September 1993 • NREL/TP-411-5739

Amorphous Silicon PVMaT Phase 2A

Semiannual Subcontract Report 1 May 1992 — 31 October 1992

G. Duran, K. Mackamul, D. Metcalf, M. Stern
Utility Power Group
Chatsworth, California

H. Volltrauer, T. Varar, E. Urbanski, T. Dibiaso, D. Skinner
Advanced Photovoltaic Systems, Inc.
Princeton, New Jersey

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Managed by Midwest Research Institute
for the U.S. Department of Energy
under contract No. DE-AC36-83CH10093

NREL/TP-411-5739 • UC Category: 271 • DE93018221

Amorphous Silicon PVMaT Phase 2A

Semiannual Subcontract Report 1 May 1992 — 31 October 1992

G. Duran, K. Mackamul, D. Metcalf, M. Stern
Utility Power Group
Chatsworth, California

H. Volltrauer, T. Varar, E. Urbanski, T. Dibiaso, D. Skinner
Advanced Photovoltaic Systems, Inc.
Princeton, New Jersey

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
Operated by Midwest Research Institute
for the U.S. Department of Energy
under contract No. DE-AC02-83CH10093

Prepared under Subcontract No. ZM-2-11040-06

September 1993

This publication was reproduced from the best available camera-ready copy submitted by the subcontractor and received no editorial review at NREL.

NOTICE

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Microfiche A01
Printed Copy A04

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issue of the following publications which are generally available in most libraries: *Energy Research Abstracts (ERA)*; *Government Reports Announcements and Index (GRA and I)*; *Scientific and Technical Abstract Reports (STAR)*; and publication NTIS-PR-360 available from NTIS at the above address.

Printed on recycled paper

SUMMARY

Goal: The primary goal of this subcontract over its (3) three year duration is to significantly advance the photovoltaic manufacturing technologies, reduce module production costs, increase average module performance, and increase the production capacity existing in Utility Power Group and Advanced Photovoltaic Systems, Inc.

Approach: Utility Power Group and Advanced Photovoltaic Systems have been conducting parallel efforts in developing their manufacturing lines. Areas of focus include:

- o Encapsulation and Termination
- o Product Design
- o Process and Quality Control
- o Automation

Utility Power Group (UPG) will improve the existing UPG encapsulation system through the development of advanced encapsulation material;s and processes which result in a module that does not require backing glass. In addition, UPG will work to develop advanced termination materials and processes. Advanced Photovoltaic Systems (APS) will perform development activities centered on the EUREKA Manufacturing line. Developments in the APS EUREKA encapsulation system will be in addition to the UPG activity on encapsulation, and will offer an alternative approach to the problems of encapsulating large area thin-film modules.

TASK 1 POWERGLASS Module Encapsulation

Utility Power Group has been developing an advanced encapsulation system for its manufacturing line. Particular emphasis is given to the simplification of the module structure to a tempered superstrate, with thin-film layers, which will be protected by advanced substitute materials. This includes a wide-range of materials for single and multi-layer encapsulation systems designs, as well as selection of vendors to demonstrate the feasibility of superstrate glass tempering. All materials will be evaluated in terms of the level of environmental protection provided to the thin-film module, manufacturing cost reduction, and photovoltaic systems related factors. Prototype modules will then be produced for evaluation by potential and existing customers, and if required, design modifications will be performed. Prototype modules will then be subjected to accelerated life testing. Issues to be addressed in product development, in addition to designing quality into the product include; considering raw material cost reduction, automation, the reliability of the product, and the weight of the product as it pertains to shipping costs.

TASK 2 POWERGLASS Module Termination

UPG has been optimizing the material(s) and process(es) utilized in the electrical termination of the POWERGLASS module. The technical approach is to design and fabricate several candidate POWERGLASS module termination configurations to be compatible with the candidate encapsulation materials and processes developed in Task 1. All termination components will be designed for use with automated insertion and assembly equipment/robotics. All designs will be analyzed in terms of manufacturing cost reduction of the current process and ease of use from the customers' viewpoint. Upon completion of design and fabrication, candidate terminals will be attached to POWERGLASS modules for evaluation and testing.

TASK 3 EUREKA Module Design

Advanced Photovoltaic Systems, Inc. (APS) has been developing, by using computer aided design techniques, several power modules based on plate generated by the EUREKA manufacturing line. Evaluation of candidate designs will be based upon the following criteria:

- Market Demand
- Quality
- Cost of Manufacture

The most successful designs will be progressed to prototype level for a second stage of critical examination. It is anticipated the several iterations will occur between the design stage and prototype fabrication. Finally, full scale modules will be assembled based on the best indications from the design and prototype studies. It is anticipated that the successful completion of this task will result in a minimum of two new products that will offer clear advantages over existing manufacturing technology such as raw material cost reduction, and the weight of the product as it pertains to shipping costs. These designs will still maintain the EUREKA modules' current high level of quality and reliability.

TASK 4 EUREKA Process and Quality Control

APS is engaged in an effort to reduce module production costs while maintaining quality and increasing module performance and throughput. This task is designed to advance the full automation of the EUREKA photovoltaic manufacturing system and its quality control. To perform this task, APS must:

- Increase predictability of the process;
- Identify the cause of extraneous variables;
- Evaluate the process without interrupting it.

Through the implementation of the necessary distributed data, acquisition and control systems, coupled with the necessary

manufacturing system management to link production, process and quality, the desired cost reductions coupled with enhanced product performance will be achieved. During this phase, an extensive review has and will be made establishing which parameters should be identified as critical control points which would greatly benefit the quality, yield and throughput of the line.

TASK 5 EUREKA Power Module Encapsulation and Termination

APS has been conducting development activities to improve the module encapsulation and termination procedure for EUREKA based product by conducting studies in the following areas:

- Cost reduction;
- Reduction of plate to module output loss.

During this phase of the project, emphasis has been given to cost reduction of EVA content in the laminate. APS has also been investigating methods of reducing plate to module power losses.

TASK 6 Automation in EUREKA Manufacturing Line

APS has increased and will continue to increase both the manufacturing capacity and yield of the EUREKA line. The key areas to be investigated include:

- Throughput;
- Reproducibility;
- Control;
- Automation.

During this first phase of the subcontract, emphasis has been given to the laser processing stations and key elements such as, increasing repeatability of the scribing process, increasing the active area utilization of the module, and decreasing the process cycle time.

TABLE OF CONTENTS

Page

1.0 Background 1

2.0 TASK 1: POWERGLASS Module Encapsulation 8

- Polyurethane 9
- Epoxy 10
- Silicone 10
- Plastic Copolymer 11
- Application Experiments 12
- Task 1 Summary 15

3.0 TASK 2: POWERGLASS Module Termination 16

- New POWERGLASS Design 18
- Terminal Cost 20
- Ease of Attachment/Connection 20
- Adaptability to Multi-Module Systems 25
- Termination Experiments 26
- Task 2 Summary 30

4.0 TASK 3: EUREKA Module Design 31

- General Approach 31
- Status 32

5.0 TASK 4: EUREKA Process and Quality Control 33

- General Procedures 33
- Special Projects 35

6.0 TASK 5: EUREKA Power Module Encapsulation 36
and Termination

- Cost Reduction 36
- Reducing Power Loss 37

7.0 TASK 6: Automation In EUREKA Manufacturing Line 37

- Silicon Deposition 37
- Box Carrier Loading 37
- Heat Age Station 38
- Lasers 38
- Encapsulation Line 38

LIST OF FIGURES AND TABLES

Figure — Page

1. Costs of Current Process Steps 3
2. Total Current Module Costs 4
3. Costs of Future Process Steps 5
4. Total Future Module Costs 6
5. Process Cost Comparison 7
6. Binding Post Terminal Design 21
7. Spring Clip Terminal Design 22
8. Wire Cage Clamp Terminal Design 23
9. Threaded Bolt and Nut Terminal Design 24
10. Torque Strength of Various Solder Methods 28

Table — Page

1. List of Current Module Process Steps 1
2. List of Future Module Process Steps 2
3. Costs of Current Module Termination Design 16
4. Percent Spread in Electrical Parameters 34
5. Relative Yields for Encapsulation Process Steps 35

1.0 BACKGROUND

As a result of Utility Power Group's participation in the Photovoltaic Manufacturing Technology - Phase 1 program, the costs for producing the type of PV modules deployed at the Photovoltaics for Utility Scale Applications (PVUSA) Project have been itemized and classified by Process Step, Materials, Operating Expense, and Labor. By examining the module fabrication processes systematically, reductions in the cost of fabrication were investigated at a level of production on the order of 10 megawatts (MWp) per year.

TABLE 1

Number	Process Step
1.	Pattern Front Transparent Conductor
2.	Clean
3.	Screen Print Conductive Paste
4.	Fire
5.	Screen Print Maskant Paste
6.	Bake
7.	Deposit a:Si
8.	Deposit Back Metal
9.	Anneal
10.	Remove Maskant
11.	Attach Ribbon Conductor
12.	Laminate
13.	Terminate
14.	Cure
15.	Final Clean
16.	Test

Table 1 is a list of the process steps utilized to fabricate the type of modules which were deployed at PVUSA in 1989 and are to be classified as the Current Module.

Figure 1 shows the costs of the Current Process Steps based on the list of steps in Table 1. The costs of each process step has been further broken down into the three components; materials, operating expenses, and labor. Steps 7 and 8 have been grouped together because these three process steps occur sequentially in the same in-line fabrication system as essentially a single step. Figure 2 shows the total Current Module Costs broken down into the materials, operating expenses, and labor.

TABLE 2

Number	Process Step
1.	Prepare Module Glass
2.	Pattern Front Transparent Conductor
3.	Clean
4.	Screen Print Conductive Paste
5.	Temper Glass
6.	Screen Print Maskant
7.	Bake
8.	Deposit a:Si
9.	Deposit Back Metal
10.	Anneal
11.	Remove Maskant
12.	Terminate
13.	Apply Encapsulant
14.	Cure Encapsulant
15.	Test

Table 2 is a list of process steps that will be incorporated into a factory producing at least 10 MWp of photovoltaic modules per year. This manufacturing line will be using glass about 8 to 10 times larger in area that our current process and will be classified as the Future Module.

Figure 3 shows the costs of the Future Module Process Steps based on the list of steps in Table 2 and further broken down into the materials, operating expenses, and labor components. Steps 8 and 9 have been grouped together as both of these process steps will be performed within an automated thin film materials processing system. Figure 4 shows the total Future Module Costs broken down into the three components; materials, operating costs, and labor.

Figure 5 shows a comparison between the process costs of the Current Module and the Future Module with the bulk of the savings due to reduced labor costs with the large amounts of automation incorporated into the Future Module manufacturing line.

Although designed for UPG's new production facility, implementation of UPG's future process into UPG's current module production facility would provide a substantial reduction in module cost. The bulk of this cost reduction is due to the elimination of the ribbon conductor, rear tempered glass, and the manual termination step.

Figure 1. Costs of the Current Process Steps based on the list of steps in Table 1 and further broken down into the three components; materials, operating costs, and labor.

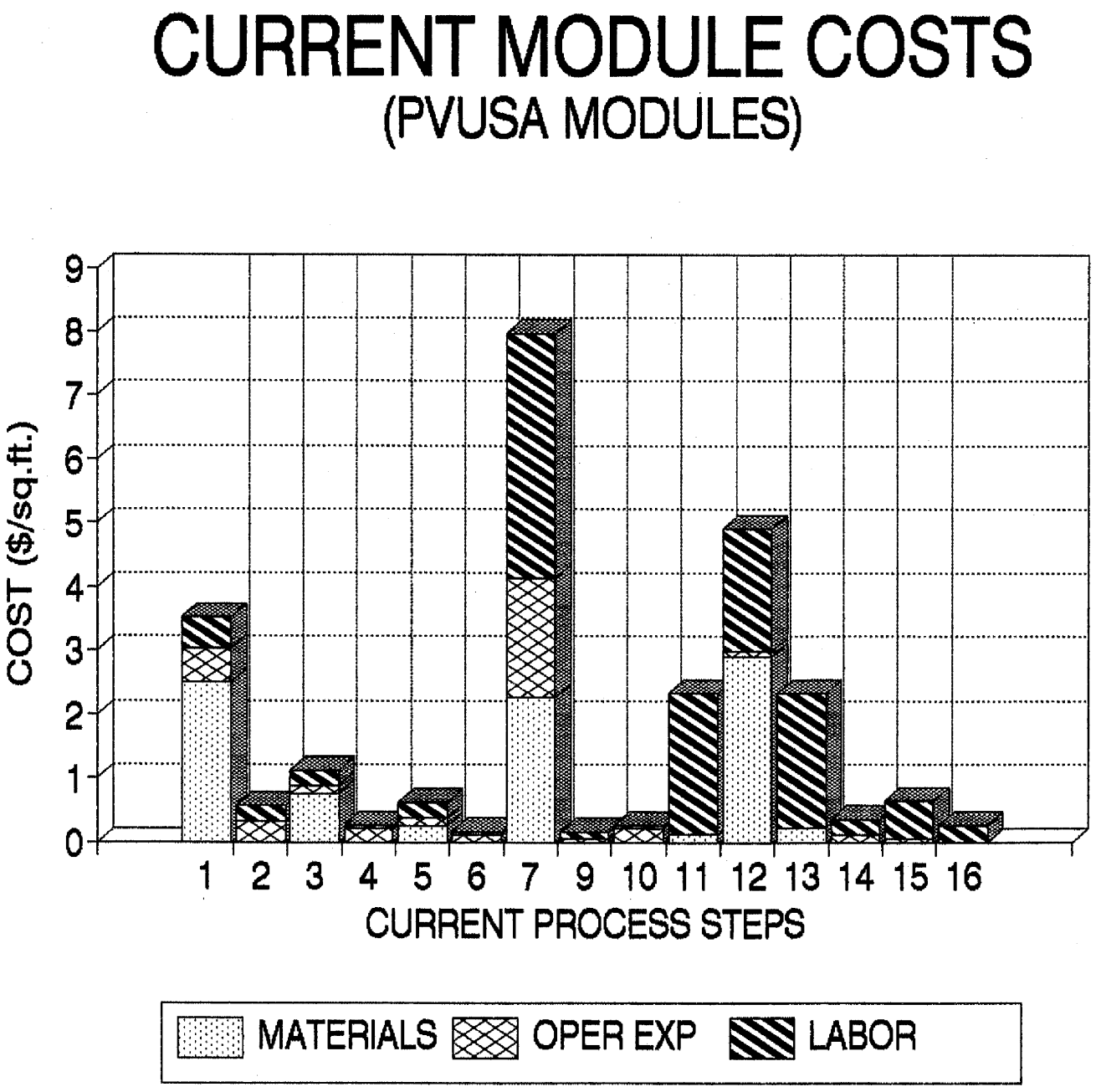


Figure 2. Total Current Module Costs broken down into the categories materials, operating costs, and labor.

