	0	0	17.1	44.1	96.3
<u>Japan</u>							
Module Shipments	15.9	20	32.2	45.1	110.4	255.6	54.1
FR Module Shipments	0	0	0	0	59.1	174.4	61.8
FR EVA Mod. Ships.	0	0	0	0	39	114.4	79.2
<u>Rest of World</u>							
Module Shipments	5.5	9.5	9.2	12.9	17	34.3	68.9
FR Module Shipments	0	0	0	0	0.9	1.7	3.4
FR EVA Mod. Ships.	0	0	0	0	0.9	1.7	3.4
<u>World Total</u>							
Module Shipments	66.6	77.5	118.4	165.8	337.8	819.7	102.5
FR Module Shipments	0	0	4.5	12	117.8	341.7	983.4
FR EVA Mod. Ships.	0	0	0	0	77.5	234.9	708.7

Again referring to the above table, the fire retardant EVA market share is expected to climb to 69 percent of fire retardant module shipments over the period 2001-2005, or 29 percent of worldwide module shipments. Come the year 2010, fire retardant EVA will hold 72 percent of the fire retardant modules market, or 34 percent of the overall module market.

The table below highlights the fire retardant and fire retardant EVA percentages for each of the world's regions, and restates them for the overall market.

Table 10.			
Anticipated FR and FR EVA Shares of Module Shipments (MW)			
	2000	2005	2010
<u>U.S.</u>			
Module Shipments (MW)	105.7	277.1	691.9
FR Module Shipments (MW)	35.4	105	291.1
FR % of Overall Module Shipments	33%	38%	42%
FR EVA Module Shipments (MW)	20.5	74.7	229.8
FR EVA % or FR Module Shipments	58%	71%	79%
FR EVA % of Module Shipments	19%	27%	33%
<u>Europe</u>			
Module Shipments (MW)	104.7	252.7	587.6
FR Module Shipments (MW)	22.4	60.6	127.1
FR % of Overall Module Shipments	21%	24%	22%
FR EVA Module Shipments (MW)	17.1	44.1	96.3
FR EVA % or FR Module Shipments	76%	73%	76%
FR EVA % of Module Shipments	16%	17%	16%
<u>Japan</u>			
Module Shipments (MW)	110.4	255.6	754.1
FR Module Shipments (MW)	59.1	174.4	561.8
FR % of Overall Module Shipments	54%	68%	74%
FR EVA Module Shipments (MW)	39	114.4	379.2
FR EVA % or FR Module Shipments	66%	66%	67%
FR EVA % of Module Shipments	35%	45%	50%
<u>Rest of World</u>			
Module Shipments (MW)	17	34.3	68.9
FR Module Shipments (MW)	0.9	1.7	3.4
FR % of Overall Module Shipments	5%	5%	5%
FR EVA Module Shipments (MW)	0.9	1.7	3.4
FR EVA % or FR Module Shipments	100%	100%	100%
FR EVA % of Module Shipments	5%	5%	5%
<u>World Total</u>			
Module Shipments (MW)	337.8	819.7	2,102.5
FR Module Shipments (MW)	117.8	341.7	983.4
FR % of Overall Module Shipments	35%	42%	47%

	<u>2000</u>	<u>2005</u>	<u>2010</u>
FR EVA Module Shipments (MW)	77.5	234.9	708.7
FR EVA % of FR Module Shipments	66%	69%	72%
FR EVA % of Module Shipments	23%	29%	34%

V. Fire Retardant Modules Application Roundup

In concluding this Task, we note the following applications, which were highlighted by the survey respondents as expected to require fire retardant PV over the next few years. We asked, "What specific applications do you see requiring FR PV modules over the next few years?"

Twenty-seven respondents noted building-related applications. These ranged from very general "Building integrated PV & PV on residential roofs" (U.S. manufacturer) to "PV roof tiles from thin-film & crystalline". (U.S. manufacturer) Other building applications included:

- "Roofing materials." (U.S. manufacturer)
- "Building integrated photovoltaics, roof mounted, residential, and curtainwall." (U.S. manufacturer)
- "Shingle products, metal roofing products (standing seam), facade, roofing, and low laminate product for bonding in retrofit market." (U.S. manufacturer)
- "Building-integrated modules (roofs or walls)." (European manufacturer)
- "All house-attached installations (facades, roofings, etc.)." (European manufacturer)
- "Roof integration." (European manufacturer)
- "Use of PV-modules in facades and glass roofs." (European manufacturer)
- "Public facility facades." (European manufacturer)
- "For building integrated PV module (wall and roof)." (Japanese manufacturer)
- "For public facilities as shelters." (Japanese manufacturer)

The next most popular category, with three mentions, was the "None" category; although one manufacturer stated that this was not in terms of the overall market, but with regards to their facility.

