DOE/GO/10262--T1

PHASE 1: COMPREHENSIVE REPORT

TRANSPARENT BUILDING-INTEGRATED PV MODULES

KISS + CATHCART, ARCHITECTS
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This Comprehensive Report encompasses the activities that have been undertaken by Kiss + Cathcart, Architects, in conjunction with Energy Photovoltaics, Incorporated (EPV), to develop a flexible patterning system for thin-film photovoltaic (PV) modules for building applications.

There are two basic methods for increasing transparency/light transmission by means of patterning the PV film: widening existing scribe lines, or scribing a second series of lines perpendicular to the first. These methods can yield essentially any degree of light transmission, but both result in visible patterns of light and dark on the panel surface. A third proposed method is to burn a grid of dots through the films, independent of the normal cell scribing. This method has the potential to produce a light-transmitting panel with no visible pattern. Ornamental patterns at larger scales can be created using combinations of these techniques.

Kiss + Cathcart, Architects, in conjunction with EPV are currently developing a complementary process for the large-scale lamination of thin-film PVs, which enables building integrated (BIPV) modules to be produced in sizes up to 48" x 96". Flexible laser patterning will be used for three main purposes, all intended to broaden the appeal of the product to the building sector.

1. To create semitransparent thin-film modules for skylights, and in some applications, for vision glazing.
2. To create patterns for ornamental effects. This application is similar to fritted glass (see below), which is used for shading, visual screening, graphics, and other purposes.
3. To allow BIPV modules to be fabricated in various sizes and shapes with maximum control over electrical characteristics.

TASK 1: MARKET RESEARCH

Previous studies by Kiss + Cathcart have made apparent that the detailed data needed for BIPV product development does not yet exist in the public domain. However, existing data from related products (i.e. products with visual and architectural qualities similar to BIPVs) can be combined with interviews and literature searches to provide a substantially accurate picture.

Data has been collected for the following product types:

Dark/Tinted glazing (60% or less light transmittance)
Fritted glass (fired-ceramic patterned glass, often used for shading or ornamental purposes)
Skylight glazing
Atrium glazing
Greenhouse glazing (some greenhouse applications do not require clear glass)

SOURCES

Interviews have been conducted with curtain wall and skylight manufacturers, contractors, and architects. Glazing trade, construction, and architectural literature have been researched to provide additional background specific to patterned and fritted architectural glass.

The following is the final list of manufacturers, architects, associations, and publications that have been solicited/referenced for contribution of information to this report:

Glass Manufacturers

AFG Industries, Inc., Kingsport, TN
Viracon, Owatonna, MN
Pilkington/ Libbey-Owens-Ford, Toledo, OH
Interpane Glass Company, Clinton, NC
Arch Aluminum & Glass, Tamarac, FL
Cesar Color, Phoenix, AZ
Guardian Industries Corporation, Carleton, MI
Visteon, Allen Park, MI
SumiGlass
Prelco, Quebec, Canada
Tempa Glass, Vancouver, Canada

Architects/Engineers/Contractors

Nicholas Goldsmith, FTL Happold Architects and Engineers, NYC
Ron Evitts, Anderson/Schwartz Architects, NYC
Bill Hutchinson, Zimmer Gunsul Frasca Partnership, Portland, OR
Craig McInroy, Anshen+Allen, San Francisco, CA
James Carpenter, Architect, NYC
Dean Evans, Former Vice President, American Institute of Architects, Washington, DC
Dave Richards, Ove Arup & Partners, NYC
Dan Kaplan, Fox & Fowle Architects, NYC
Lutz Weisser, Sommer + Partner, Berlin, Germany
Jennifer Kinkead, Venturi, Scott Brown Architects, Philadelphia, PA
Mark Shoemaker, Cesar Pelli & Associates, New Haven, CT
Walt Urbanek, Hellmuth, Obata + Kassabaum (HOK), Washington, DC
Josef Gartner & Co., Gundelfingen, Germany
Mel Ruffini, Tishman Construction, NYC
Terence Riley, Curator, "*Light Construction*" Exhibit, Museum of Modern Art, NYC
Robert Milburn, Pei Cobb Freed & Partners, NYC
Lucy Fellowes, Curator, "*Under The Sun*" Exhibit,
Cooper-Hewitt National Design Museum, NYC
Thomas Herzog, Thomas Herzog and Partners, Bad Munder, Germany

SOURCES, Continued

Associations

American Architectural Manufacturers Association
American Institute of Architects
National Glass Association
U.S. Census Bureau
Glass Association of North America
Bureau of Labor and Statistics
International Window Film Association
Thomas Register of Products and Services

Publications

Glass Magazine, National Glass Association
USGlass, Metal and Glazing Magazine
Glass Association of North America Glazing Manual, Glass Association of North America
R.S. Means Construction Cost Data, R.S. Means Co.
1998 Glass for Construction Handbook, Interpane Glass Company
Industry Statistical Review and Forecast 1997, The Architectural Manufacturers Association

SURVEY

Surveys have been conducted on an ongoing basis with the various manufacturers, architects and trade associations mentioned above. Questionnaires were tailored to the category of the participant in order to elicit relevant information.