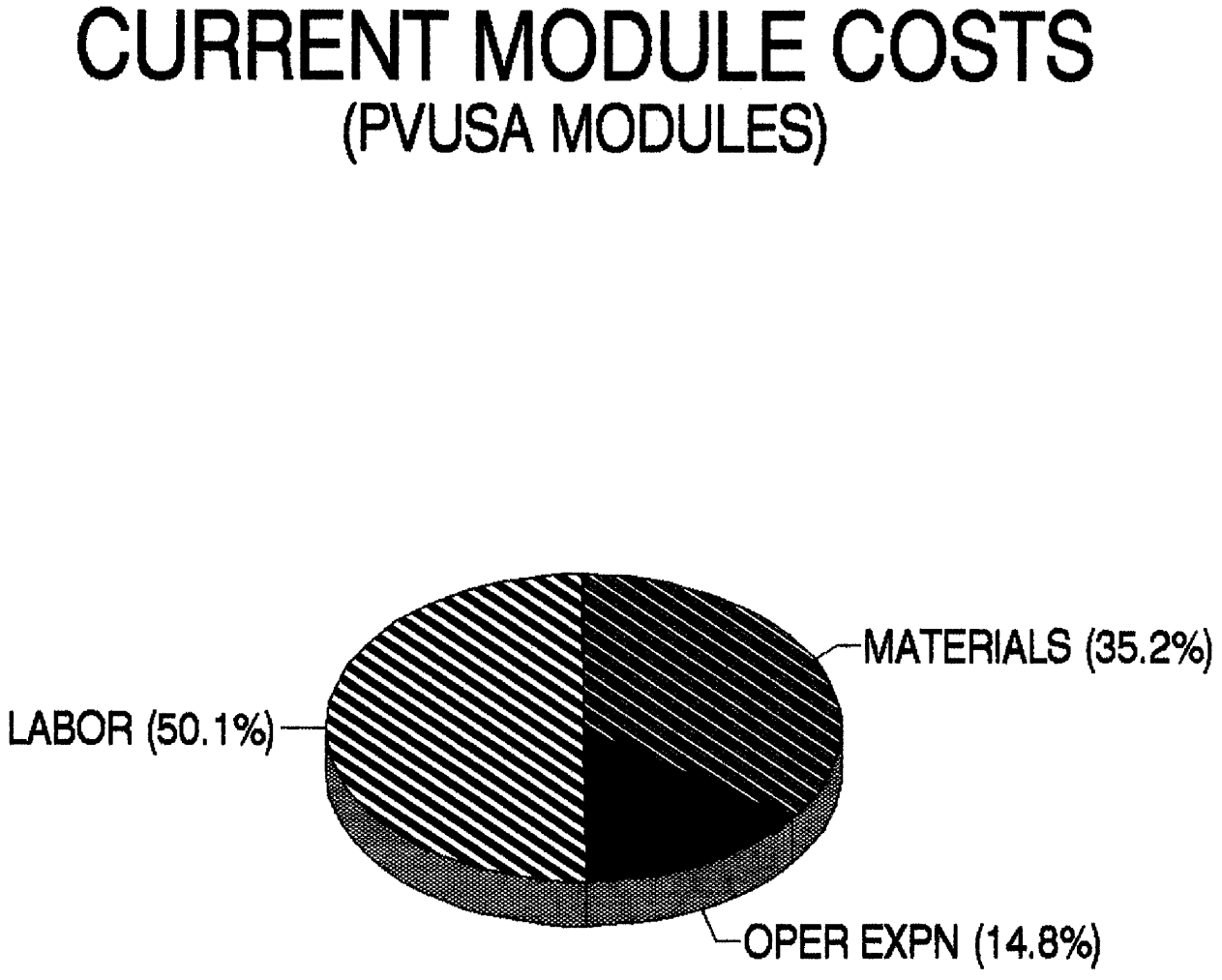


Figure 3. Costs of the Future Module Process Steps based on the list of steps in Table 2 and further broken down into the materials, operating expenses, and labor components.

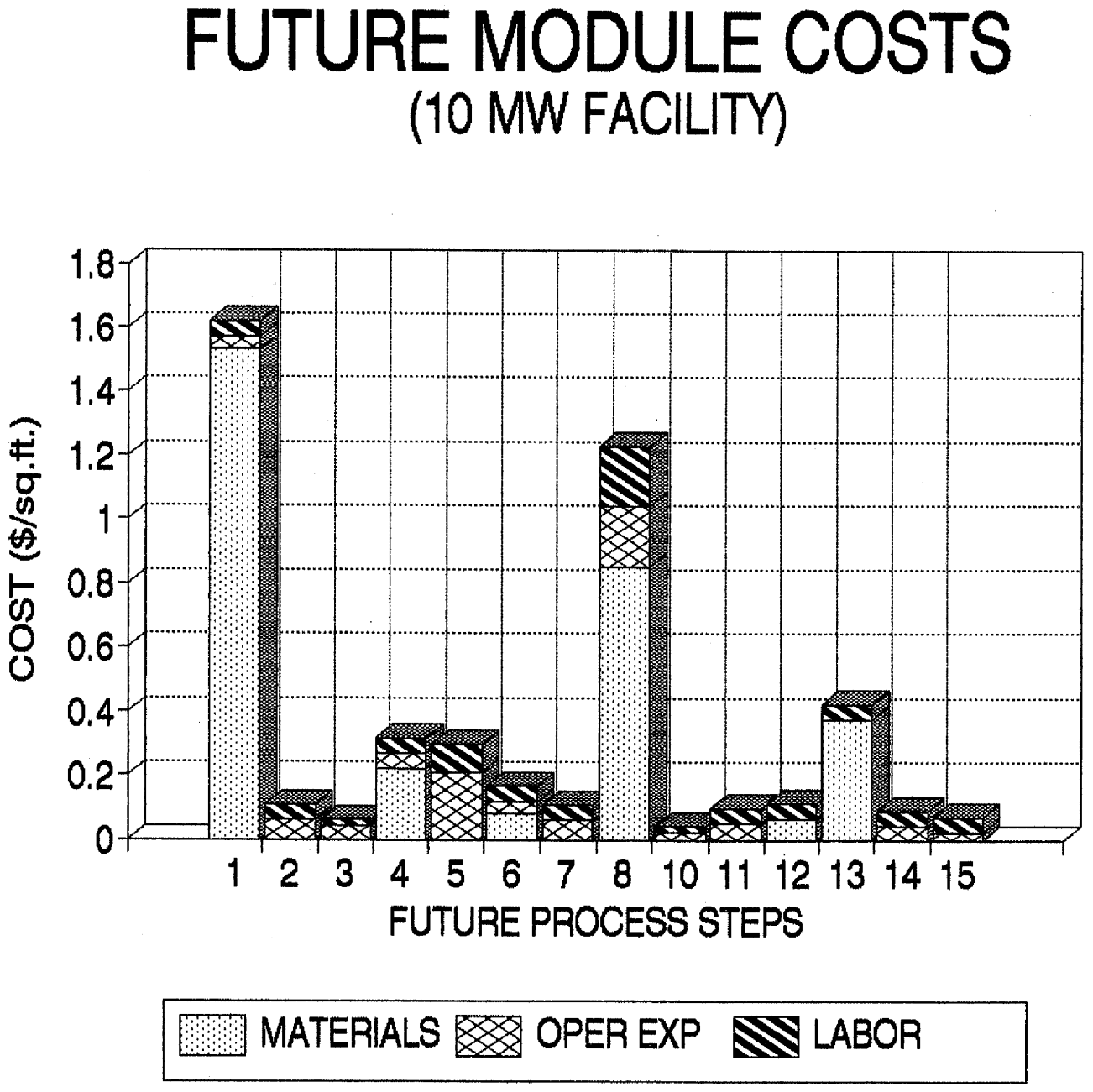


Figure 4. Total Future Module Costs broken down into the three components; materials, operating expenses, and labor.

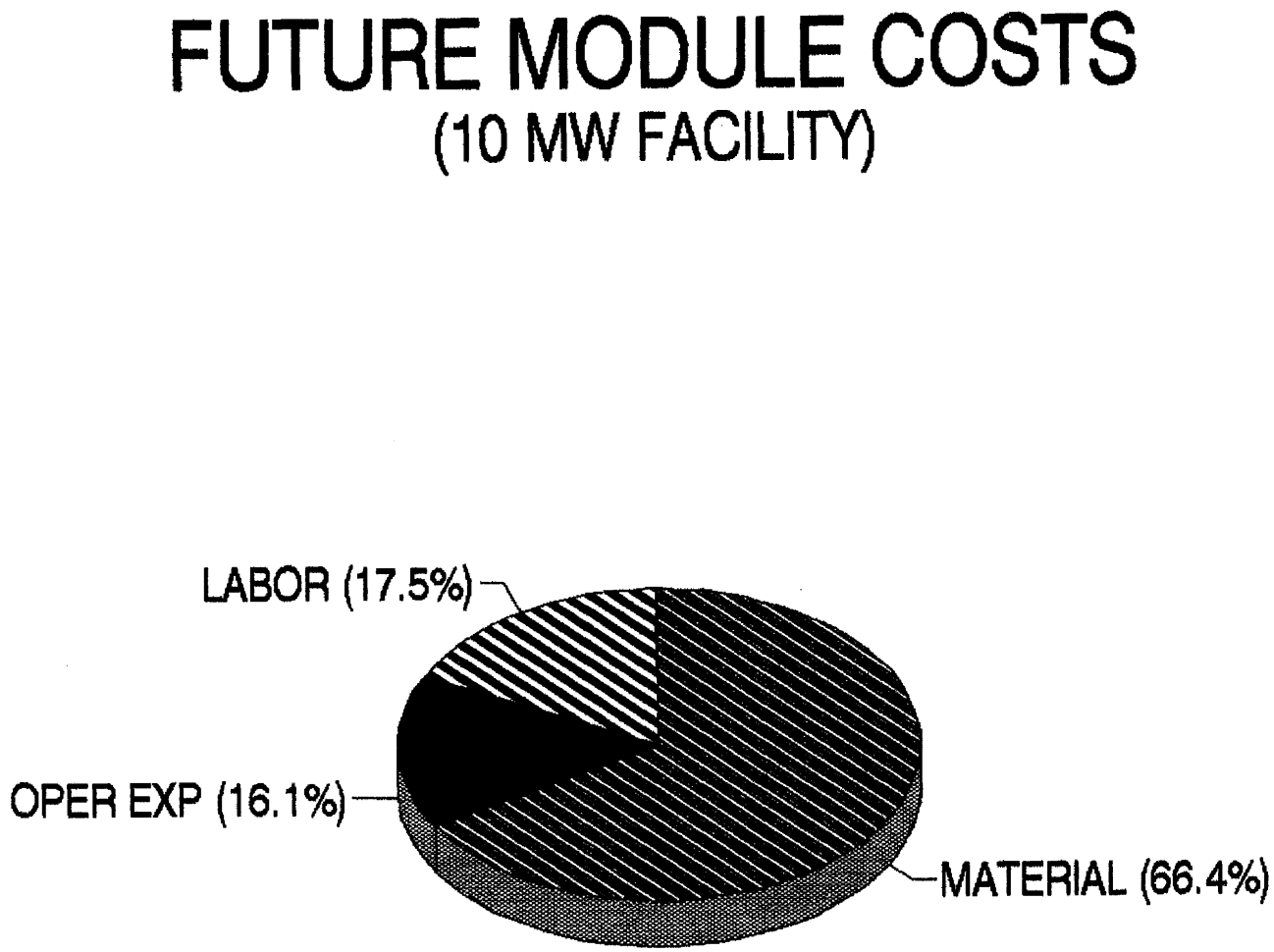
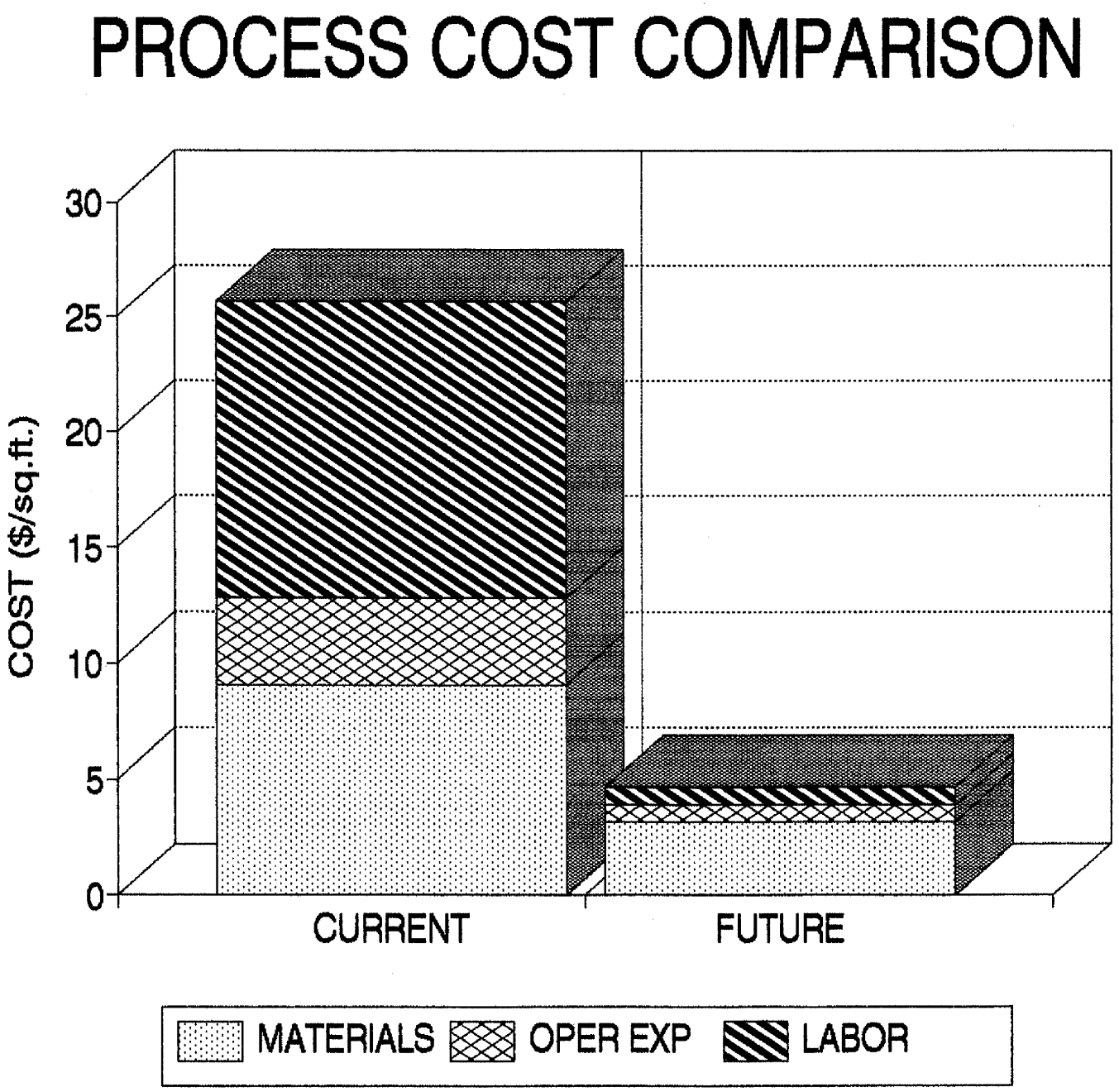


