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INVESTIGATION OF TEST METHODS, MATERIAL PROPERTIES, AND PROCESSES FOR SOLAR CELL ENCAPSULANTS

Twenty-Sixth
Quarterly Progress Report

JPL Contract 954527
Project 6072.1

For

JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91103

ENCAPSULATION TASK OF THE FLAT-PLATE
SOLAR ARRAY PROJECT

The JPL flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE

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TECHNICAL CONTENT STATEMENT

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I. SUMMARY

Springborn Laboratories, Inc. is engaged in a study of potentially useful low cost encapsulation materials for the Flat-Plate Solar Array Program (FSA) funded by the Department of Energy and administered by the Jet Propulsion Laboratory. The goal of the program is to identify, test, evaluate and recommend encapsulation materials and processes for the fabrication of cost-effective and long life solar modules.

Of the $18 (1948 $) per square meter allocated for the encapsulation components approximately 50% of the cost ($9/m^2 may be taken by the load bearing component. Due to the proportionally high cost of this element, lower costing materials were investigated. Wood based products were found to be the lowest costing structural materials for module construction, however, they require protection from rainwater and humidity in order to acquire dimensional stability. The cost of a wood product based substrate must, therefore, include raw material costs plus the cost of additional processing to impart hygroscopic inertness. This protection is provided by a two step, or "split" process in which a flexible laminate containing the cell string is prepared, first in a vacuum process and then adhesively attached with a back cover film to the hardboard in a subsequent step. The additional processing cost is calculated to be $3.19 per square meter (1984 $). This additional cost component may be acceptable if an expensive load bearing material, such as glass, is replaced with a wood product. Overall module manufacturing costs could possibly be reduced by several dollars per square meter in large volume operations.

II. INTRODUCTION

The goal of this program is to identify and evaluate encapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DOE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of $0.70 per peak watt ($70/m^2) (1980 dollars). The project is aimed at establishing the industrial capability to produce solar modules within the required cost goals by the year 1986.

To insure high reliability and long-term performance, the functional compnents of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirement, and to maximize cost/performance.

Assuming a module efficiency of ten percent, which is equivalent to a power output of 100 watts per m^2 in mid-day sunlight, the capital cost of the modules may be calculated to be $70.00 per m^2. Out of this cost goal, only 20 percent is available for encapsulation due to the high cost of the cells, interconnects, and other related components. The encapsulation cost allocation[a] may then be stated as $14.00 per m^2 which included all coatings, pottants, and mechanical supports for the solar cells.

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a. JPL Document 5101-68

Assuming the flat-plate collector to be the most efficient design, photovoltaic modules are composed of seven basic construction elements. These elements are (a) outer covers; (b) structural and transparent superstrate materials; (c) pottants; (d) substrates; (3) back covers; (f) edge seals and gasket compounds; and, (g) primers. Current investigations are concerned with identifying and utilizing materials or combinations of materials for use as each of these elements.

Throughout this program, extensive surveys have been conducted into many classes of materials in order to identify and compound,or class of compounds optimum for use as each construction element.

The results of these surveys have also been useful in generating first-cut cost allocations for each construction element which are estimated to be as follows (1980 and 1984 dollars):[a]

Construction Elements	Approximate Cost Allocation* ($\$/m^2$) 1980\$	1984\$
Substrate/Superstrate (Load Bearing Component)	7.00	9.10
Pottant	1.75	2.27
Primer	0.50	0.65
Outer Cover	1.50	1.95
Back Cover	1.50	1.95
Edge Seal & Gasket	1.85	2.40

* Allocation for combination of construction elements: $\$14/m^2$ (1980 \$) and $\$18.20/m^2$ (1984 \$).

From the previous owrk, it became possible to identify a small number of materials which had the highest potential as candidate low cost encapsulation materials.

(a) CPI average inflation factor for 1980 to 1984 is \$1.30.

In addition to materials, two encapsulation process are being investigated:

1) vacuum bag lamination
2) liquid casting

The suitability of these processes for automation is also being investigated. However, the selection of a process is almost exclusively dependent on the processing properties of the pottant. This interrelationship may have a significant influence on the eventual selection of pottant materials.