Other mentions were:

- "Off shore drilling platform." (European manufacturer)

- "Gas/oil platforms." (European manufacturer)
- "Automotive headliners." (European manufacturer)
- "Boats, cars, futuristic homes." (European manufacturer)
- "Obviously architectural & building integrated as well as stand alone installations that are in close proximity to dwellings or other potentially hazardous areas." (U.S. manufacturer)

Task 4.: Business Planning & Formation of Commercial Relationships

With the market potential for fire retardant photovoltaic modules, and more specifically fire retardant ethylene vinyl acetate encapsulated modules, determined, the next natural question is how will STR ensure its concept fire retardant EVA products get to market and find market acceptance? The purpose of this Task is to discuss STR's fire retardant EVA Business Strategy, Competitors, and its Capital Expenditure and Staffing Plans.

I. Business Strategy

A. Product Development

In a break from the past, STR has approached the development of a fire retardant EVA encapsulant line from purely a market-driven needs perspective. Upon noting interest in such a product line, we first explored the opportunities, obstacles, and requirements of such a product line in "Task 1. Further Problem Definition." This Task focused on the "Can it be done?" question, and included a review of background information and current literature on fire retardant systems, fire codes, and fire standards.

Next, we proceeded to "Task 2. Product Conceptual Design," where STR developed conceptual fire retardant strategies, and estimated the economics and pros and cons of each. These concept products were of particular importance as they allowed us to proceed to "Task 3. Market Assessment," with tangible products in hand, and gave the module manufacturers actual configurations on which future production could be estimated.

During Task 3, we contacted each module manufacturer worldwide and inquired as to their interest in fire retardant PV, solicited suggestions for achieving fire retardance, and asked about their interest in the concept EVA products. Somewhat surprisingly, the response rate was phenomenal, with 50 of the 53 module manufacturers contacted agreeing to participate in our market forecast, and 46 actually returning completed surveys in time for publication. Also, the feedback received was well thought out. The outlook is thus indeed encouraging, and we do expect to continue with both our research and market development efforts.

Throughout this effort, our intention has been to develop a product line that the market both requires and has the means to purchase. To do so, we have worked hard at bringing everyone on

board early, and will continue with this approach. This is to ensure both the proper product portfolio and an adequate market. Such an approach ensures not only the achievement of the right product or product line for the right market, but gives the users both a financial and emotional stake in its development.

Much of this work was accomplished under Task 3. STR used this effort to inform every major module manufacturer of our intentions--to develop a fire retardant EVA encapsulant product line--to note the market conditions prompting our efforts, and to introduce our five concept products. As noted above, the response was huge. In fact, a good portion of the respondents asked for more information on the subject, with some even offering to participate in our development efforts at their own expense.

With the market now somewhat educated on the subject, we now intend to expand participation to the encapsulant industry's indirect customers. These include PV module dealers and distributors, national and international regulatory groups (UL, IEEE, IEC, ISO, NEC, and NFPA, etc.), PV architectural organizations, construction organizations (the Construction Specification Institute, and the American Institute of Architects, etc.), and experts from the U.S. Department of Energy, Sandia National Laboratory, and the National Renewable Energy Laboratory. Our intention is to put together a Development Panel, with representatives from each of these stakeholding groups plus the module manufacturer group. This panel will serve to direct both product and market development efforts, and meetings can be planned to coincide with industry conferences and workshops for maximum participation.

Concurrently, we also intend to formalize our Project Team. This under-development committee of module manufacturers and additive producers is charged with assisting with the development of the series of flame retardant encapsulants, qualifying those encapsulants, and then demonstrating their performance. Specifically, participating manufacturers have agreed to construct mini-modules based on the most promising flame retardant EVA encapsulant configurations for laboratory testing, and then will construct full-sized modules for qualification testing using the better performing mini-module employed formulations. STR has already secured participation commitments from two flame retardant additive producers, three major module manufacturers, and two qualification laboratories.

The strategy which has brought us so far so fast, and which we consider to be the key to succeeding at the above efforts, and in this project as a whole, is the continued and timely release of information. This strategy resulted in our extremely high industry participation level, and provided us with a captive and committed audience that is now clamoring for more information. For example, under "Task 3. Market Assessment," we discussed in detail our conceptualized products and their economics--an initiative which is normally not taken in today's very competitive and highly secretive marketplace. We additionally invested the time and effort to educate the market. The result: we succeeded in stimulating interest in fire retardant EVA, and received offers of support from end-users worldwide. Many of these offers came from module manufacturers who had never even given a thought to fire retardant PV modules.