Figure 5. Comparison between the process costs of the Current Module and the Future Module with the bulk of the savings due to the reduced labor costs associated with the large amounts of automation incorporated into the Future Module manufacturing line.



2.0 TASK 1: POWERGLASS Module Encapsulation

In this task UPG is investigating a wide variety of materials and processes for the encapsulation of amorphous silicon thin film PV circuits deposited on glass substrates. These materials are to be evaluated in terms of their substrate adhesion, scratch resistance, chemical resistance, water penetration resistance, compatibility with module fabrication techniques, and air quality environmental concerns. Methods and materials are sought which lend themselves to environmentally safe application, high volume throughput, low unit cost, and automated application techniques. Areas of focus include:

- Materials
- Application
- Reliability
- Cost

The materials considered so far fall into four main categories:

1. Polyurethanes
2. Epoxies
3. Silicones
4. Plastic Copolymers

The following is a list of the materials investigated to date:

Polyurethanes:

Hardman, Inc.	-	Kalex 13361 A/B
Conap, Inc.	-	Conathane CE-1163
	-	Conathane CE-1175
Chase Humiseal Corp.	-	Humiseal 1A27
	-	Humiseal 1A33
	-	Humiseal 1A20
Epmar Corp.	-	EX165

Epoxy:

Ameron Corp.	-	Amercoat 385P

Silicone:

Dow Corning Corp.	-	Q3-6611
	-	577
Chase Humiseal Corp.	-	Humiseal 1C49
General Electric	-	RTV 630
	-	RTV 128

Plastic Copolymer:

Plastic Flamecoat	-	PF 110
	-	PF 112
	-	PF 160

Polyurethane

Hardman, Inc. - Kalex 13361 A/B
This material is a filled, nonabrasive, medium viscosity, two part, rigid urethane system, curable at room temperature, useful for low and medium voltage applications with superior thermal cycling performance. The viscosity of this material lends itself to screen printing. However, this material provided very poor protection against chemical attack to the encapsulated thin film. In addition, the adhesion of the polyurethane to the substrate was not adequate.

Conap, Inc. - Conathane CE-1163
This material is a single component polyurethane coating developed specifically for protecting printed circuit boards under adverse environmental conditions. It cures at room temperature in the presence of moisture to form a highly cross-linked film that appears glossy. Methods which may be used to apply CE-1163 include airless spray, pour curtain, dipping, and brushing. CE-1163 contains xylene, toluene diisocyanate, and propylene glycol methyl ether acetate. The organic solvent vapors which evolved from the material as it cured were strongly present. The cured coating was hard and adhesion to the substrate was excellent. The coating protected the thin aluminum film on the substrate from being attacked by a hot NaOH solution.

Conap, Inc. - Conathane CE-1175
This material is a single component polyurethane similar to CE-1163 except that it is water based. Since the CE-1175 is water based, clean up of application equipment is simpler, less time consuming, and less hazardous compared to the CE-1163 product. However, after application to test coupons and overnight cure, portions of the aluminum film appeared discolored. It is believed that the water contained in the product reacts with the thin film aluminum causing the discoloration.

Chase Humiseal Corp. - Humiseal 1A27
This material is an air drying single component polyurethane coating widely used for printed circuit board applications. The Humiseal 1A27 is low to medium viscosity allowing it to be poured onto the test coupons. The cured coating was hard and adhesion was excellent. After immersion in the hot NaOH for one hour, the underlying aluminum thin film being protected by the coating was etched by the NaOH, and the coating appeared damaged as evidenced by 1mm-2mm diameter holes in the coating itself. Adhesion remained unaffected.

Chase Humiseal Corp. - Humiseal 1A33
This material is a single component fast air drying polyurethane coating well suited for general printed circuit board applications. After application to test coupons and recommended cure, the test coupons were subjected to the hot NaOH immersion test for a period of one hour. The results of this test were identical

to those found for the Humiseal 1A27.

Chase Humiseal Corp. - Humiseal 1A20
This material is a single component, durable and chemically resistant moisture curing coating for printed assemblies. After application to test coupons and recommended cure, the test coupons were subjected to the hot NaOH immersion test for a period of one hour. The results of this test were identical to those found for the Humiseal 1A27 and 1A33.

Epmar Corp. - EX 165
This material is a two component, unfilled, 100% solids polyurethane potting and casting compound for electronic circuitry. Upon mixing according to the manufacturer recommended ratios, the two component material was poured onto test coupons and cured at the recommended schedule. Tests could not be performed due to the poor cure which occurred. After removel from the cure oven, the material on the test sample was only slightly more viscous than before entering the cure oven.

Epoxy

Ameron Corp. - Amercoat 385P
This material is a two component, sprayable coating, highly stable in harsh, aggressive environments. It forms a tough, abrasion resistant, durable film suitable for immersion in fresh and salt water up to 140 F continuously and can be used as a tank lining for alkaline and salt solutions, petroleum fuels, sewage waste, and other chemicals. The material applied to test coupons proved to have excellent adhesion characteristics, resistance to chemical attack, and scratch resistance. A relatively mild amount of organic solvent (compared to the Conap polyurethanes) was detected by smell during application and ambient cure.

Silicone

Dow Corning Corp. - Q3-6611
This material is a one part, flowable, silicone elastomer that develops a strong, self priming adhesive bond to many substrates when cured at high temperatures (125 C). Application of the silicone adhesive to test coupons was performed by two methods; brushing and by screen printing. After curing, the silicone exhibited excellent adhesion to the substrates and excellent resistance to the hot NaOH bath.

Dow Corning Corp. - 577 Primerless
This material is a two part, flowable, silicone elastomer which develops a strong, self priming adhesive bond to many substrates when cured. Application of the silicone adhesive to coupons was performed by spatula. Parts were cured at 125 C for a period of one hour. After curing, the parts exhibited excellent adhesion to the substrates before and after hot NaOH immersion and excellent resistance to chemical attack. No etching of the underlying

aluminum thin film was observed.

Chase Humiseal Corp. - Humiseal 1C49
This material is a fast curing, 100% solids single component silicone coating providing moisture protection for printed circuit assemblies. The Humiseal 1C49 was applied by directly pouring the material onto the test coupons. The material was then cured at 170 F for a period of 20 minutes per manufacturer's recommendation. After cure, the chemical resistance of the material was tested by immersing in hot NaOH solution for one hour. The 1C49 provided excellent protection to the underlying aluminum film from the NaOH. The adhesion remained excellent.

General Electric Corp. - RTV 630
This material is a liquid silicone rubber compound that cures at room temperature to a high strength silicone rubber with the addition of a curing agent. This two component product is "moderately pourable" according to the manufacturer. The two part product was mixed in the recommended 10:1 ratio of base to catalyst. The homogeneous mixture was then applied via spatula to a test coupon and cured per the manufacturer's recommended schedule. After the curing cycle, it was found that adhesion to the coupon was poor. It was subsequently determined that the manufacturer recommends a primer be applied to the surface of the substrate to be coated prior to application of the silicone elastomer. Never the less, the coupon was then subjected to the hot NaOH immersion test for one hour. The results of the immersion test found that the silicone did protect the underlying aluminum thin film from being etched although the adhesion was poor.

General Electric Corp. - RTV 128
This material is a single component adhesive sealant which cures at room temperature to a tough, silicone rubber. The immersion test results were identical to the GE RTV 630. The material provided excellent protection for the underlying aluminum thin film. The adhesion of the silicone to the substrate was excellent, however, the scratch resistance was poor. It was possible to scratch through a 0.075" thick film with a moderate pressure of a fingernail.

Plastic Copolymer

Plastic Flamecoat Systems, Inc. - PF 110
This product is a Dupont Surlyn based blend of materials which is UV stable, repairable, and environmentally safe. The softening temperature of the material is 176 F. Test coupons were coated and then subjected to the hot NaOH immersion test for the standard period. The results found that the adhesion and integrity of the coating were unaffected. The immersion test was performed at 77C. A subsequent test subjected another coated coupon to 30 minutes at 90 C in an oven. Upon removel, the thermoplastic was found to be soft and adhesion was poor, As the coupon cooled to ambient room temperature, the adhesion, toughness, and abrasion resistance returned to original values.

Plastic Flamecoat Systems, Inc. - PF 112
This material is a Dupont Surlyn based blend similar to PF 110 but with a softening temperature of 142F. After application, it was found that coating uniformity, scratch resistance, and adhesion were excellent. After hot NaOH immersion, the adhesion of the coating on parts which had cooled as well as parts that were still hot was tested. The coating on the parts which had after immersion exhibited the same excellent adhesion originally observed before immersion. The coating on the parts which had not completely cooled after immersion could be peeled away from the surface, Inspection of the aluminum film below the plastic which was peeled away revealed that no etching of the aluminum had occurred.

Plastic Flamecoat Systems, Inc. - PF 160
This material is based upon ethylene vinyl acetate copolymer (EVA). The melting point is the same as that of the PF 112 (149 F). Adhesion to the substrate was excellent. Softening occurred after NaOH immersion and adhesion reduced. However, while returning to room temperature, adhesion and toughness returned to original values. The aluminum below the EVA coating remained unaffected by the hot NaOH immersion.

At the conclusion of the first stage of materials investigation and selection, it was determined that the two most promising encapsulation materials were; Dow Corning 577 Primerless Silicone and Plastic Flamecoat Systems PF 110.

Application Experiments

Dow Corning Corporation - 577 Primerless Silicone
Application methods are sought which lend themselves to environmentally safe application, high volume throughput, and automation. One such application technique is spraying. During a demonstration at GRACO Inc. of Los Angeles, California, an attempt was made to spray the DOW 577 product, using air-assisted/airless spray technology, onto otherwise uncoated glass. The purpose of the test was to determine if the extremely high viscosity material could be sprayed to provide a uniform, thin (0.005" - 0.006"), coating over a one square foot area.

The experiments were conducted using only the base component of the two part DOW 577 product. Due to equipment limitations, the curing agent could not be included in the tests. This was due to the fact that the equipment which was available for use did not have mixing or metering capability. It was thought that if the method provided acceptable results using only the base material that the two part mixture would be relatively easy due to its lower mixed viscosity. The following data describes the viscosity of the DOW 577 product per Dow Corning's technical publication:

BASE
Viscosity @ 25C, centipoise 135,000

CURING AGENT
Viscosity @ 25C, centipoise 5,000

CATALYZED 10:1 ratio base to curing agent by weight
Viscosity @ 25C, centipoise 87,244

A fair amount of time was spent changing spray parameters in order to optimize delivery pressure, air tip pressure, and air tip size. Material was delivered from a five gallon pail to the spray gun by applying 300 psi at a following plate. By the time the material had reached the spray gun, the pressure at the gun had dropped to 1000 psi. The base material left the spray gun in strings closely resembling spagetti. The velocity of the strings was surprisingly low considering the pressure at the gun. Attempts were made to break up the strings into small droplets by atomization at the gun tip exit. The best results yielded strings that were approximately 0.50" in length and 0.001" - 0.002" thick.

A single pass of the gun at a distance of approximately one foot did not provide continuous coverage. Six to seven passes of the gun at the same distance provided close to continuous coverage. After 15 to 20 minutes standing, the voids began to fill as the material coalesced. Six to seven passes of the gun provided 0.012" wet film thickness.

DOW Corning Product Q3-6611 is a single component primerless silicone adhesive. Its viscosity is 95,000 centipoise @ 25C. Since this material's viscosity closely matches the mixed two part product's viscosity, it was decided to try to spray the single component material to see if the lower viscosity material, compared to the base material used prior, would allow better spray performance. Glass was cleaned, coated with sputtered aluminum, and cut to 10 cm x 10 cm size. Approximately 30 of these samples were sprayed with silicone, varying the thickness of the coating.

The first result which was apparent was that the Q3-6611 material's lower viscosity provided a spray pattern which more closely resembled small droplets as opposed to the string pattern produced with the 577 base material. The thickness and uniformity of the coating was controlled by speed of application, distance between gun tip and sample, and the number of spray passes.