For glass manufacturers, questions were aimed at identifying:

- types of glass that are presently manufactured.
- applications this glass is used for.
- what standard and/or custom options are available.
- special installation or manufacturing requirements/limitations inherent to glass products.
- product quantities and market value produced annually.
- recent marketing and aesthetic trends.
- what built projects have used their products.

For architects, designers, and engineers, questions were aimed at identifying:

- projects that have been designed and/or engineered using custom glass.
- specifications/main considerations in specifying custom glass.
- applications for which glass is used for in specific projects.
- special installation requirements/limitations.
- quantity specified and cost.
- the degree of interest/knowledge the architect has in PV systems.

For representatives of associations and publications, questions were aimed at identifying:

- industry-wide data resources.
- current and predicted market trends .
- marketing/promotional methods or strategies and their audiences.

SURVEY RESULTS

At this writing, the following pertinent responses have been collected from manufacturers, architects and engineers who agreed to contribute information.

Glass Types

Most manufacturers who produce custom glass identified the primary customizing options as fritted, silk-screened, and film-applied.

Application Types

Manufacturers report, and our research verifies, that custom glass is predominantly used in exterior commercial applications and, to a lesser degree, interior commercial projects. Its use in residential construction has been very limited to date. In most projects, vertical, skylight, and atrium glazing are all potential areas of custom glass use.

Standard Pattern Options

Standard manufacturer options usually include coloring/tinting and a set range of coatings and patterns. The average number of available standard patterns per manufacturer surveyed is nine (9), and these typically consist of stripe, hole, and dot patterns. Often, standard options also encompass non-visual energy-saving features such as low-E and insulated glass.

Custom Pattern Options

Custom pattern types include architect-specified film-applied patterns from camera-ready artwork, architect-specified silk-screened patterns, and colored-fritted and graduated-fritted patterns.

Size and Thickness

Maximum glass sizes average 70" x 108" for skylight/atrium glazing. Maximum glass sizes for vertical glazing range from 60" x 138" to 96" x 144". Glass thicknesses range from 1.7 mm to 8 mm.

Installation Requirements and Limitations

In atrium and skylight glazing applications, the most common concern is structural stability per square area of glass. Other concerns include airspacing, heat gain, and ease of installation.

Price Range

Prices vary according to degree of customization, installation, and fabrication. Typically, amounts range from $12 to $65 per square foot (mid-1998).

Annual Production of Standard versus Custom Patterned Glass

Most manufacturers reported that the amounts of standard versus custom patterned glass produced annually are effectively equal.

SURVEY RESULTS, Continued

Marketing and Promotional Methods

Industry-wide promotional activities include brochures, customer surveys, advertising in building industry trade magazines and publications, Sales Representatives, participation in trade shows, and sample mailings.

Trends in Demand

High-performance glass (i.e. insulated and low-E coatings) was identified as the foremost current market trend by most large-volume glass manufacturers. Manufacturers noted a decrease in the demand for tinted glass, and an increased demand in fritted and patterned glass. Our survey of Architects suggests that these trends are related, and arise from a preference for the quality of natural light filtered through fritted glass, as well as the potential for custom patterning. Architects also preferred fritted glass as a permanent solution to solar shading over post-construction shading applications such as vertical/horizontal blinds, shades, velas, etc.

Architects emphasized the flexibility of fritted glass in achieving aesthetic goals. By designating fritted patterns on any one of the four glass surfaces in a double-glazed unit, many pattern appearances can be achieved. A fritted coating on surface #1 (outside outboard layer) reduces exterior reflectivity and adds a textured appearance, although it degrades at a faster rate than coatings not exposed to exterior conditions. A coating on either surface #2 (inside outboard layer) or #3 (outside inboard layer) produces a subtle sandblasted appearance on the exterior and interior surfaces while maintaining high reflectivity. A coating on surface #4 (inside inboard layer) performs similarly to #1, except that the reduced reflectivity is achieved on the interior surface and coatings are usually subject to less wear.

Architects surveyed often inquired about the potential for PV panels to be customized in a manner similar to fritted glass.

ARCHITECTS/ENGINEERS - CASE STUDIES

Project #1: Doernbecher Children's Hospital

Location: Portland, OR
Owner: Oregon Health Sciences University
Architects: Anshen + Allen, San Francisco, CA
Zimmer Gunsul Frasca Partnership, Associate Architect

MAIN CONSIDERATIONS

Solar shading, privacy, and decorative articulation of façade.

GLASS APPLICATIONS

Curtainwall and skylight glazing.

SPECIFICATIONS/PATTERN OPTIONS

White fritted pattern fired on clear, untinted glass. One custom pattern per in-patient floor, five total. All custom patterns were designed by a local artist.

INSTALLATION REQUIREMENTS/LIMITATIONS

Glass fitted to curtainwall frame dimensions.

QUANTITY AND PRICE RANGE

N/A

PV INTEREST/KNOWLEDGE

Little to no knowledge of PVs, but interested in PV's potential as a viable substitution for fritted glazing.