B. Marketing Channels

STR will use its current, fully-developed EVA encapsulant marketing channels to bring fire retardant EVA encapsulant to its client base. The company's existing EVA encapsulant products, sold under the PhotoCap trademark, hold a 50 percent share of the worldwide PV module market, and 52 percent share of the worldwide EVA encapsulant market. PhotoCap products are today sold in 28 countries. The domestic share is 86 percent of the U.S. PV module market, and 93.3 percent of the U.S. EVA encapsulant market.

Sales are generally direct to the customer--in this case the module manufacturer--but in hard to access areas are handled by local agents.

Incorporation of fire retardant products into the PhotoCap line is expected to be relatively easy. Grades are planned to be primarily fire retardant versions of existing products, and should process and perform exactly as their non-fire retardant counterparts. This means that a manufacturer could simply drop-in replace a FR designated grade for a non-FR designated grade. The one exception is a planned low cost fire retardant backsheet, which will replace the substrate layer in a PV module.

Current Marketing Efforts

STR currently markets its PhotoCap products via industry participation. We host exhibitors booths at international and national conferences and exhibitions, present technical papers and posters at these same conferences and exhibitions, and actively network within the PV and certifying agency communities.

We further are very active in the research and development area, and thus have been proactive about developing new and improved products. Additionally, we provide our customers with technical services and R & D programs, often at little to no charge, and regularly visit and make technical presentations at client facilities.

In hard to access markets, we use local agents. And, we freely provide samples to any interested module manufacturer. Finally, we are committed to providing high quality, competitively priced products, and support these products with highly trained technologists, who not only know the market and its participants, but are true, participating insiders.

Any Changes Necessary or Expected?

As noted above, we do not expect fire retardant EVA to require new or different marketing channels. Because we are aiming for drop-in replacement grades, we expect to rely on our existing marketing channels and methods. If anything, we may see an expansion of our use of agents in the Asia-Pacific, as the new Japanese standards gain acceptance.

C. Marketing Mix

Product

The new fire retardant products will be marketed as premium versions of our existing products. This is necessitated by both the increase in performance, and the increase in fabrication cost. No existing grades are expected to be deleted. The one new product will be the low cost fire retardant backsheet alternative, which is expected to result in substantial fabrication savings. Grades with fire retardance will be designated with the suffix FR, and will be labeled and promoted as such.

Price

While most fire retardant grades are expected to be priced from 50-300 percent higher than existing grades, depending on the level of clarity desired, the margin percentage will remain unchanged. Increased prices will thus be based solely on increased costs.

The notable exception is the low cost fire retardant backsheet, which we expect to price well below our existing encapsulant products.

Our discount structure will also remain as is, and will be based on the total encapsulant quantity purchased annually, as opposed to the quantity of fire retardant encapsulants purchased annually.

Promotion

STR will continue with its highly successful push strategy, with the promotion of the fire retardant encapsulant line handled as a premium extension of our existing EVA encapsulant product line. The fire retardant market will additionally be developed through industry participation, both via our Development Panel and Project Team efforts, and through exhibition and paper and poster presentations at the various international and national conferences and exhibitions. Such hands-on market development efforts highlight STR as a knowledgeable insider, and allows for our technologists to establish direct dialog with customers and potential customers.

Also, in keeping with our strategy of information release, we intend to periodically update all industry parties, including the module manufacturer contacts made during Task 3., on our product development progress, and on the progress of the draft international standard IEC 1730. Employed will be press releases and targeted direct mail. And, as samples of our new products become available, we will offer test quantities to all interested participants at no charge.

To fund these efforts, STR has authorized a promotional budget of approximately 1.5 percent of anticipated sales. This has proven an appropriate budget setting method for us due to the strong growth of our EVA encapsulant business. Completely new products, such as the low cost flame retardant backsheet, are not expected to require an expanded budget, as they can be promoted to our existing customer base through our existing channels and methods.

Our promotional message is that fire retardant PhotoCap encapsulants are the correct products for assuring the fire resistance of PV modules intended for mounting on or incorporation into buildings. Specification and use of FR designated PhotoCap encapsulants will result in the assignment of a specific international flammability rating, which may be printed on the module's label.