Wet film thickness of the samples ranged from 0.002" to 0.016". The parts were transported back to UPG and cured for one hour at 120C. Portions of the cured silicone coating were removed from each 10 cm x 10 cm sample for thickness measurements. The thickness of each coating sample was profiled in three locations along the length of the 10 cm strip removed for thickness measurements. For coating thicknesses in the range between 0.002" and 0.004", pinholes in the cured coating were apparent. Coating thicknesses

from 0.005" to 0.006" had no apparent pinholes. Immersing samples into hot NaOH for a period of 30 minutes revealed that coating thicknesses of 0.005" or greater provided complete protection for the underlying aluminum from the hot NaOH etch.

The conclusion of these tests found that the single part DOW Q3-6611 material can be sprayed fairly uniformly with a continuous coating achieved with a minimum thickness of 0.005". The minimum thickness also provides protection to the thin film aluminum from the NaOH etch. From these results it may also be concluded that no fundamental problem exists which would prevent the spraying of the two part DOW 577 product since its viscosity is lower that the Q3-6611.

Plastic Flamecoat Systems, Inc. - PF 110

PF 110 is a Dupont Surlyn based blend of materials which is UV stable, repairable, and environmentally safe. The PF 110 material is a finely ground powder. It is received from Dupont as pellets. The powder is produced by grinding the pellets after they have been cooled cryogenically. The softening temperature of the material is 176 F (80 C). Prior to application, the starting section of the surface to be coated is pre-heated using the flame torch. The surface is pre-heated to approximately 170 F. The material is then fed from the hopper through compressed air lines at 60 PSI and forced through the spray nozzle and propane flame. The molten material blend strikes the surface to be coated, then cools to form a tough, adherent, monolithic, pinhole free film.

Representatives from Plastic Flamecoat Systems (PFS) and Sinclair Paints, (PFS product distributor), visited UPG's facility to demonstrate the PFS coating equipment. Several attempts at coating glass substrate were made with varying degrees of success. It is very important to preheat the substrate in a controlled manner. The substrate is preheated with the flame torch by manually passing the torch a predetermined distance from the part uniformly across the surface of the part to be coated. Measurement of the temperature was accomplished by placing a digital thermometer probe on the surface of the part. For our application, parts were preheated to 107 C.

Substrates broke during the demonstration, as they were being coated. In one case, the time duration of the flame in proximity to the substrate was too long. In another case, the flame was too close to the glass with the coating passes too slow.

Several glass substrates were coated without breaking. The most difficult variable to control, even for the experienced operator, with this application seemed to be associated with the flame. The mechanical yield for the large area (1 sq.ft.) parts was 50%. All yield loss was directly related to thermal stress.

An interesting result was observed when a glass part was placed on a hot plate and heated to 150 C, and a coating subsequently

applied by spraying the PF 110 powder without the flame. A high quality film was formed. This indicated that the torch is not necessary for a successful coating. This result led to experiments which eliminated the flame torch altogether.

One method we investigated to apply the PF 110 material uniformly to a glass surface used nylon mesh stretched over a wire frame. Placing powder on the mesh and then softly forcing the material through the mesh provided a fairly uniform dry film thickness. This approach was tried on both preheated parts and parts that were not preheated. Adhesion of the final film was excellent in both cases after the material had been given a chance to set and flow at elevated temperatures.

Task 1 Summary

A wide variety of materials and processes for the encapsulation of amorphous silicon thin film PV modules deposited on glass substrates have been investigated. These materials have been evaluated in terms of their substrate adhesion, scratch resistance, chemical resistance, water penetration resistance, compatibility with module fabrication techniques, and air quality environmental concerns.

At the conclusion of the first stage of materials investigation and selection, it was determined that the two most promising encapsulation materials were; DOW Corning 577 Primerless Silicone and Plastic Flamecoat Systems, Inc. PF 110 plastic copolymer.

The DOW 577 Silicone can be applied in a variety of ways, however, the first technique which was investigated at length has been spraying. This air-assisted/airless spraying technology was satisfactorily demonstrated to UPG by an equipment manufacturer, GRACO, Inc. of Los Angeles, California.

The Plastic Flamecoat Systems, Inc. (PFS) plastic copolymer product PF 110 utilizes a powder coating technology which has been modified by UPG to produce a higher yield glass coating process.

3.0 TASK 2 POWERGLASS Module Termination

In this task UPG shall optimize the material(s) and process(es) utilized in the electrical termination of the POWERGLASS module. The role of module termination is to provide an electrical connection between the module and the external power circuit. The design of an advanced module termination system requires optimization of the following criteria:

1. Terminal material cost
2. Terminal attachment cost
3. Terminal reliability
4. Terminal adaptability

The current POWERGLASS module termination design was analyzed, and as shown in Table 3, the material cost and attachment cost of new terminal designs must not exceed $1.66 to achieve at least a 50% reduction in POWERGLASS termination cost.

Table 3

Item	Cost
Ribbon (2)	$0.12
Connector (2)	$0.16
Boot (2)	$0.46
Pottant	$0.08
Labor	$2.50
Total	$3.32
Design Goal	$1.66

Standardization is an important element in the reduction of PV module manufacturing cost. For example, PV modules may be manufactured in a variety of sizes and power levels, but if they each utilized the same termination design, termination cost could be kept at a minimum. Different terminal designs may require different attachment equipment or tooling, additional inventory of terminal components, increased downtime for changeover, and a higher level of employee flexibility and training. The ideal termination design is low cost, high reliability, and is equally adaptable to single module consumer applications as well as multiple module power systems. Achieving this level of adaptability is non-trivial, since consumer modules may provide a power cord with no user accessible terminals, while power system mod-

ules are usually factory assembled and wired into panels where junction boxes (J-boxes) permit attachment of diodes and multiple module paralleling directly at the module's terminals.

A vendor literature search of off-the-shelf terminals has resulted in the conceptualization of four initial terminal configurations:

1. Binding Post
2. Wire Cage Clamp
3. Threaded Standoff
4. Spring Clip

Initial literature searches and discussions with vendors of automatic assembly equipment has brought into question the viability of flat ribbon in module termination. The value of a ribbon as strain relief for the bus bar and as an "edge friendly" wraparound conductor, were weighed against its performance in a high throughput production environment.

As shown earlier, $2.50 or 75% of the cost of termination was due to labor. This cost of labor can be further broken down as follows:

Ribbon attachment:	$1.50
Terminal attachment:	$0.75
Boot attachment:	$0.25
Total:	$2.50

In terms of materials cost (conductivity per unit $), aluminum ribbon or tin plated copper ribbon is a better choice than a high silver content glass frit paste. The POWERGLASS module utilizes a metal ribbon assisted bus bar design in which a 0.003" thick tin plated copper ribbon is soldered to an underlying fired conductive paste bus bar. The purpose of the ribbon is twofold:

1) to carry current flow with a minimum of resistance,
2) to permit routing of that current flow through the back glass surface of the module.

Given UPG's goal of elimination of the back glass surface, the ribbon must be evaluated based upon its first purpose. Since the conductive bus bar is a critical component of the POWERGLASS module interconnection process, its elimination will not be considered. To achieve an acceptable level of conductivity along the bus bars, a redesign has been performed to optimize the width, length, and thickness of the bus bar. The added bus bar material cost and the effect of the active area loss associated with a larger area bus bar were compared to the material and labor cost of the metal ribbon.

Underwriter's Laboratories Standard (UL 1703-Flat Plate Photovoltaic Modules and Panels) contains a terminal torque test which we will use as a terminal design acceptance criteria. The termination system on the current POWERGLASS module easily meets the UL 1703 torque requirements. Elimination of the metal ribbon will necessitate direct soldering of the terminal to the conductive fired frit bus bar, and the current bus bar fabrication process did not permit passage of the terminal torque test based on the preliminary measurements of torque applied to various terminal designs soldered directly to the bus bar.

The four candidate terminal concepts (Binding Post, Wire Cage Clamp, Threaded Standoff, and Spring Clip) required slight modification to be applicable to a module design without metal ribbon.

The POWERGLASS module terminal boot, which serves as a "sealed junction box", lacks the level of adaptability required by UPG for the future POWERGLASS module. Although the boot provides a reliable and low cost terminal seal for large PV system applications (PVUSA), feedback from the low power PV marketplace indicates a significant problem for the boot in those applications. Specifically, the boot is described as esthetically unattractive, and on a practical level, it does not allow the exit of a two conductor cable from a single module. UPG's design goal is to create a terminal which is adaptable to both single module and multiple module applications, yet which maintains the qualities of low cost and high reliability. A possible design solution is the use of two small injection molded plastic boxes directly over the terminals and which provide cable strain relief. The single module market also requires a frame, and we have investigated the feasibility of incorporating the terminal/junction box into a module frame.

New POWERGLASS Module Design

The new POWERGLASS module design utilizes a novel "U-turn" concept to allow the positive and negative terminals to be protected by a single enclosure (J-box), thereby eliminating the need for external conductors (busbar ribbons). The idea behind the "U-turn" concept is to have current flow from the bottom terminal of half of the module (submodule) to the top of the submodule, across to the other half of the module (the other submodule), and down to the opposite terminal. Using this technique, the silver paste busbar replaces the busbar ribbon. In addition, this design increases the active area of the module by decreasing the number of interconnects required to attain the desired module voltage. Unfortunately, this improvement is offset by the area loss associated with the terminal solder pads. Further refinement of this design could place the solder pads within the area of the busbar. The net increase in conductive paste usage is 1.44 cm^2 which at

a cost of $0.018/cm^2 results in a cost increase of $0.026. The elimination of the busbar ribbon reduces cost by $1.62, so the new design yields a reduction in module cost of $1.59.

Solder pads:

0.70 cm x 0.70 cm = 0.49 cm^2
+ (0.30 cm x 0.75 cm = 0.23 cm^2)
* 2 pads = 1.44 cm^2

One gram of silver paste will cover 74 cm^2.
One gram of silver paste costs $1.30.
Therefore $0.018 worth of silver paste covers 1 cm^2.

$0.018 x 1.44 cm^2 = $0.026

$1.62 - $0.026 = $1.59 savings

The elimination of the busbar ribbon could result in an increase in the resistive losses at the power collection points (the terminals). The following is a calculation of the predicted losses due to current flow through the silver paste busbar:

The silver paste has a bulk resistivity of 7 x 10^-6 ohms-cm as fired according to the paste manufacturer.

The cross sectional area of the busbar is:

0.25 cm x 2.5 x 10^-3 cm = 6.25 x 10^-4 cm^2

The linear resistivity of the busbar is:

7 x 10^-6 ohms-cm / 6.25 x 10^-4 cm^2 = 1.12 x 10^-2 ohms/cm

The length of the busbar is 32 cm. The calculated resistance of the busbar is:

32 cm x 1.12 x 10^-2 ohms/cm = 0.36 ohms

Maximum current of the module is 0.495 amps. The I^2R loss is:

(0.495 amps)^2 x 0.36 ohms = 0.088 watts

For the six watt module:

0.088 watts / 6 watts = 0.015 = 1.5%

This is assuming all of the current is flowing through the entire length of the busbar which would be the worst case scenario.

Excellent progress had been made in transferring the new POWER-GLASS module design (U-turn) from concept to pilot production. Pilot production is required to produce active modules for reliability testing purposes and to determine the manufacturability

of the design. Several modules were produced with total area efficiencies of greater than 4%, and the speed at which this was accomplished indicates a high level of manufacturability. Although placing the terminal pads at right angles to the busbars adds an undesired level of complexity to the TCO patterning step, it is expected to increase module reliability by moving the terminal area away from the module's edge.

Four candidate terminal designs (Figures 6-9) have been completed and samples were fabricated and evaluated in terms of cost and manufacturability. The four candidate terminal designs are:

1. Binding Post
2. Spring Clip
3. Wire Cage Clamp
4. Threaded Bolt and Nut

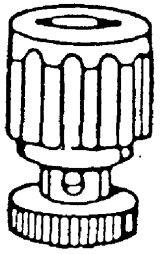
The four candidate terminal designs (Binding Post, Spring Clip, Wire Cage Clamp, and Threaded Bolt and Nut) were evaluated in terms of materials cost, ease of attachment/connection, and adaptability to multi-module systems.

Cost

The Treaded Bolt and Nut is the only terminal available "off-the-shelf", (it is a standard machine screw and nut) and as such, has a cost of $0.07 each in 10,000 piece quantities. In the same quantities, the cost of the Binding Post is $0.30 each, the Spring Clip is $0.20 each, and the Wire Cage Clamp is $0.45 each. Each module requires two terminals.

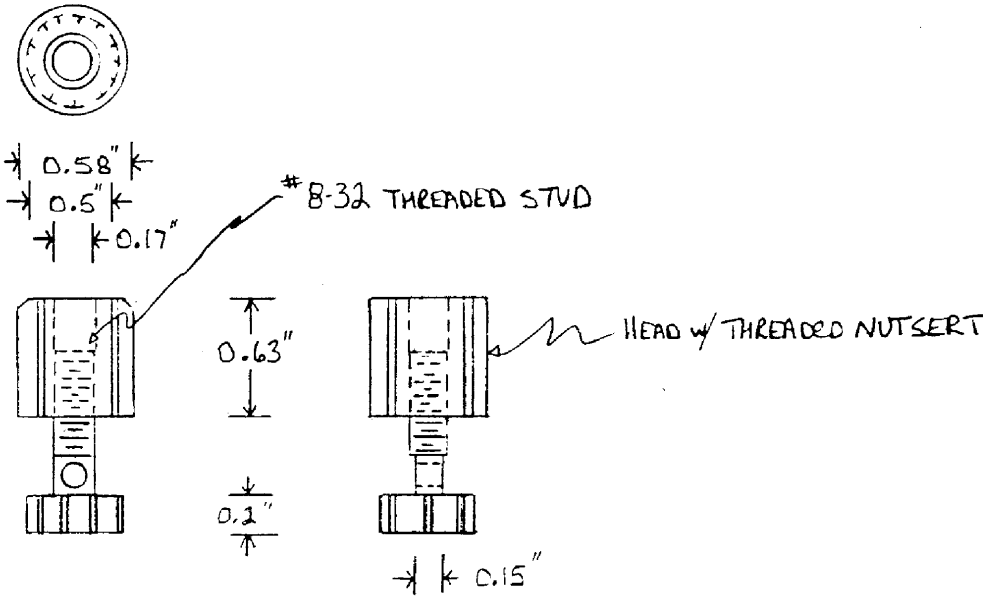
Ease of Attachment/Connection

All four of the candidate terminals can be automatically soldered to busbar pads with a robotic soldering station, however, only the Threaded Bolt and Nut will not require rigorous orientation tolerance. In terms of connection to a power cable or wire, the Binding Post will accept either a stripped wire end or a ring/spade lug, the Spring Clip and Wire Cage Clamp will accept only stripped wire ends, and the Threaded Bolt and Nut will accept only a ring/spade lug. All cable/wire connections to these terminals will be made by hand until module production quantities justify automation. A human operator will be able to make the terminal connection and perform a torque test at the rate of 500 per hour. Ring/spade lugs cost $0.04 each crimped onto wire/cable.