Project #2: Four Times Square

Location: New York, NY
Owner: Durst Organization
Architects: Fox & Fowle, Building Architects
Kiss + Cathcart, Architects, PV system designers

MAIN CONSIDERATIONS

Solar shading and opacifier

GLASS APPLICATIONS

Fritted Glass: Spandrel panels and vision panels on 1st nine stories
Photovoltaic Glass: Spandrel panels

SPECIFICATIONS/PATTERN OPTIONS

Fritted Spandrel Glass: Four sizes of spandrel glass panels (3' x 5' average) with opacifier on #4 surface.

Fritted Vision Glass: Panels up to 4' x 5' of custom-colored fritted glass, tinted glazing installed on 1st nine floors.
Photovoltaic Glass: On 37th through 43rd floors, conventional spandrel glass on both south and east facades has been replaced with PV panels to match spandrel sizes.

INSTALLATION REQUIREMENTS/LIMITATIONS

Conventional curtainwall framing installation

QUANTITY AND PRICE RANGE

Fritted Glass:
Photovoltaic Glass:

PV INTEREST/KNOWLEDGE

Extensive knowledge of BIPV applications provided by PV-specific consultant. Because this project is a demonstration installation of BIPVs in urban environment, cost considerations were dependent on scheduling and assembly.

Project #3: Whitehall Ferry Terminal

Location: New York, NY
Client: New York Department of Transportation
Architects: Schwartz Architects, NY

MAIN CONSIDERATIONS

Energy Efficient Strategy and PV demonstration project

GLASS APPLICATIONS

Photovoltaic Glass: Curtainwall glazing on south façade

SPECIFICATIONS/PATTERN OPTIONS

1/8" laminated glass / polycrystalline panels in 1 meter x 2 meter panels

INSTALLATION REQUIREMENTS/LIMITATIONS

Weathersealing required

QUANTITY AND PRICE RANGE

1800 S.F. @ approximately $125/sf

PV INTEREST/KNOWLEDGE

Very knowledgeable about PV technologies. Because this project is a demonstration installation of building-integrated PVs, premiums over standard glazing costs were adjusted. Architects stated that cost analysis of PV panel applicability in curtainwall has been difficult due to unavailability of accurate and/or consistent cost information.

Project #4: Photovoltaic Glass Pavilion, "Under The Sun" Exhibit

Location: New York, NY
Client: BP Solar and Cooper-Hewitt National Design Museum
Architects: Kiss + Cathcart, Architects
FTL/Happold Architects and Engineers

MAIN CONSIDERATIONS

Demonstration of building-integrated photovoltaic application in urban environment

GLASS APPLICATIONS

Vertical and horizontal structural glazing

SPECIFICATIONS/PATTERN OPTIONS

2'x 4' Thin-film PV panels laminated to 4'x4' clear tempered panels

INSTALLATION REQUIREMENTS/LIMITATIONS

Non-weathersealed application; glass panels and steel brackets/hardware form structure and skin of pavilion.

QUANTITY AND PRICE RANGE

N/A

PV INTEREST/KNOWLEDGE

Extensive knowledge of BIPV applications; because this project is a demonstration installation of BIPVs in urban environment, cost considerations were dependent on scheduling and assembly.

Project #5: Los Angeles Convention Center

Location: Los Angeles, CA
Client: Los Angeles Convention and Exhibition Center Authority
Architects: Pei Cobb Freed and Partners

MAIN CONSIDERATIONS

Extensive solar shading; light diffusing (day) and light containing (evening)

GLASS APPLICATIONS

Curtainwall and sloped glazing

SPECIFICATIONS/PATTERN OPTIONS

Over 100 custom patterns in both orthogonal and radial designs;
Tinted glazing with frit applied on #2 surfaces

INSTALLATION REQUIREMENTS/LIMITATIONS

N/A

QUANTITY AND PRICE RANGE

N/A

PV INTEREST/KNOWLEDGE

Moderate knowledge of PVs. Has not used PVs to date mostly because of concerns about cost and aesthetic s. Regards PVs as being "too opaque."

Project #6: National Air and Space Museum, Dulles Center

Location: Washington, DC
Client: Smithsonian Institution
Architects: Hellmuth, Obata + Kassabaum / Washington, DC

MAIN CONSIDERATIONS

Demonstration project, Energy-efficient strategy and solar shading

GLASS APPLICATIONS

Sloped glazing on awning
Vertical and sloped glazing on east, south, and north facades of entrance canopy

SPECIFICATIONS/PATTERN OPTIONS

2' x 4' thin-film PV panels on awning – shading device
3' x 3' laminated Polycrystalline/ clear glass panels on north and south canopy facades – shading device

INSTALLATION REQUIREMENTS/LIMITATIONS

Awning: Weatherproofing required between panels to maintain translucency
Entrance canopy: Installed in conventional curtainwall framing

QUANTITY AND PRICE RANGE

Awning: 3024 S.F.
Entrance canopy: 7137 SF

PV INTEREST/KNOWLEDGE

Extensive knowledge of BIPV applications; because this project is a demonstration installation of BIPVs, cost considerations are dependent on available rebates, scheduling, and assembly.