Distribution

We will continue to sell and supply PhotoCap EVA encapsulants direct to the customer in most cases. In hard to penetrate areas, we use and will continue to use local agents. Our encapsulant products are in all cases made to order due to their limited shelf life.

II. The Competition

A. Competing Technologies

Section "C. Competing Technologies" under "III. Fire Retardant PV Module Production Forecast for 2000, 2005, 2010" of Task 3 discusses the various technologies now in use or suggested for achieving fire retardance, and the pros and cons of each. A total of seven technologies are discussed.

But of these seven, only two are economically feasible, and the tempered glass superstrate/EVA/tempered glass substrate combination has a high weight drawback. Modules employing this construction are indeed fire retardant, but are nearly two times heavier than single glass modules. Weight has gained attention as a concern in recent years, especially with regards to handling large area modules. Complaints have obviously become more prevalent with the growth of the industry, and are expected to grow exponentially as both the number of installations and installers increase.

The second economically feasible technology is STR's fire retardant EVA encapsulant technology. To summarize, "It is expected to be appropriate for any module construction type, will be optically transparent, so it can be used both in front of and behind the solar cells, and will be substantially lower in cost than silicones and fluoropolymers. It is also expected to be easy to process (dry lamination process), will have identical lamination parameters to existing EVA encapsulant, will be lightweight and flexible, and will have no hazards associated with its handling or processing. Finally, the fire retardant additives are expected to meet all current environmental criteria worldwide."

Thus, we expect the fire retardant PV market to be basically shared by these two technologies, though fire retardant EVA is forecast to claim the lion's share. Fluoropolymer and silicone encapsulants will hold a slight portion of the market, but their shares are expected to advance strongly over the next few years and then crest with the development and commercial release of fire retardant EVA encapsulants.

The table below highlights fire retardant EVA's expected share of the fire retardant PV module market.

<p align="center">Table 11. Anticipated FR EVA Shipments Versus FR Module Shipments (MW)</p>					
	<u>1997</u>	<u>1998</u>	<u>2000</u>	<u>2005</u>	<u>2010</u>
<u>U.S.</u>					
FR EVA Mod. Ships.	0	0	20.5	74.7	229.8
FR Module Shipments	4	8.2	35.4	105	291.1
<u>Europe</u>					
FR EVA Mod. Ships.	0	0	17.1	44.1	96.3
FR Module Shipments	0.5	3.8	22.4	60.6	127.1
<u>Japan</u>					
FR EVA Mod. Ships.	0	0	39	114.4	379.2
FR Module Shipments	0	0	59.1	174.4	561.8
<u>Rest of World</u>					
FR EVA Mod. Ships.	0	0	0.9	1.7	3.4
FR Module Shipments	0	0	0.9	1.7	3.4
<u>World Total</u>					
FR EVA Mod. Ships.	0	0	77.5	234.9	708.7
FR Module Shipments	4.5	12	117.8	341.7	983.4

Fire retardant EVA encapsulated modules will account for approximately 66 percent of all fire retardant modules shipped in the year 2000, that is provided fire retardant EVA products are available. Then the fire retardant EVA percentage will advance to 69 percent between 2001-2005, and 72 percent by the year 2010. Thus, non-EVA fire retardant technologies will hold 44 percent of the fire retardant PV module market in the year 2000, 31 percent from 2001-2005, and 28 percent come the year 2010.

B. Notable Competitors

On the EVA front, five companies plus STR manufacture EVA encapsulants, but only four of these five are considered viable competitors. One is based in Europe, two in Asia, and one in the U.S. The non-viable competitor is based in Asia, and is reported to have poor quality products.

Competitor Resources

All of the four viable competitors have the financial resources available to compete in the fire retardant encapsulant market. We do expect that three of the four will eventually follow suit and develop their own fire retardant encapsulant formulations. The fourth competitor has been slowly withdrawing from the EVA encapsulant market, having focused on other business areas since coming under new ownership almost two years ago.

It is our feeling that the Asian producers will be driven by the changing Japanese regulations, and the European competitor will be forced to follow suit in order to compete. However, we do

expect to benefit from a huge lead time. Our "Fast-Cure" EVA encapsulants have been available commercially since 1986, but only recently have our competitors released comparable products.

Specifically:

Asian Competition--None of our Asian competitors have been spotted at any of the international PV conferences, including those held in their home country of Japan. It appears they rely heavily on Japan's nationalistic culture, under which Japanese companies tend to buy from other Japanese companies where product is available. Also, their skill level and production resources are substantial. However, the PV business is a relatively small business area for both of these large organizations, and therefore their PV businesses are felt to receive only token attention.