SOLDERING SURFACE

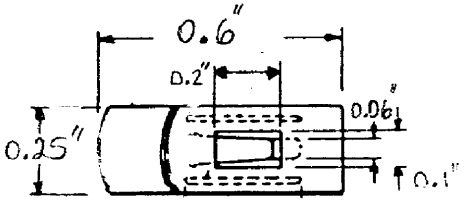
CONCEPTUAL VIEW (NOT TO SCALE)

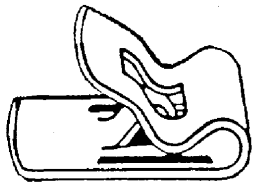


MATERIALS: HEAD: POLYCARBONATE, FLUTED
BODY: BRASS, NICKEL PLATED
NUTSERT: BRASS NICKEL PLATED

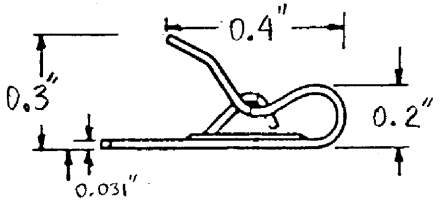
BINDING POST		
SCALE: ACTUAL	APPROVED BY:	DRAWN BY MJS
DATE:		REVISED
UTILITY POWER GROUP		
Figure 6		DRAWING NUMBER PMAT 1

8½ X 11 PRINTED ON NO. 1000H CLEARPRINT





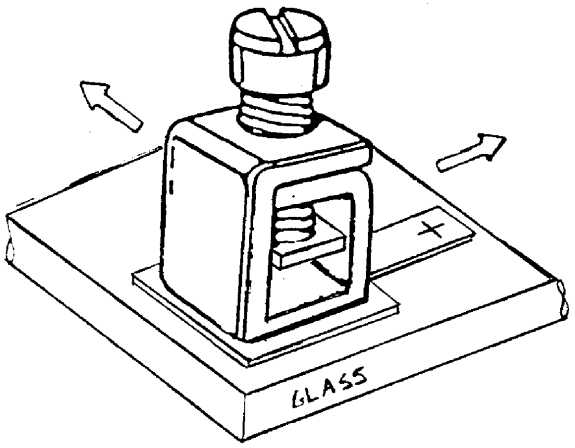
SOLDERING SURFACE



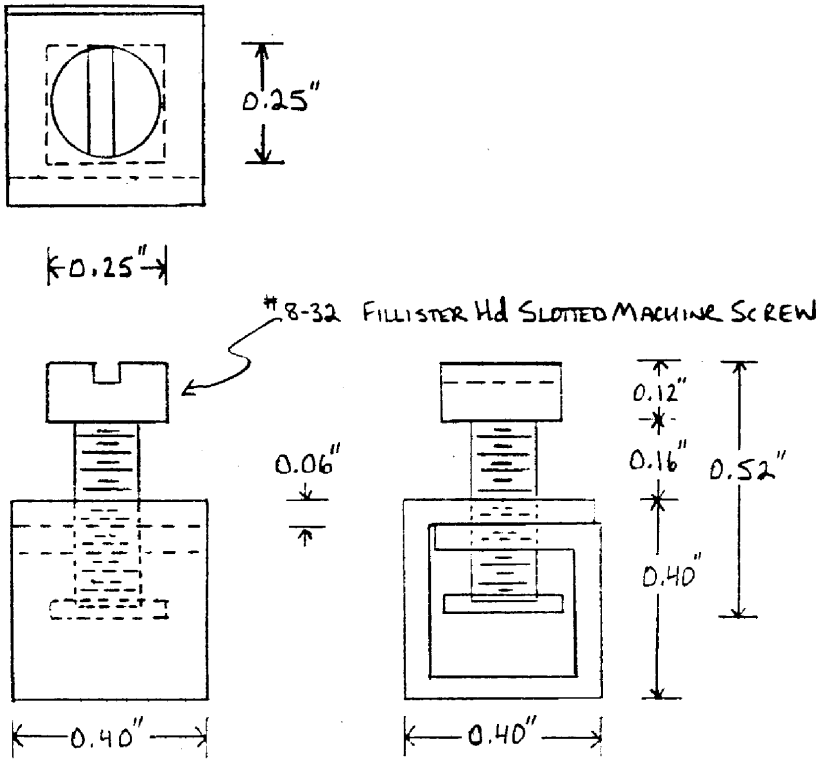
CONCEPTUAL VIEW (NOT TO SCALE)

MATERIAL: 0.031" SPRING BRASS - NICKEL PLATED

SPRING CLIP		
SCALE: NONE	APPROVED BY:	DRAWN BY MF
DATE: AUGUST-92		REVISED
UTILITY POWER GROUP		
Figure 7		DRAWING NUMBER PVMAT 2



CONCEPTUAL MODULE VIEW (NOT TO SCALE)



MATERIAL: 0.062" STEEL - NICKEL PLATED

WIRE CAGE CLAMP

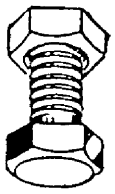
SCALE: 0.1" = 0.04"	APPROVED BY:	DRAWN BY NJS
DATE: AUGUST-92		REVISED

UTILITY POWER GROUP

Figure 8

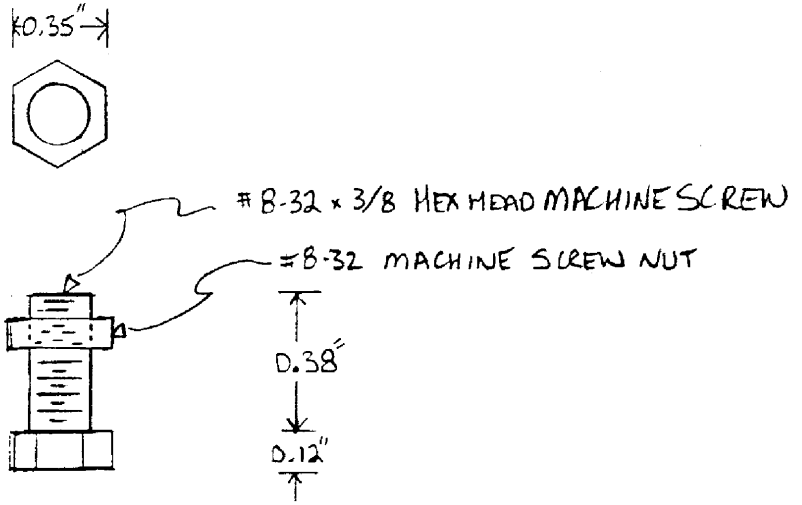
DRAWING NUMBER PV MAT 3

8½ X 11 PRINTED ON NO. 1000H CLEARPRINT •



SOLDERING SURFACE

CONCEPTUAL VIEW (NOT TO SCALE)



MATERIAL: STEEL - NICKEL PLATED

THREADED BOLT AND NUT		
SCALE: NONE	APPROVED BY:	DRAWN BY MJS
DATE: AUGUST -92		REVISED
UTILITY POWER GROUP		
Figure 9		DRAWING NUMBER PVMAT 4

8½ X 11 PRINTED ON NO. 1000H CLEARPRINT

Adaptability to Multi-Module Systems

In multi-module systems, the Spring Clip and Wire Cage Clamp require jumpers of cable/wire since threading a wire through them in a parallel configuration is not practical. The Binding Post and Treaded Bolt and Nut permit the use of flat rectangular copper bus bar stock with center spaced holes for parallel and series strings. Based upon UPG's PVUSA system design, the use of the copper bus bar stock would greatly reduce module to module interconnection costs.

The Threaded Bolt and Nut was determined to be superior to the other candidate terminal designs based upon the above evaluation criteria. The Spring Clip was removed from consideration due to the lack of confidence in its long term reliability and the question of whether it would be an acceptable terminal to Underwriters Laboratories, Inc. (UL).

The Threaded Bolt and Nut will now be referred to as the POWER-GLASS terminal in all future discussions until such time as a superior terminal design is developed.

Terminal Soldering Experiments

A thermocouple was attached to the head of a nickel plated 6-32 hex head bolt currently used in our termination process, in order to determine the temperature that the bolt achieves during soldering. Initial tests found that when heated for 10 seconds the temperature averaged 203C at the end of the 10 seconds with a gradual increase of temperature to 280C. Reducing the amount of time that the heat is applied from 10 seconds to 7 seconds yielded an average temperature of 125C @ 7 seconds and Tmax of 208C. No discoloration at the termination pads was observed on the front side of the glass using the new termination schedule.

Tests were next conducted to refine the solder schedule using 7 second heat duration. A new screen print test pattern was designed and fabricated which allows 42 individual termination pads to be printed onto a single substrate. This allows a large number of experiments to be more readily conducted.

The experimental matrix includes three different silver pastes printed onto both tin oxide coated glass and bare glass. Tests thus far have examined solder volume, variations of solder heating techniques, variations or terminal placement techniques, and preparing the terminal with a thin film of solder before soldering to the silver pad. The effect of the variables on the torque strength of the terminal were observed.

Initial results of these experiments have defined a termination method which consistently passes the UL Test No. 27 "Terminal

Torque Test" , as defined in UL Publication No. 1703 "Standard For Flat Plate Photovoltaic Modules and Panels". In addition to passing the UL standard, the initial results indicate high average torque strengths of 20 lb.-inches using the newly defined termination method. Finally, the discoloration which was seen at the termination sites of earlier samples is not seen using the new method. Further humidity-freeze tests were conducted on terminals to determine if the reduced local heat duration during termination reduced local stress at the termination site and resulted in an improved, more reliable termination.

A problem arose concerning the reliability of the terminal design. Results of humidity/freeze cycling indicate reduced torque strength after 20 cycles, and an initial experimental matrix was designed and initiated to determine the cause. The following list of terminal variables illustrates the complexity of this issue:

1. TCO material
2. Busbar material
3. Busbar material firing temperature
4. Solder alloy
5. Solder flux type
6. Soldering time/temperature schedule
7. Encapsulation material
8. Encapsulation process
9. Humidity/freeze cycle
10. Repeat torque testing

The failure interface is between the TCO and the terminal pad, and appears to be exacerbated by the number of times the torque test is repeated. Our goal is to obtain a termination process where no loss of terminal torque strength occurs after qualification testing. A critical question to be answered is what type and level of terminal torque or stress test is equivalent to a 30 year outdoor life? Terminal strength/mechanical reliability is not addressed in the standard qualification test sequence.

Termination Experiments

The occurrence of terminal failure was observed on two test coupons which were removed from the humidity/freeze test as described in the SERI publication on Interim Qualification Tests. At that time the exact cause of the physical failure of the terminal on the solder pad was not known.

The following facts were determined at that time:

1) Discoloration of the terminal pad was observed through the front side of the glass after the coupon had been removed from the environmental chamber.

2) Discoloration of the terminal pad was also observed on coupons which had not undergone humidity/freeze cycling.

3) The temperature of the terminals using that particular solder schedule were recorded reaching as high as 280C.

4) Terminal failure had not occurred on a coupon which had undergone thermal cycling but not humidity/freeze.