Project #7: Main Terminal of Washington/Reagan National Airport

Location: Washington. DC
Client: Metropolitan Washington Airports Authority
Architect: Cesar Pelli & Associates

MAIN CONSIDERATIONS

Solar shading, glare and heat gain reduction, and aesthetic application on façade

GLASS APPLICATIONS

Extensive fritting on clear glazing along main concourse. Most applications are vertical glazing.

SPECIFICATIONS/PATTERN OPTIONS

4' x 5' panels. All custom patterns in both lines and dots of various sizes. Fritting in white ceramic with varied opacities.

INSTALLATION REQUIREMENTS/LIMITATIONS

Installed in conventional curtainwall framing.

QUANTITY AND PRICE RANGE

32,000 S.F.; nominal charge over cost of insulated unit

PV INTEREST/KNOWLEDGE

Moderate knowledge of PVs. Main areas of concern are cost-related; how does PV factor into the life cycle of a building?

Project #8: Owens-Corning World Headquarters

Location: Toledo, OH
Client: Owens-Corning
Architect: Cesar Pelli & Associates

MAIN CONSIDERATIONS

Solar shading, glare and heat gain reduction, and aesthetic application on façade

GLASS APPLICATIONS

Extensive fritting on tinted vertical glazing along SW façade.

SPECIFICATIONS/PATTERN OPTIONS

3' x 4' panels. All custom patterns in both lines and dots of various sizes. Fritting in gray ceramic with varied opacities.

INSTALLATION REQUIREMENTS/LIMITATIONS

Installed in conventional curtainwall framing

QUANTITY AND PRICE RANGE

50,000 S.F.; nominal charge over cost of insulated unit

PV INTEREST/KNOWLEDGE

Moderate knowledge of PVs. Main areas of concern are cost-related; how does PV factor into the life cycle of a building?

CONCLUSIONS

The results of this market research strongly suggest that the building profession is ready for the technological advancement that building-integrated photovoltaics afford. In fact, products that closely resemble translucent BIPVs (without, of course, their energy producing benefits) are already becoming an accepted part of the architectural palate for public and institutional buildings. Many of the Architects surveyed expressed a general goodwill toward the concept of building integrated solar energy production, tempered mainly by reservations about the aesthetic qualities of PV panels. Thus, improvements in scribing technology that are hastening development of custom patterning (see next section) are likely to make PVs highly attractive to both architects and clients when they become commercially available.

These improvements, though, must be aggressively publicized and marketed to ensure that they are fully recognized throughout the Architectural and Engineering professions. Our research suggests that there is a disproportionately small *perceived* need for BIPVs, despite their benefits. On the other hand, our professional surveys indicate that an energetic introduction of translucent BIPVs can overcome market hesitancy and lead to widespread use.

The current acceptance of fritted glass as a building material (highlighted in many of the case studies) is a good indicator of how translucent BIPVs might begin to be used by designers. Fritted glass is generally used for exterior, vertical glazing applications, although its application in sloped areas is not unusual or functionally problematic. Fritted glass is predominately used in public areas of buildings where light transmission, solar shading, and ambient quality are significant design issues. In two Case Studies, multiple patterns were deployed to mark the function or location of a space. For the Doernbecker Children's Hospital, each floor of the inpatient rooms was identified by a different pattern, representing various natural landscapes. These facades also faced onto courtyards, thereby distinguishing those exterior spaces as well.

Our survey indicates that there are no limitations to the installation of fritted glass beyond those imposed on conventional double-glazed units. Most panels were installed in conventional curtainwall framing. Some installations included larger glass panel sizes, requiring additional framing support, but all employed typical glazing procedures. In all of the Case Studies a BIPV system could be substituted for custom glazing using similar structural and installation parameters.

It is important to note that fritted glass is widely used not only because it acts to shade interior spaces from solar loads - and consequently, reduces energy loads on the building - but also because it can act as an aesthetic feature. In fact, our discussions with the Architects surveyed strongly suggest that the multiple possibilities for customizing fritted glass may be its primary appeal to designers. Note that, in three of the case studies, the Architects who specified use of fritted glass on facades called on local artists to create custom patterns. In several instances, Architects went so far as to design irregular patterns that actually required a prolonged set-up time on behalf of the glass manufacturer. In these cases, the manufacturers used CAD/CAM software in order to carry out the designs.

Most "custom" designs, however, appear to be adaptations of standard patterns offered by the manufacturer. In surveyed instances, the breakdown of custom versus standard designs and colors was equally divided, and of those 50% custom patterns, approximately 60% used custom ceramic ink colors. Initially, translucent BIPV technology would necessitate use of standard patterns with custom/adjustable features, and would clearly not be able to match the flexibility of ceramic fritting in achieving more complex/pictorial patterns. However the demand for truly complicated patterns is limited, so this should not be a significant obstacle to acceptance of translucent BIPVs.

In the Case Studies where actual photovoltaic glass panels were specified, half used PVs as an opacifier or spandrel glass, while the remaining projects exploited its solar-shading capabilities. The amount of light transmission in the latter cases was dependent on the manufacturer's own specifications, (usually between 5-8% transmission). Increased transmission was achieved by arranging polycrystalline cells (approximately 4" x 4"), in a grid pattern, then laminating these cells between clear glass. While the size of the cells was fixed, the pattern grid was entirely custom.