European Competition--Last year was the first time this company ever visited a PV conference. Representatives spent one day in the exhibit area of the European Conference & Exhibition. This appears to be part of a larger "wake up call," as the company has in the last few years become aggressive about regaining lost market share. Like our Japanese competitors, this company is owned by a large, deep pocketed company. However, their EVA encapsulant business appears to be understaffed in the research and development area, as they have not kept pace in the area of product improvements.

U.S. Competition--As stated above, this competitor came under new ownership almost two years ago, and appears to be well on its way to withdrawing from the EVA encapsulant market. Representatives were formerly visible at industry conferences, but have not been noted since the acquisition. Also, all of the company's EVA sales and marketing staff were eliminated, and the company has gained the reputation of being non-responsive to customer requirements. Reportedly, the company has lost 60-70 percent of its market share since the acquisition.

C. STR Share of Market

STR expects to greatly benefit from its 2-3 year lead time on the competition. In fact, we anticipate that STR will be the major to only recipient of fire retardant EVA market share over the next few years. Once our Japanese competitors catch up, though, we do expect to lose any Japanese customers we have gained. Europe, on the other hand, is expected to prove a more lasting market, as we see our competition there taking 5-10 years after our introduction to respond with a comparable formulation. As of the year 2010, STR is expected to hold 45-50 percent of the fire retardant EVA market.

III. STR Capital Expenditure and Staffing Plans

STR currently has capacity for approximately 150 MW/year worth of EVA encapsulant, or 25 million square feet of 18 mil thick EVA encapsulant per year. However, plans for additional capacity are in the works, and have already received Board approval. STR intends to substantially expand its EVA encapsulant manufacturing capacity during the year 2000.

The addition of fire retardant EVA to our current product portfolio will not require the addition of extra capacity or capabilities at our Connecticut facility. We manufacture to order, so a

request for a fire retardant grade will simply require that a fire retardant compound be used in place of a non-fire retardant compound. This also means that very little extra training will be required. We draw our manufacturing staff from the local labor pool of previously experienced equipment operators. All are trained in-house for two months before being assigned manufacturing operator responsibilities. Given these business-as-usual expectations, we intend to manage the expansion of our fire retardant business in tandem with and under the heading of our EVA encapsulant business.

However, the addition of the fire retardant EVA grades will likely push us to explore in-house compounding capabilities. Early on, we plan to rely on external toll compounding, but intend to invest in in-house compounding capabilities once we reach a demand level where it becomes economically advantageous. The cost of bringing compounding in-house is estimated at \$500,000.

STR does have the financial resources and corporate commitment necessary to achieve its fire retardant EVA encapsulant, as well as overall EVA encapsulant, business objectives.

Timeline Forecast

Quarter 2, 1999 -	Commercial introduction of low-cost fire retardant backsheet.
Quarter 3, 1999 -	Commercial introduction of opaque fire retardant EVA encapsulant.
Quarter 2, 2000 -	Installation of additional EVA encapsulant manufacturing capacity.
Quarter 1, 2001 -	Commercial introduction of optically transparent fire retardant EVA encapsulant.
Quarter 1, 2002 -	Addition of internal compounding capability.

3.0 Conclusions

- In the absence of an affordable flame retardant EVA encapsulant system, the future growth rate for BIPV will be hampered due to the high costs and/or weight constraints associated with the PV module manufacturer's ability to conform with the flammability requirements of many local building codes worldwide.
- The draft IEC Standard 1730 will require all PV modules to be rated for flammability resistance. Those ratings will be used to verify conformance to local building code requirements.
- PV module manufacturers are currently limited in their market opportunities due to inadequate flammability resistance of current module encapsulation technologies or weight constraints for the final end-use.

- Current alternative encapsulation materials that offer superior flammability resistance are too cost prohibitive for implementation.
- The product conceptualizations from Task 2 are economically viable for acceptance by the PV module manufacturers.
- There is a real flammability issue for PV modules, and it is just coming to light as BIPV applications and products are being increasingly conceptualized for deployment.
- The global PV community is quite enthusiastic to follow the progress of the subsequent FR EVA encapsulant systems developmental effort, already requesting samples as soon as they become available.
- The PV module producers view flame retardancy as flame retardant or not, desiring to achieve the highest degree of flame retardancy.

Figure 1.

Crystalline/Polycrystalline Module Configurations

Thin Film Module Configurations

Appendix I

Key Contacts By Company

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