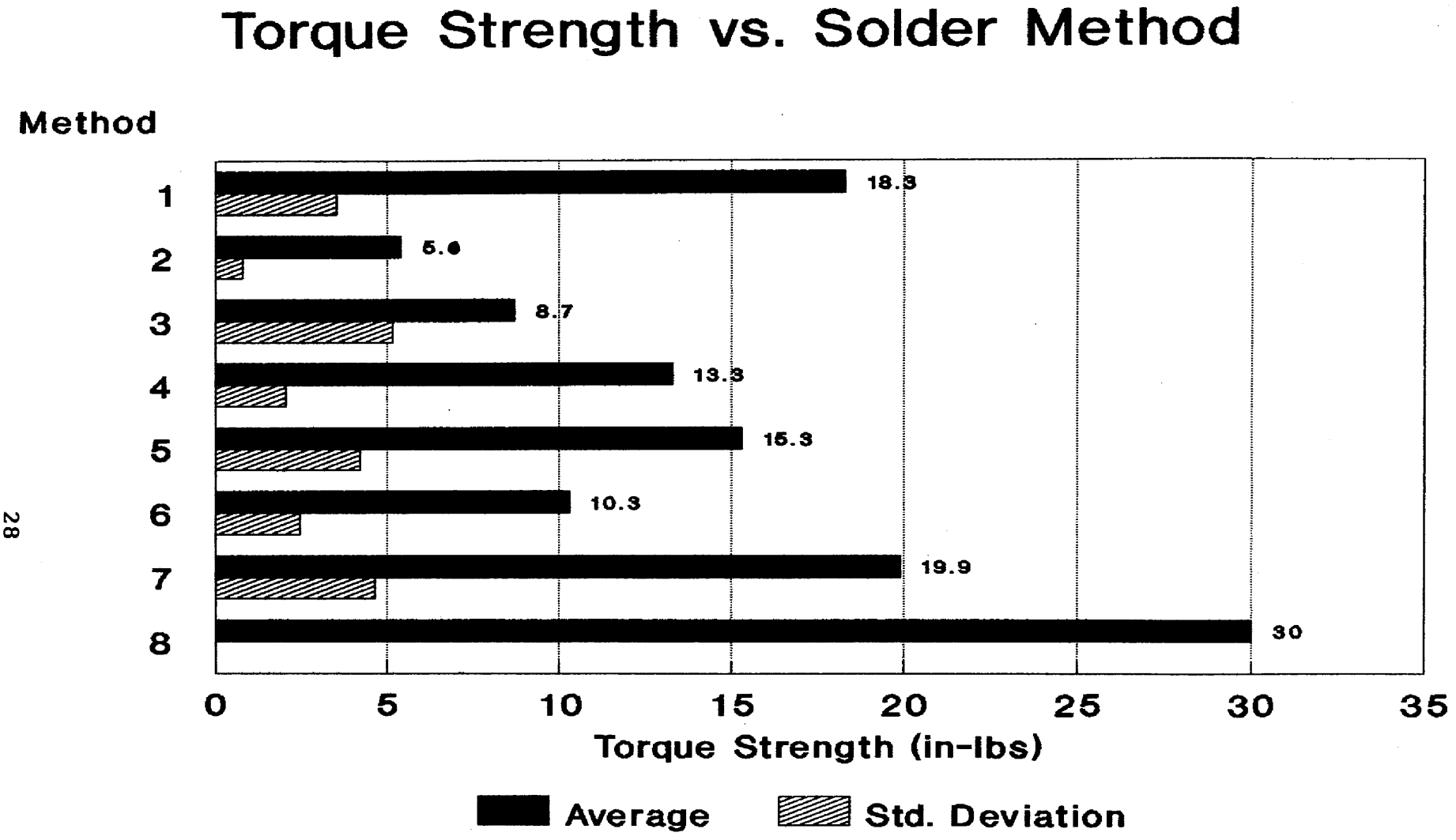
Since that time experiments have been conducted to determine a solder method which will yield a high torque strength termination, while minimizing local solder step induced stress at the termination/glass assembly.

The following section describes the evolution of determining the current solder method, results of termination torque strength after humidity/freeze cycling, the correlation observed between Ag terminal pad discoloration and torque, initial results of a new termination assembly method which examines the use of a buffer layer, and initial results of a large multiple element experimental matrix designed to eliminate and determine causes of termination failure.

Before a large experimental matrix to determine causes of terminal failure could be performed, the soldering method itself needed to be re-examined. Issues such as repeatability, temperature profile, and torque strength needed to be quantified to gain a confidence level in a given method.

The question of terminal torque strength and how it relates to long term reliability remains unanswered. The UL requirement for terminal torque strength states that a #6 screw must be capable of withstanding 10 cycles of tightening to and releasing from a value of 12 in-lbs without damage to the terminal supporting member, loss of continuity, or short circuiting of the electrical circuit to accessible metal. Our data shows some terminals with initial post-solder torque strength of 30 in-lbs or greater which have degraded to less that the UL requirement after humidity/freeze cycling. It is our goal to obtain a termination process in which no loss of terminal torque strength occurs after qualification testing.

Several solder methods were tried with the objective of determining a method which would reliably and repeatably give high torque strength, without discoloring the solder pad when observing from the front glass side. Figure 10 shows the average soldered torque strength of the terminal as a function of solder method.



Single Print Ag
Paste No. 1
TCO/Glass Substrate

Figure 10

The conclusions of these steps to define a repeatable, high strength solder method found 1) a repeatable process which yields greater than 30 in-lbs terminal torque strength, 2) pre-tinning the terminal prior to termination resulted in lower torque strength, 3) pre-heating the terminal prior to applying it to the solder and pad resulted in higher torque strengths, 4) using a solder alloy containing 2% silver improved terminal torque strengths.

During the course of investigating the various solder methods, it was found that the discoloration only appeared AFTER the terminal had been torqued. That is, when a homogeneous AG pad viewed from the front side of the glass, is torqued to a value less that the failure point, the discoloration or spot appears when viewed from the front side again. Previously, it had been thought that the spot appeared as a result of the humidity/freeze cycle, or from local stress caused by heat from the solder method. This latest evidence now identifies the act of torque testing as a possible first cause of failure. In addition, in most cases torque induced failure identifies as failure between the TCO and the terminal pad.

Termination/Encapsulation Matrix

1) Does the encapsulation cure cycle affect the termination torque strength?

2) Is the termination torque strength higher on TCO coated glass or bare glass?

3) Examining three different AG paste formulations produced by different manufacturers, does one paste out perform the others in terms of torque strength?

4) How does humidity/freeze cycling affect the torque strength of two separate groups with different encapsulation and an unen capsulated group?

5) Comparing two different thicknesses of fired AG paste, does one group out perform the other in terms of torque strength?

6) What will be the extent if any of degradation to each group after humidity/freeze when compared to each control group?

Task 2 Summary

Four candidate terminal designs have been completed and samples have been fabricated and evaluated in terms of cost and manufacturability. The four candidate designs are:

1. Binding Post
2. Spring Clip
3. Wire Cage Clamp
4. Threaded Bolt and Nut

The Threaded Bolt and Nut was determined to be superior to the other candidate terminal designs based upon the above evaluation criteria.

While the initial torque strength of a terminal soldered to the silver pad was quite high, recent results have shown a degradation of that torque strength after subjecting the soldered joint to the humidity/freeze test. More work will be required to determine the problem and either develop a new soldering process or a terminal design and terminal attachment process.

A new POWERGLASS module design was developed which utilizes a novel "U-turn" concept to allow the positive and negative terminals to be protected by a single enclosure (J-box), thereby eliminating the need for external conductors (busbar ribbons).

Task 3 - Eureka Module Design

General Approach

Input from Marketing suggested three directions to pursue for new products. The most definitive input that market studies provided was to change the electrical connection point from the edge of the module as done in the Eureka module made for PVUSA, towards the interior and thereby provide an unobstructed border. Thus, our design and test efforts have gone into arriving at a connection scheme in which the edges of the modules are left bare. Secondly, a smaller module was needed; one-half the size of the PVUSA module was thought suitable. Thirdly, a module voltage appropriate for 12 volt battery charging was deemed necessary. These requirements resulted in the redesign of the current 38 volt power module used for PVUSA, the EP2, into the EP50, as well as two new modules for 12 volt applications.

The new modules are the EN50, a full size 50 watt module with a nominally 17 volt operating voltage, and the EN25, a half-size power module with 25 watt output also nominally at 17 volts.

The two new module designs share three main features that differ from the EP2. The first, deals with the lowered voltage of the modules. The voltage reduction is obtained by first increasing the cell width from 1.11cm to 1.25cm, thus reducing the number of cells. This results in a roughly 10% reduction in maximum power voltage to about 34 volts. To reduce this to 17 volts, the plate layout uses a mirror image cell design, whereby cell patterning extends symmetrically outward from the center positive cell and effectively connects the two halves in parallel. This approach requires the two end cells to be connected and the common connection point to be brought out. To carry out this procedure, several new steps in the encapsulation process had to be added, as well as some additional equipment. The design required the junction covers to be at the center of one end of the module rather than at the corners as with the EP2.

The second change is common to all three new designs. In these products access to the PV cells is gained through holes in the cover glass, rather than through the edge of the glass laminate. Two in-line holes in the center of one end of the module are used for the 17 volt modules and holes near two corners are used for the EP50. Our standard connector terminates both the positive and negative leads.

The third new feature that the three modules share is the means of protecting the connection to the thin-film. The "terminal cover" used to accomplish this differs from its predecessor the silicone "boot", in that it is molded in place on the back of the module, rather than glued to the edge.

In addition to being undesirable because of their location, the silicone boots that we used for the EP2 were both labor intensive in their application and prone to assembly error. We believe that the molded terminal cover placed on the surface of the glass results in a higher quality product because sealing of the connector is done on a flat surface as opposed to

having to seal around the edge of the laminate. To maintain the excellent insulation properties that the edges of our modules had, we have retained the roughly half-inch border isolation area around the perimeter of the modules.

Additional power modules are being considered and preliminary specifications are being formulated and designs made. These range from architectural PV products to new designs for commercial applications.

We are using the PVUSA qualification test sequence as a starting point to judge the quality of these and any other new products that will be developed.

Status

EP50 - Manufacturing product specifications (MPS) for this product have been completed and approved for all critical steps of the encapsulation process. A complete engineering drawing package has been generated and approved. Testing has been carried out that specifically addresses the differences between this product and its predecessor, e.g. static load testing to verify that the holes in the cover glass do not significantly weaken the module, humidity freeze cycling and thermal cycling. Additional testing is in progress, in part to determine the limits of performance and to test consistency of the process.

EN25 - Prototypes of this design were made, followed by a first cut at equipment modifications to accommodate the smaller size and the additional foil placement that this product requires. Several dozen modules were then produced and preliminary testing carried out, again to test the differences between this and previous product. Further testing will take place shortly, when a production run is made. Drawings for the EN25 have been approved and other documentation is in preparation.

EN50 - Some of the equipment modifications needed for the EN25 apply to this product as well and a production run for it is also imminent. A draft of a drawing package for the EN50 is being reviewed and as with the EN25, manufacturing product specifications are in preparation.

Other Products - Several new products are being designed for special applications. These share the main three changes from the older PVUSA module in that they have a free border, access to the thin-film through holes in the cover glass and a molded cover for the connection. Some designs being worked on involve the use of darkened oversize cover glass and include other size modules.

Milestone m-1.7 - Complete initial CAD iteration and prototypes of Eureka Module designs (Task 3) have been achieved.

Outline drawings of the three new modules are attached.

Task 4 - Eureka Process And Quality Control

The goal of this task is to improve module quality and throughput and to reduce manufacturing costs by gaining a better understanding of the process. Implicitly we also expect to improve process reliability. Our effort in this area can be divided into three separate but related activities: in-line process control and monitoring, in-line product monitoring and off-line measurements on selected Eureka plates. Additionally, specific projects have been defined and will be discussed.

General Procedures

Process Control and Monitoring - Throughout the process, parameters are monitored to verify that the process is being carried out as defined in the MPS (Manufacturing Process Specification) sheets. Some of the important parameters now being monitored and controlled are the following (process parameters specifically selected for study are discussed below). For tin oxide, we verify that the coating meets our specification for optical transmission, haze and sheet resistance. The a:Si deposition process is the most extensively instrumented. Here we monitor and control temperatures, pressures, flow rates, rf power levels and the timing of all steps. One of the deposition systems is automated and for it, much of this information is acquired and stored by computer. In the laser stations, we monitor beam power and quality, x-y table speed and position. Routine methods of dealing with this information are still being developed.

Of the process parameters on the thin-film line that are routinely monitored, the two specifically selected for initial study are the rf delivered to the chamber and flow rates of the deposition gases. These are believed to be the most critical parameters determining properties of the thin-film deposits.

The encapsulation line is also instrumented, although not as extensively. Air, water and other process pressures and temperatures are monitored throughout the line. Two variables were singled out for initial study. First is a shunt measurement following the border isolation step. In the past, some variation in power loss between plate and module was attributed to this step. The other parameter being investigated is the temperature profile in the terminal cover curing oven. Some preliminary observations suggest that the frequency and size of voids that occasionally occur in the terminal covers are related to the temperature profile of the oven.

In-line Product Monitoring - Product is checked, and measurements made at several stages of the process to detect line malfunctions or performance deviations. We are using these measurements to keep track of the process itself in the instances where the process is not very well understood and hence, difficult to define precisely. The data collected in this area include alignment and laser scribe quality checks, cell isolation measurements, silicon thickness determinations and plate IV measurements.

In addition to the shunt measurement mentioned above, QC checks in the encapsulation line include a test for bracket adhesion. In this test, we pull on the edge of the mounting

bracket with an excess of 100 lbs. force. After a sufficient number of samples were tested with no failures, the test was changed to a sampling procedure, with roughly 10% of product tested. A second QC check which is done on 100% of the modules is a leakage test of the terminal cover. In this test, the edge is immersed in a conductive water solution which covers the terminal cover and leakage at 500 volts is measured. The final module check is again an I-V measurement, which provides the most useful and most used information on the process. Comparisons are routinely made between I-V measurements on thin-film processed plates and the modules resulting from them.

Off-Line Measurements - Eureka product is tested off-line in routine tests done on one to six plates each day and specialized analysis on an as needed basis, e.g. Auger analysis, spectral response measurements, etc. In the routine tests, a Eureka plate is cut into twelve 4" x 12" sections, each of which consists of a string of small interconnected cells, as well as nine isolated dots about 0.1"in diameter. On these plates we measure silicon film thickness by capacitance, scribe widths, standard electrical parameters plus low light level measurements, series and shunt resistances and light degradation measurements. Since all areas of the full plate are represented, these measurements give us information on the uniformity of the product (however on only a small sample of product made), both as-made and also after light soaking.

The electrical parameters obtained in I-V measurements are probably the most direct measure of control of the process. In the first monthly report, these were used as an overall evaluation of our progress and the spread (standard deviation as percent of average) in the electrical parameters for several months prior to the start of this Contract were presented (some experimental runs were excluded, e.g. tandem runs done for R & D). Thus:

Table 4. Percent Spread in Electrical Parameters

(Power Spread Related To Electrical Yield Losses)

	Voc	Isc	FF	Power
January	6.5	4.0	9.0	15.0
February	3.6	3.8	6.8	8.8
March	2.3	2.3	2.5	4.9
April	2.3	2.4	2.9	4.4
May	2.7	3.2	3.4	5.5

A detailed analysis of available data through October shows the following yields for the encapsulation line:

Table 5. Relative Yields for Encapsulation Process Steps

Process Step	Relative % Yield
Edge Isolation/Foil Placement	98
Lamination	97
Bracket Application	100
Boot Application	96
Cleaning/Inspection	95
Insulation Test	99
I-V Test	94
Final Inspection	100

Special Projects

Specific efforts that we have initiated to improve our process are:

I-V Measurements - Short term repeatability of I-V measurements is excellent, with a standard deviation of less than 1% for multiple measurements. Longer term we see several percent drift and evidence of non-uniformities in light intensity (in spite of careful calibration). For several reasons, panels are not totally uniform; measuring them in the standard way and upside down has revealed differences as high as 2% to 3%, which we ascribe to the interaction of light and panel non-uniformities. Correcting this problem will presumably lead to a tighter distribution of product power. Possibly of more importance will be higher precision data that will make it easier to interpret other observations (i.e. the power of tests to judge the effects of process improvements will be greater).