The appearance of all the BIPV installations surveyed was significantly circumscribed by available technologies and, more importantly, products. Until recently, PV panel colors and patterns have been limited, and are generally incidental to generating a maximum amount of electricity from each panel. The next report section describes several studies undertaken to provide new aesthetic options for PV appearance. As noted above, these new choices may well spur a vastly increased demand for building-integrated photovoltaic systems.

TASK 2: SCHEMATIC PRODUCT AND PROCESS DESIGN

INTERIM REPORT

In Phase I, Task 2 work was undertaken primarily in the following areas:

- Exploratory fabrication and testing of translucent a-Si modules to verify the feasibility of the chosen approach.
- Evaluation of the visual properties of said modules by means of photographs.
- Extension of the concept to cover thin film Cu [In-Ga] Se2 (CIGS) modules.
- Involvement of the Keller Companies (manufacturer of Kalwall translucent building products) in product definition.
- Assessment of equipment requirements for Phase II.

Results in these areas will now be described.

Linear Scribing

It was decided that a working prototype of a translucent module would provide a tremendous impetus for the project, and such prototypes were consequently fabricated. Conventional linear laser scribing was adopted as the means of obtaining transparency, with the third (aluminum isolation) scribe being effectively broadened in width by the expedient of making 10 successive cuts adjacent and slightly overlapping. A ratio of clear area to opaque area of about 15-20% was thereby achieved. Modules generating about 30 watts in power were produced, and I-V curves were recorded.

Overall, these results were most encouraging. The concept has been proven to be technically feasible, the only drawback being the length of time needed for performing the increased number of laser cuts. In principle, however, use of a higher power laser, with beam defocusing, should permit removal of material in a stripe 1mm in width using a single pass. This would restore processing time to that of conventional modules.

The visual quality of the modules was documented by placing two modules side by side in a window, and taking photographs through the modules of an outdoor scene. One of the modules was a conventional EPV a-Si module with normal laser scribing, the other a translucent module fabricated as described above. Depending on the focussing of the camera, remarkably clear images could be obtained of the outdoor environment. This demonstrates the usefulness and desirability of the translucent module.

Stencil and Dot Patterning

Another type of module was fabricated using a stencil in conjunction with laser scribing performed at right angles to the scribing of a conventional a-Si module. The stencil bore the lettering "EPV", and this image was likewise successfully transferred to the module. The electrical performance of this type of module was considerably inferior, and highlighted the need for additional shunt removal via electrical biasing. Visually, however, the desired effect was achieved.

A dot array of transparent regions was formed by increasing the x-y table speed during laser scribing until individual ablated areas were physically separated. No attempt was made to pattern an entire module using this technique in Phase I.

CIGS Modules

The possibility of fabricating a translucent CIGS module was also explored. At first sight, this would appear to be unfeasible, since the final scribe leaves behind opaque molybdenum (rather than transparent tin oxide in the case of a-Si). Nevertheless, a scheme was devised involving an extra laser scribe (4 instead of 3) that allows partial transparency. The processing sequence is as follows:

1. A *double Mo* scribe is made at locations A and B.
2. A double (or broad single) CIGS scribe is made at locations B and C.
3. The usual ZnO isolation scribe is made at location D. Transparency is achieved at B.

This interesting invention allows us to extend the concept of translucent thin film modules to the domain of substrate-type devices such as CIGS, as well as superstrate devices such as a-Si. This will be added to the Phase II proposal.

Collaboration with Keller Companies

Extensive discussions were held with the Keller Companies, Manchester, New Hampshire, concerning integration of thin film PV modules into Kalwall insulating units. Sample tandem junction a-Si modules manufactured by EPV were provided to the Keller Companies for construction of demonstration prototypes. Reciprocal visits were made between EPV and Keller. Keller has agreed to participate in Phase II of PV:BONUS Two by contributing some product development as cost sharing. The project and product has received a very favorable and committed response from Keller.

Equipment Requirements

Equipment requirements for Phase II include a diode laser pumped solid state Q-switched laser with a beam power of 3 watts (e.g. Spectra-Physics T40-X30-532Q) to allow blow-off of the 1 mm wide strip of material, and assorted laser optics (lenses, beam expanders, attenuators etc) for achieving a suitable beam width and intensity. A custom-made shunt buster for defect removal is also required, with automated stepping from cell to cell.

FINAL REPORT

In the latter part of Phase I, functional demonstration products were fabricated in two areas:

- Cross-scribed thin-film a-Si modules having increased translucency (up to 30%).
- Integration of EPV a-Si modules into Kalwall translucent window assemblies.

Cross Scribing

The cross-scribed modules were prepared and evaluated as follows. Figure 1a is a schematic of EPV's standard 25" x 49" tandem junction a-Si module (model EPV-40) showing the metal foil bus bars (hatched) and definition of unit cells by laser scribe lines (not to scale). Transparency in the module was produced by laser ablation of both the a-Si and Al metallization. A diode-laser-pumped, frequency-doubled YAG laser was used. Multiple, parallel, overlapping cuts were made to remove a total width of material of 0.255 cm per cell, the cell-cell spacing being 1.56 cm. A higher than normal table speed was used to speed up the process, and adjusted for minimal dot overlap. Cuts parallel to the long edge were made first, and the I-V curve of the module was recorded at the flash test station at this stage of fabrication. The plate was returned to the laser station and the perpendicular crosscuts were added. After bonding of the metal foil bus bars, the appearance of the module was as shown in Figure 1b.