Modifications to the light source placement and careful adjustment of intensities, together with continued monitoring of the measurements have reduced this problem.

Silicon Thickness Measurement - As stated above, we typically evaluate one to six plates per day in the laboratory, including thickness measurements of the a-silicon; roughly 100 separate determinations are made on each plate. The information obtained is taken to provide information on the run to run uniformity; it may however merely represent plate to plate variations. To ultimately improve uniformity on a plate, we realized that we needed to have more extensive measurements on thickness variations than on 1 percent or so of the product made. Preliminary testing suggested that light transmission measurements could provide reasonably accurate thickness estimates. From comparisons of optical transmission at several wavelengths with profilometer thickness determinations, we concluded that 600 nm was the best region in which to make measurements.

A prototype in-situ thickness measuring device based on optical transmission measurements has been constructed and installed. Measurements are made at twenty-five points on each plate, with the data stored on disk for analysis. Since thickness variations are typically larger than IV parameter variations, these measurements provide a more sensitive measure of process conditions. Thus, some thickness variations seen from run to run have been attributed to variations in rf power applied to the discharge.

Documentation - Manufacturing Process Specifications (MPS) have been generated for the module encapsulation workstations in order to define the process steps, to introduce additional process controls and to obtain essential parametric information. Statistical techniques are being applied to some of these data, both to obtain baseline information on the process and to evaluate and control the process.

Milestone m-1.8 - Complete yield analysis review of Eureka modules (Task 4) has been achieved.

Task 5 - Eureka Power Module Encapsulation And Termination

The two specific goals of this task are to achieve cost reductions in the encapsulation process and to reduce power losses between module and plate.

Cost Reduction - Cost reduction can be achieved in several ways; use of less expensive raw materials, designing the process to use less labor (including more automation) and increasing the power output of the module or its yield.

As discussed above, we have totally redesigned the means of accessing the thin-film. In order to seal the edge of the EP2, where the foil was brought out, we had to use an expensive sealant that in addition to high cost, required days to fully cure. The amount of work-in-progress necessitated by this long cure time presented a problem that would have been extremely serious in the larger operation that will exist in our new plant in Fairfield, California. The new in-line molded terminal cover requires only a few hours to fully cure and be ready for testing and packing. The terminal cover as now used, has evolved somewhat from the first design. The initial design had erratic yield due to periodic appearance of excessive voids in the molded material. There were also signs of poor adhesion, although those may have been in part due to mechanical damage after the mold was removed. Both problems were greatly reduced with the redesigned mold. Studies of adhesion under a variety of conditions resulted in some modification of the cleaning and molding procedure which also improved adhesion.

Thus, cost reduction has focused on reducing labor costs through simplifying and automating the process. While the new molded terminal cover is still applied mostly manually, this step has the potential of being automated in the future. New dispensing equipment has been tested for applying the terminal cover; this equipment will be used in Fairfield. The equipment both mixes the components of the material in line as well as dispenses a predetermined amount. Currently, mixing is done as a batch process and dispensing is controlled by the operator.

Full automation will significantly reduce labor costs. Refinements to the new foil bonding process are being investigated to approach this goal. Since the new design has the foil accessible through holes in the cover glass, the possibility exists to bond directly to the foil through the hole, rather than bring the foil out and bond externally. Early tests suggested that this approach can work, but details have to be worked out.

An area that will have to be streamlined is the lamination itself, where we have to reduce cycle time by several minutes for the Fairfield operation. Some material cost reduction have been realized by the use of the less expensive raw materials that have replaced the combination of adhesive and silicone boot that was previously used. Other material cost savings such as thinner EVA and possibly thinner glass will be evaluated at a later date.

Reducing Power Loss - The power loss between plate and module can readily be estimated; it essentially amounts to the loss of one cell, or approximately 0.5V in operating voltage. Plates are now prepared for initial measurement in such a way as to make the measurement as similar to the module measurement as possible. Differences in output between modules and plates are typically between about 0 and 3 watts. Measurement precision contributes about 1 watt to this difference.

Some gain in module output can be achieved by reducing the 31 square inch dead area at the two ends of the module. This is the area between a laser isolation line and the cleared border area. Testing suggested that this loss could be cut by more than half, but this change has not yet been implemented.

Task 6 - Automation In Eureka Manufacturing Line

At the start of the Contract, much of the thin-film line was automated, although not necessarily optimally so. Some of this automation has been enhanced and missing links have been added. Four areas we are focusing on are:

Silicon Deposition - One of the two deposition systems has been automated; the software is currently being evaluated. In addition to executing a standard deposition procedure, the software records some of the important process parameters during the deposition. Thus, pressures, flow rates and temperatures are recorded at time intervals of the order of seconds. Based on the initial performance, some changes and additional features are contemplated for an update. These deal with adding flexibility, safety, self-test features and increased data gathering ability; the latter may include parameters from related equipment.

Box Carrier Loading - The box carriers are the containers in which the tin-oxide coated plates are transported into the silicon deposition chambers. Unloading after silicon deposition is already automated through the sputtering station, but the loading is done manually. The equipment for automatic loading has been assembled and auxiliary pieces installed, e.g. an in-line glass washer, transport and rotating stages. Final installation has not been scheduled.

Heat Age Station - Transportation of plates from the sputtering system to and through the heat aging station is currently a batch process. Automation is conceptually worked out (it was attempted a year ago without success), but will require more design work. Near term effort is planned to improve the temperature profile of the cycle and reduce its duration.

Lasers - This critical equipment has been made more reliable and its throughput increased. To improve reliability, instrumentation has been added to monitor beam power and quality. Automated in-line power measuring equipment has been installed at one station; this measures and stores on disk for later analysis the laser power prior to lasering each plate. Secondary registration sensors have been added to prevent misalignment of scribes. Water flow and other critical parameters are monitored and cause system shutdown if warranted.

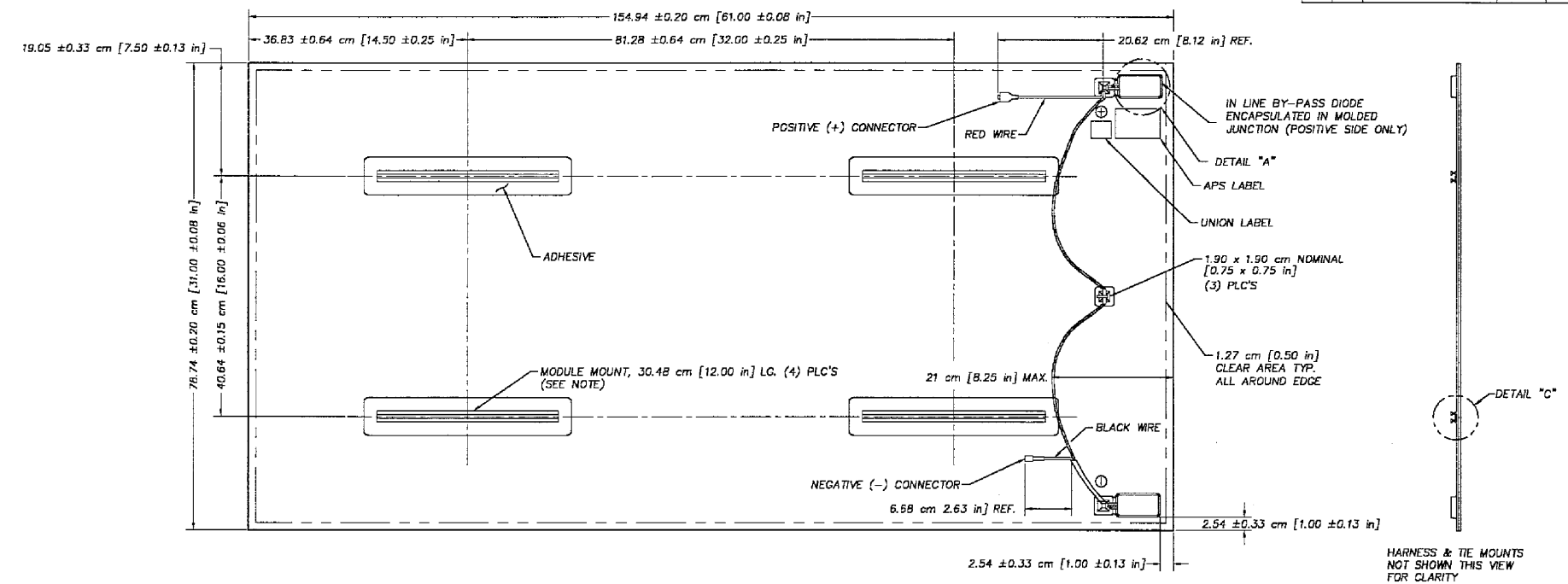
A detailed investigation was made to determine the requirements for achieving a 90 second cycle time for the laser stations. Of the two main components of the laser stations, the x-y tables can readily be made to operate at the required speed. Specifications for x-y tables for California have been defined so as to achieve the required speed. Vendors have been identified that can deliver equipment meeting the specifications. To achieve quality scribes, laser power, repetition rate and beam quality have to also be within specified limits. These limits have been identified. Lasers and associated optics have been specified and vendors identified that can meet the specifications. For scribing the back contact, we have determined that an additional laser station will be required to perform the end isolation scribes our modules incorporate. A design for such a station has been completed.

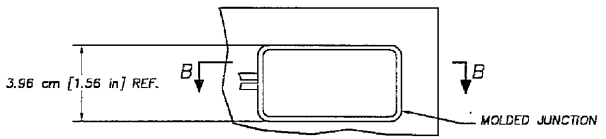
Encapsulation Line - Much less automation is introduced into the encapsulation line. Individual pieces do, however, automatically handle the plates. Much of what has to be added is transportation equipment to move the plates from station to station; this will be available for the California plant. General purpose transport tables have been designed and built; these include tables that will handle straight one way transport, tables that rotate the plates and tables that can move plates in both directions.

Some of the initially constructed equipment was designed to handle only one size plate. With the need to develop the half-module and the lower voltage products, some redesign has taken place so that the equipment has sufficient flexibility to handle these variations without lengthy adjustment and delay.

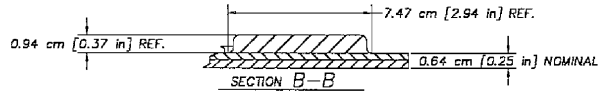
Milestone m-1.9 - Complete SnO2 Scribing Investigation for 90 second/plate laser systems for the Eureka module (Task 6) has been achieved.

REVISION HISTORY				
ECO	REV	DESCRIPTION	DATE	APPRVD
	A	INITIAL RELEASE	3/9/93	

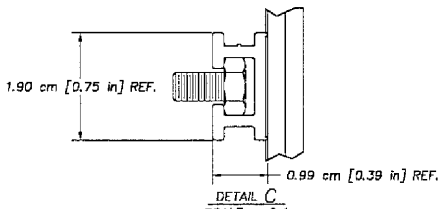




DETAIL A
(ENLARGED VIEW)



SECTION B-B



DETAIL C
SCALE = 2:1

ELECTRICAL SPECIFICATIONS	
NOMINAL POWER (Wp)=	50 W
MAX. POWER VOLTAGE (Vmp)=	38 V
MAX. POWER CURRENT (Imp)=	1.32 A
OPEN CIRCUIT VOLTAGE (Voc)=	55.5 V
SHORT CIRCUIT CURRENT (Isc)=	1.80 A

MECHINICAL SPECIFICATIONS	
DIMENSIONS:	154.94 x 78.74 x 1.91 cm
	[61.00 x 31.00 x 0.75 in]
WEIGHT:	20 KG [44 lb]

NOTES:

1. 30.48 cm [12.00 in] LG. MODULE MOUNT DESIGNED TO HOLD M6 (6mm) HEX HEAD BOLT WITH MAX. TORQUE= (8.8N-m) 75 in lbs.
2. ALL DIMENSIONS ARE FROM MODULE EDGE.
3. I/V DATA @ STC. SUPPLIED AS AN OPTION.

ITEM NO.	QTY REQ'D	PART OR IDENT. NO.	DESCRIPTION

LIST OF MATERIALS OR PARTS LIST

SD4	
SD3	
SD2	
SD1	
REF. SUPPORT DOCUMENT	
SPECIFICATIONS	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES UNLESS NOTED OTHERWISE:
DEC. TOL.:
X.±
XX.±
XXX.±
ANGULAR:±
ALL SURF

SIGNATURES	DATE
JNJ	1/29/93

THIS DOCUMENT CONTAINS INFORMATION WHICH ADVANCED PHOTOVOLTAIC SYSTEMS, INC. CONSIDERS PROPRIETARY AND CONFIDENTIAL. NO PORTION SHALL BE REPRODUCED IN COPIES WITHOUT PRIOR WRITTEN PERMISSION OF ADVANCED PHOTOVOLTAIC SYSTEMS, INC.

AUTOCAD DRAWING | DO NOT SCALE DWG.