The panel produced consists electrically of many series strings of square unit cells, with the series strings being connected in parallel by the metal foil bus bars. The I-V curve of the cross-patterned module was then remeasured, although for technical reasons not all of the series strings of cells were contacted. The I-V results are shown in Tables 1 and 2. After the first stage, the module power was 36.0 watts, and after the second stage 26.2 watts. Given the contacting problem, and that no electrical shunt busting was performed on this module after laser scribing, the final wattage is quite respectable. With proper contacting and shunt busting a power of at least 30 watts would be anticipated from this particular module, even after the direct loss of 30% of active area due to the cross-scribing. This demonstration module proves the electrical viability of this new class of highly translucent modules.

The cross-patterned module had a most striking appearance as shown in the color photographs seen in Figures XIIa and XIIb (indoor and outdoor shots). The visual quality of the patterned module was good. The pattern chosen could find architectural applications where fritted glass might otherwise be employed.

Integration with Kalwall Product

In the collaboration with the Keller Companies, Inc. of Manchester, NH, an earlier 19" x 49" a-Si module was shipped to Keller for integration into a Kalwall translucent panel window assembly. An attractive blue unit measuring 61.5" horizontally x 72" vertically was fabricated, and consisted of 8 Kalwall panels and the a-Si module of limited translucency. A letter from Keller is attached describing this activity. EPV will continue to develop this product and relationship by shipping the new, higher translucency cross-scribed modules described above.

TASK 3: DRAFT BUSINESS PLAN

TRANSPARENT PV MODULES PRODUCTS

1. Translucent Building-Integrated Photovoltaic windows (T-BIPV)

   - transparency from 10% to 50%
   - sizes from 1' x 1' to 4' x 8' modules

2. Insulated T-BIPV modules for windows and skylights

Manufacturing costs for T-BIPV

Cost of Standard plate:		
10% efficiency CiS		\$1.00/Watt
6% efficiency a-Si		\$1.66/Watt
Cost of Additional Patterning:		
Large-area patterning equipment capable of patterning 1000m²/yr		\$1 million
Amortizing over 5 years		\$20/m²
	at 10% efficiency	\$.50/Watt
	at 6% efficiency	\$.35/Watt
Labor Requirements:		
Ten (10) employees/year		\$500,000/yr
		\$50/ m²
	at 10% efficiency	\$.50/Watt
	at 6% efficiency	\$.85/Watt
Partially transparent plate cost:		
		\$170/ m²
or	for 10% efficiency	\$1.70/Watt
	for 6% efficiency	\$2.82/Watt

Note: All efficiencies are original plate efficiencies.

Encapsulation cost into triple laminate:		
	BIPV module	\$40/ m²
Encapsulation cost into double laminate:		
	BIPV module	\$30/ m²
Total T-BIPV module cost:		
	for triple laminate	\$210/ m²
	for double laminate	\$200/ m²

Product Pricing

The above cost analysis is based on the assumption that multiples of the basic module size can be used (2 ft x 4 ft). If part of the module has to be discarded to reach the required BIPV module, the costing is based on the number of basic modules required.

The standard gross margins for sustainable operation is 100% of costs. Thus proposed selling prices will be \$400/ m^2 to \$420/ m^2.

Marketing

The marketing plan will be based on:

1. Direct marketing to architects and builders
2. Advertisements in builder and architectural magazines
3. Trade shows

Funding Requirements

We assure that during the proposed period of the pre-cut contract the manufacturing process will be developed.

At the end of the contract, \$1.8 millions investment is required for an annual capacity of 10,000 m^2.

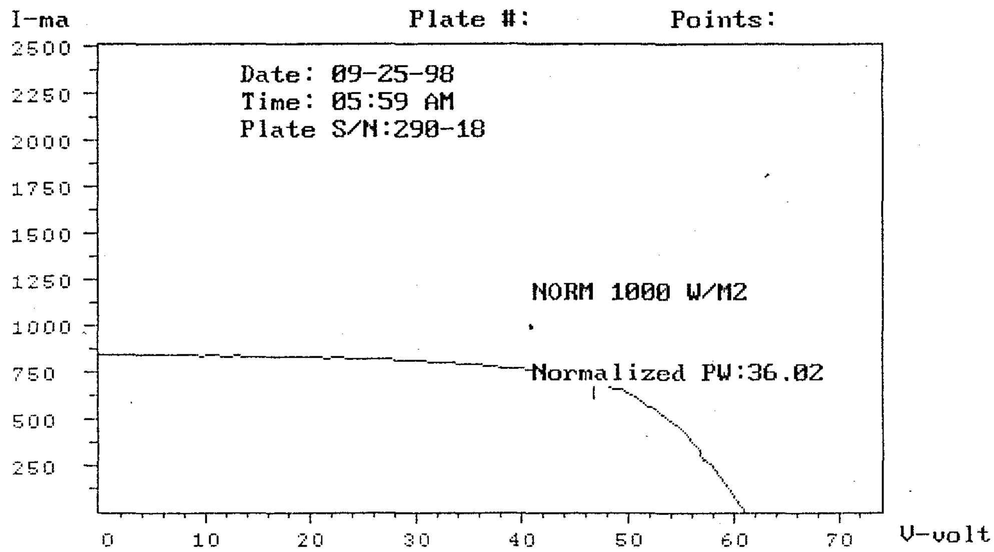
Use of funds:	Equipment	\$1.00 million
	Building infrastructure	\$0.30 million
	Working capital	\$0.50 million
	Total	\$1.80 millions

Profit/Loss

P+L (\$millions)

Year	1	2	3
Production m^2	5000	10,000	10,000
Sales \$million	2.00	4.00	4.00
Cost of sales \$million	1.00	2.00	2.00
Gross margin	1.00	2.00	2.00
G>A	0.20	0.40	0.40
Debt service	0.10	0.10	0.10
Amortization	0.10	0.20	0.20
Total costs	1.50	2.90	2.90
Profit before taxes	0.50	1.10	1.10

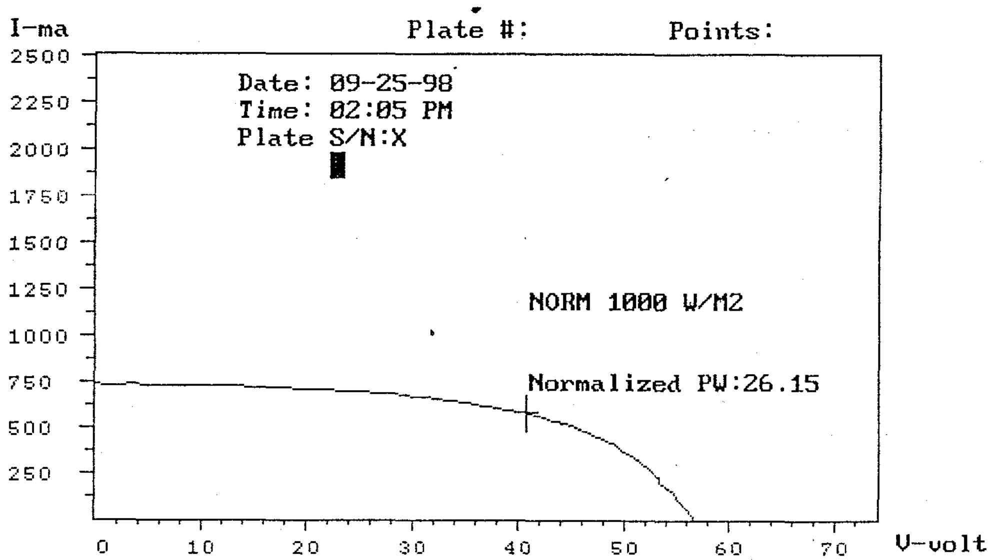
P+L shows more than 50% rate of return on investment.



Voc:60.7 Isc:0.934 %FF:63.5 Pw :36.02 LLVoc:11.13
Vm :46.6 Im :0.772 Rs :13.2Ω Rsh:1167.6Ω TEMP :16.9°C

Table 1

Cross-Scribed Panel I-V Curve, First Stage

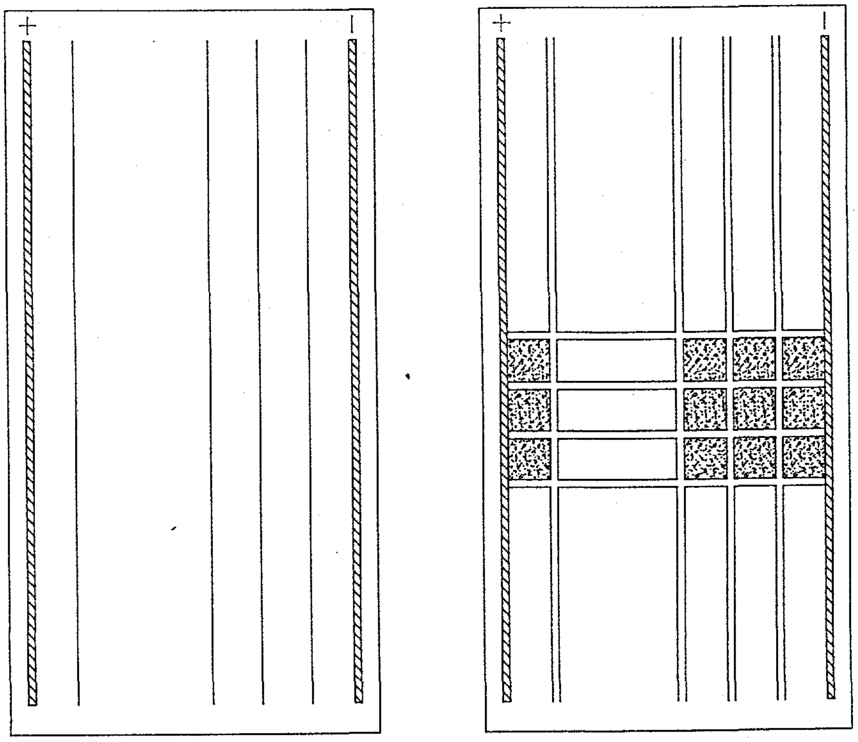


Voc:57.0 Isc:0.814 %FF:56.4 Pw :26.15 LLVoc:2.54
Vm :40.9 Im :0.639 Rs :15.9Ω Rsh:540.5Ω TEMP :22.8°C