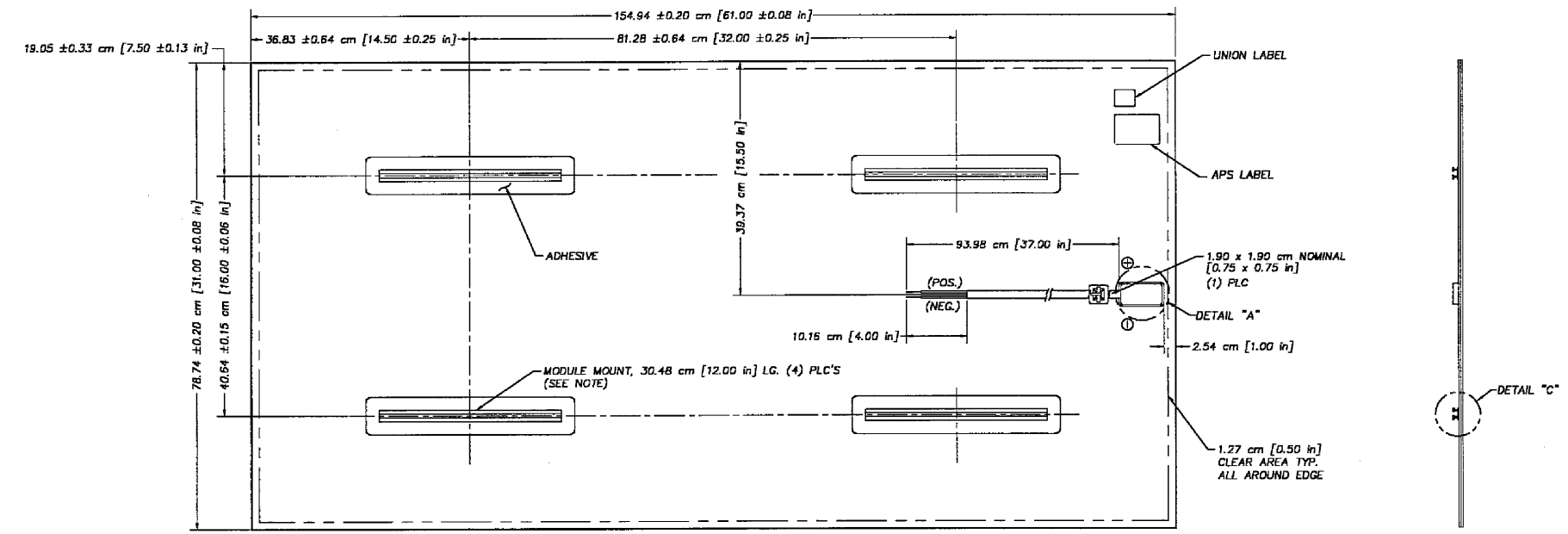
P.O. BOX 7093
PRINCETON, N.J.
08543-7093

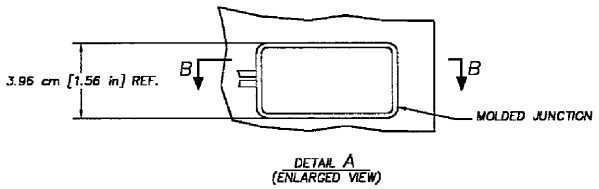
EP50 MODULE (10/9)

SCALE: NTS | WT: | SHEET 1 OF 1 | DWG NUMBER: 802030 | REV: A

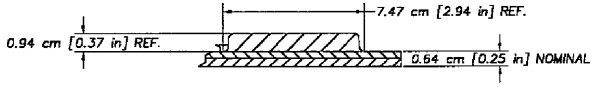
FILE # 802030A

REVISION HISTORY				
ECO	REV	DESCRIPTION	DATE:	APPRVD
	A	INITIAL RELEASE	5/20/93	

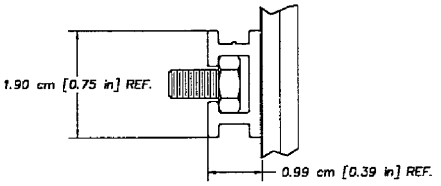




DETAIL A
(ENLARGED VIEW)



SECTION B–B



DETAIL C
SCALE = 2:1

ELECTRICAL SPECIFICATIONS	
NOMINAL POWER (Wp)=	50 W
MAX. POWER VOLTAGE (Vmp)=	16.7 V
MAX. POWER CURRENT (Imp)=	3.0 A
OPEN CIRCUIT VOLTAGE (Voc)=	25.0 V
SHORT CIRCUIT CURRENT (Isc)=	4.0 A

MECHNICAL SPECIFICATIONS	
DIMENSIONS:	154.94 x 78.74 x 1.91 cm
	[61.00 x 31.00 x 0.75 in]
WEIGHT:	20 KG [44 lb]

NOTES:

1. 30.48 cm [12.00 in] LG. MODULE MOUNT DESIGNED TO HOLD M6 (6mm) HEX HEAD BOLT WITH MAX. TORQUE= (8.8N-m) 75 in lbs.
2. ALL DIMENSIONS ARE FROM MODULE EDGE.
3. I/V DATA @ STC. SUPPLIED AS AN OPTION.

ITEM NO.	QTY REQ'D	PART OR IDENT. NO.	DESCRIPTION
LIST OF MATERIALS OR PARTS LIST			

SIGNATURES	DATE
JMJ	5/20/93

THIS DOCUMENT CONTAINS INFORMATION WHICH ADVANCED PHOTOVOLTAIC SYSTEMS, INC. CONSIDERS PROPRIETARY AND CONFIDENTIAL. SO FORTH. MAY BE REPRODUCED OR COPIED WITHOUT PRIOR WRITTEN PERMISSION OF ADVANCED PHOTOVOLTAIC SYSTEMS, INC.

SD4	
SD3	
SD2	
SD1	
REF. SUPPORT DOCUMENT	
SPECIFICATIONS	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES UNLESS NOTED OTHERWISE:
DEC. TOL.:
X±
XX±
XXX±
ANGULAR±
ALL SURF.

AUTOCAD DRAWING

DO NOT SCALE DWG.

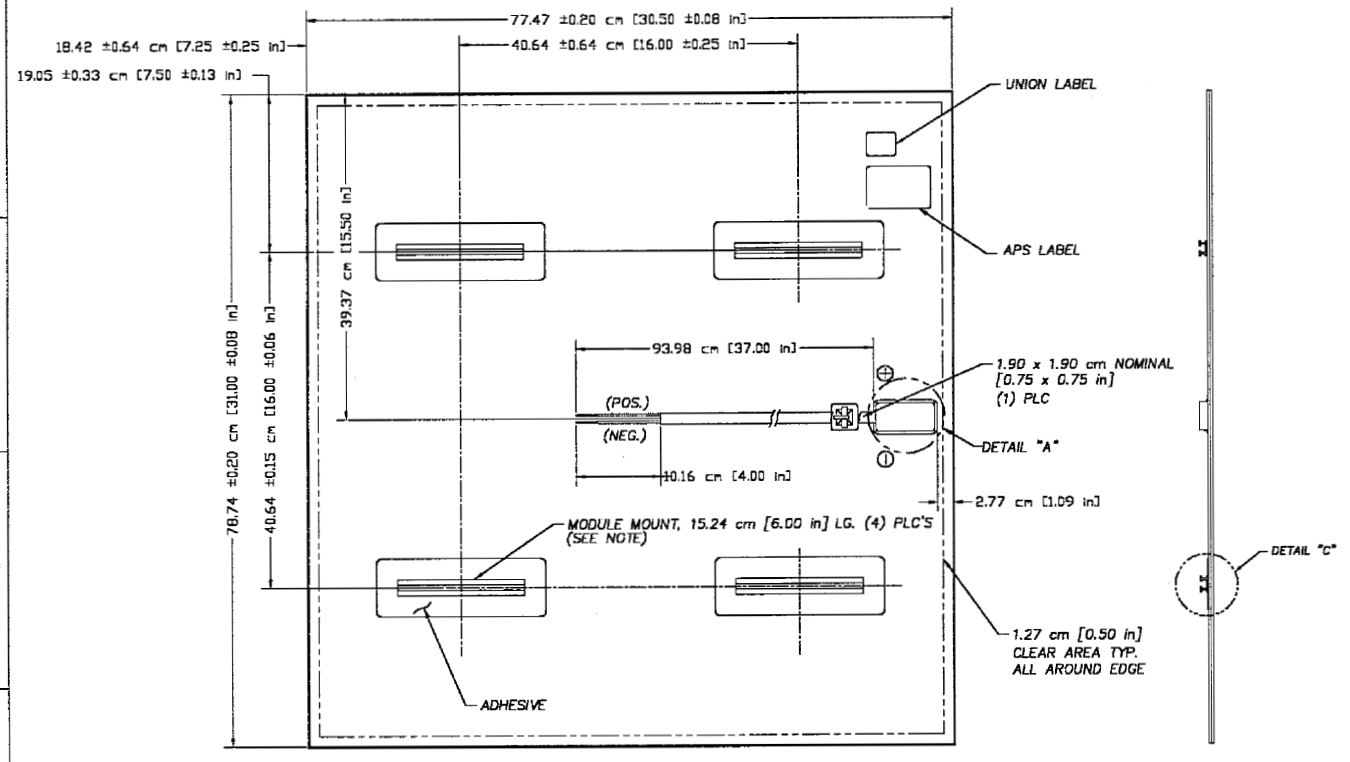
ADVANCED PHOTOVOLTAIC SYSTEMS, INC.
P.O. BOX 7093
PRINCETON, N.J.
08543-7093

EN50 MODULE (10/8)

SHEET	NO.	REV
NTS	1 of 1	A
D-SIZE	802043	

FILE # 802043A

REVISION HISTORY				
ECO	REV	DESCRIPTION	DATE	APPRVD
	A	INITIAL RELEASE	5/25/93	

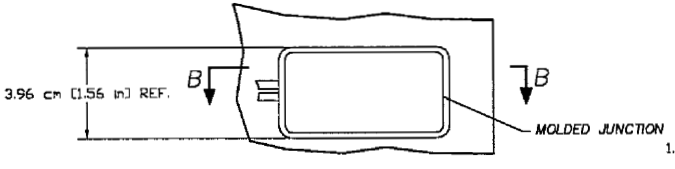


ELECTRICAL SPECIFICATIONS	
NOMINAL POWER (Wp)=	25 W
MAX. POWER VOLTAGE (Vmp)=	16.7 V
MAX. POWER CURRENT (Imp)=	1.5 A
OPEN CIRCUIT VOLTAGE (Voc)=	25.0 V
SHORT CIRCUIT CURRENT (Isc)=	2.0 A

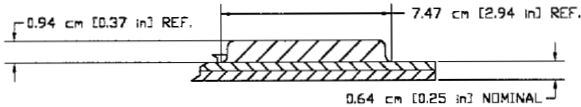
MECHNICAL SPECIFICATIONS	
DIMENSIONS:	77.47 x 78.74 x 1.91 cm
	[30.50 x 31.00 x 0.75 in]
WEIGHT:	10 KG [22 lb]

NOTES:

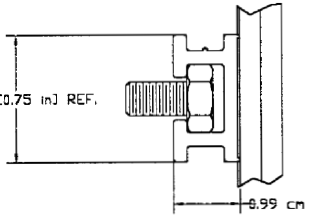
1. 15.24 cm [6.00 in] LG. MODULE MOUNT DESIGNED TO HOLD M6 (6mm) HEX HEAD BOLT WITH MAX. TORQUE= (8.8N-m) 75 in lbs.
2. ALL DIMENSIONS ARE FROM MODULE EDGE.
3. I/V DATA @ STC. SUPPLIED AS AN OPTION.



DETAIL "A"
(ENLARGED VIEW)



SECTION B--B



DETAIL "C"
SCALE = 2:1

ITEM NO.	QTY REQ'D	PART OR IDENT. NO.	DESCRIPTION
			LIST OF MATERIALS OR PARTS LIST

SIGNATURES	DATE
JNJ	5/25/93

SIZE	
SIZE	
SIZE	
SIZE	
REF. SUPPORT DOCUMENT	
SPECIFICATIONS	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES UNLESS NOTED OTHERWISE:
DEC. TOL.:
XX ±
XXX ±
XXXX
ANGULAR:
ALL SURF

AUTOCAD DRAWING | DO NOT SCALE DWG.

P.O. BOX 7093
PRINCETON, N.J.
08543-7093

EN25 MODULE 10/8

SIZE	SCALE	SHT.	DRAWING NUMBER	REV.
B	NTS	1 / 1	802044	A

FILE # 802044A

THIS DOCUMENT CONTAINS INFORMATION WHICH ADVANCED PHOTOVOLTAIC SYSTEMS, INC. CONSIDERS PROPRIETARY AND CONFIDENTIAL. NO PORTION MAY BE REPRODUCED OR DISCLOSED WITHOUT PRIOR WRITTEN PERMISSION OF ADVANCED PHOTOVOLTAIC SYSTEMS, INC.

Document Control Page	1. NREL Report No. NREL/TP-411-5739	2. NTIS Accession No. DE93018221	3. Recipient's Accession No.

4. Title and Subtitle
Amorphous Silicon PVMaT - Phase 2A
Semiannual Subcontract Report

5. Publication Date
September 1993

6.

7. Author(s)
G. Duran, K. Mackamul, D. Metcalf, M. Stern

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Utility Power Group
Chatsworth, California

10. Project/Task/Work Unit No.
PV350101

11. Contract (C) or Grant (G) No.
(C) ZM-2-11040-06
(G)

12. Sponsoring Organization Name and Address
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

13. Type of Report & Period Covered
Technical Report
1 May 1992 - 31 October 1992

14.

15. Supplementary Notes
NREL technical monitor: R. L. Mitchell

16. Abstract (Limit: 200 words)

This report describes work done under a subcontract to significantly advance the photovoltaic manufacturing technologies, reduce module production costs, increase average module performance, and increase the production capacity existing at Utility Power Group (UPG) and Advanced Photovoltaic Systems, Inc. (APS). Areas of focus include (1) encapsulation and termination, (2) product design, (3) process and quality control, and (4) automation. UPG will improve its encapsulation system through the development of advanced encapsulation materials and processes that result in a module that does not require backing glass. In addition, UPG will work to develop advanced termination materials and processes. APS will perform development activities centered on the EUREKA manufacturing line. Developments in the APS EUREKA encapsulation system will be in addition to the UPG activity on encapsulation, and will offer an alternative approach to the problems of encapsulating large-area thin-film modules.

17. Document Analysis
a. Descriptors
amorphous silicon ; manufacturing ; photovoltaics ; solar cells

b. Identifiers/Open-Ended Terms

c. UC Categories
271

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
52

20. Price
A04

Form No. 0069E (6-30-87)