DATE: 09-25-98

Table 2

Cross-Scribed Panel I-V Curve, Second Stage



Figures 1a and 1b

Schematic Diagrams of Standard and Cross-Scribed PV Panels

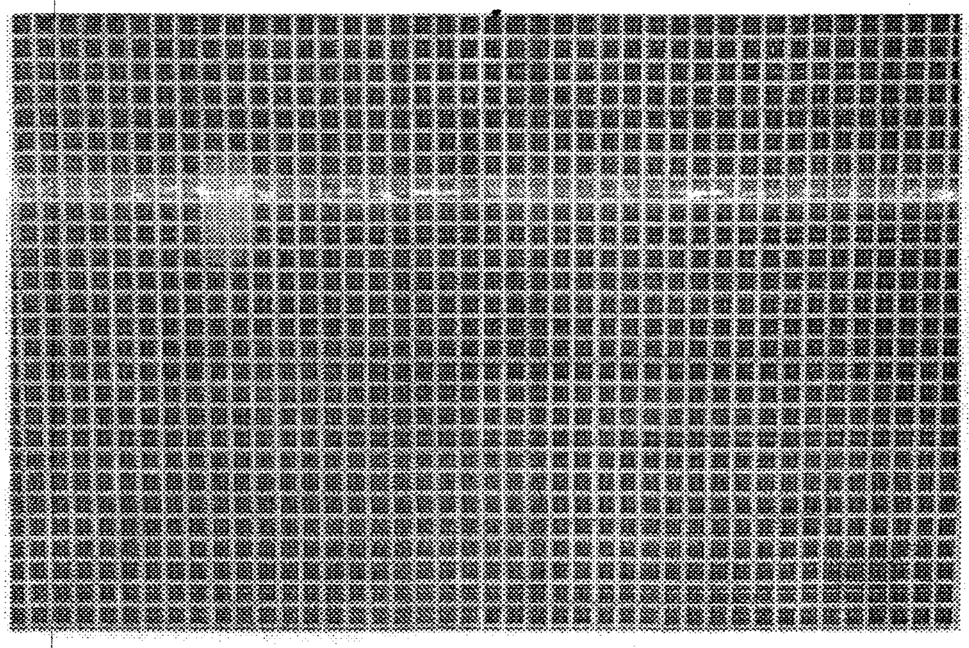


Figure 2

Cross-Scribed Panel Surface

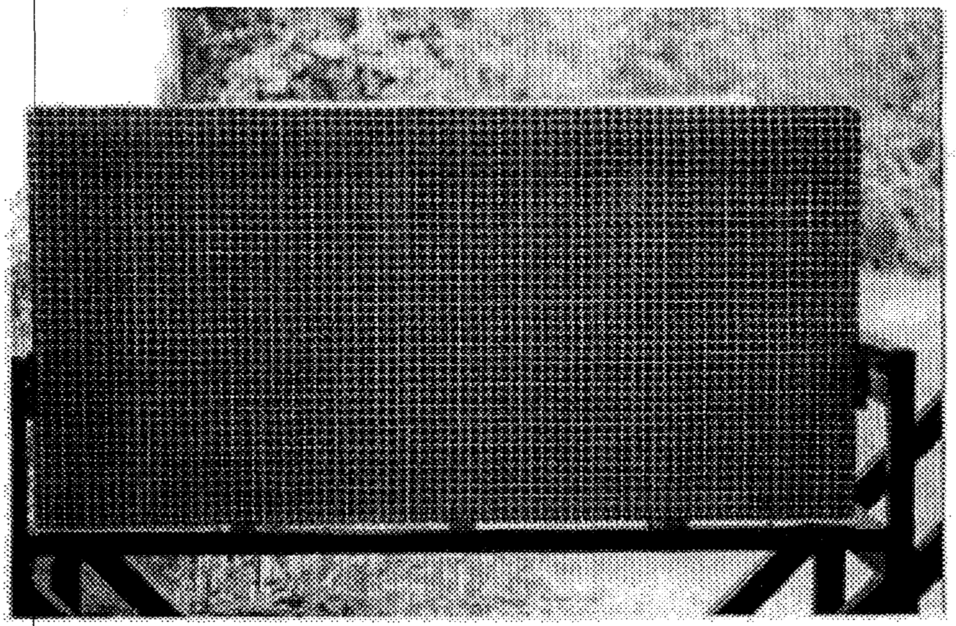


Figure 3

Cross-Scribed Panel

Figure 4

Exterior Seen through Cross-Scribed Panel