Recent efforts have emphasized the identification and development of potting compounds. Pottants are materials which provide a number of functions, but primarily serve as a buffer between the cell and the surrounding environment. The pottant must provide a mechanical or impact barrier around the cell to prevent breakage, must provide a barrier to water which would degrade the electrical output, must serve as a barrier to conditions that cause corrosion of the cell metallization and interconnect structure, and must serve as an optical coupling medium to provide a maximum light transmission to the cell surface and optimize power output. The cells, encapsulated in the rubbery pottant, must also be prevented from bending and flexing that will result in cell fracture. A load bearing component, either substrate or superstrate, is required as a carrier. Surveys of materials have shown that the least expensive superstrate (transparent) is glass, at an estimated cost of $9.70 per square meter. Candidate substrate materials resulting from this survey indicate that considerable savings may be possible through the use of materials such as cold rolled steel (appx. $\$3.70/m^2$) or wood products such as hardboard (appx. $\$2.25/m^2$). These lower costing materials have weathering deficiencies, however, and an additional process cost is required to give stable performance in PV module applications. The acceptability of a low cost candidate substrate material is,therefore,dependant on the overall cost associated with its use and not just the raw material cost. In this report, these costs are determined for the hardboard condidate substrate system.

III. COST ANALYSIS OF HARDBOARD SUBSTRATE

This report details the costing required to determine if the use of hardboard for substrate designed PV modules is feasible. Hardboard has been found to have the best cost/performance ratio of any structural material investigated as a candidate substrate to date. Mechanical analysis shows that 1/4" hardboard at cost in the range of $0.18 to $0.20 per square foot offers the highest flexural strength at the lowest possible cost. Only a single reinforcing rib in the longitudinal direction is required for the fabrication of a 2' by 4' substrate module. The difficulty with the use of hardboard is that an additional cost component must be included for some type of protective treatment. Hardboards are very hygroscopic materials with coefficients of hygroscopic expansion in the order of two magnitudes larger than the coefficient of thermal expansion. In order for these materials to be used effectively the dimensional changes that occur with the uptake and loss of water must be eliminated. There are no inexpensive chemical treatments that can be used to prevent the hardboard from being hygroscopic and there do not appear to be any occlusive paints that are capable of preventing the intrusion of water, as either liquid or vapor. The proposed solution to this problem is the application of some type of film material that is either totally occlusive, such as a metal foil, or partially occlusive such as a polymer film. The protective film need not be totally occlusive as long as the water vapor permeation rate is low enough to damp out the effects of varying humidity in the environment.

Due to the tendency for hardboards to dessicate very rapidly under these conditions, the protective films must be applied without the vacuum lamination process. It is necessary to "seal in" an amount of water equal to the seasonal mean humidity so that there is no gradual trend for the hardboard to change its dimension through gradual gain or loss of water.

Solar cell fabrication using these materials necessitates a "split process" in which the unmounted "module" of encapsulated solar cells is prepared in a vacuum process and then laminated to the hardboard under ambient temperature and pressure conditions in a subsequent step. This prevents exposure of

The hardboard dessicating conditions. The encapsulated solar cell assembly constitutes the protective film on the top side and therfore only one other is needed for the underside.

Selecting the costing-out candidate protective films for this application is not too difficult, however the major concern has been the cost of the process in which the films are attached to the hardboard to produce a "module ready" substrate. This has required careful consideration of the types of adhesives to be used, application machinery, cure cycles, raw materials handling, factory operation, equipment costs, depreciation, etc.

The attached pages in the appendix provide the detail for a "typical" manufacturing operation in which a flexible laminate of encapsulated solar cells forms one of the protective water vapor barriers for the hardboard and an occlusive film is used to cover the opposite side. Due to the fact that the attachment of the cell string to the load bearing member occurs in two stages, we are using the term "split process" to designate this type of fabrication. The appendixed pages give the manufacturing and cost details considered in this process. Pages A-1 through A-3 gives the sequence of manufacturing steps required; page A-4 shows the Production Flow Chart, and pages A-5 and A-6 give the resulting cost estimates in 1984 and 1980 dollars, respectively. The supporting calculations used in the preparation of these estimates are also attached in Appendix B .

IV. CONCLUSIONS

The results of this analysis indicate that the process only cost for fabrication of PV modules by the "split process" using hardboards is about $2.46/m^2$ in 1980 dollars, and about $3.19/m^2$ in 1984 dollars. This is process cost and does not include any raw materials such as adhesives, films, or solar cells. This cost is additional to the cost of preparing modules by the vacuum bag process in a single step in which glass is usually used, and a completed module results. Soda-lime glass is currently about $9.70 per square meter. The split process would employ the same vacuum bag cycle for solar cell encapsulation at $6.08/m^2$, [a] and add about $3.19/m^2$ for the split process, about $1.80/m^2$ for the hardboard and (for example) $1.10 per square meter for adhesives and the back cover film for a total of $12.17/m^2$ total process cost. This would constitute a savings of $3.61/m^2$ over the cost of a glass superstrate module costing $15.78/m^2$. This potential cost reduction indicates the split process idea is worthy of further investigation and should now be costed out, including raw materials for a more accurate comparison.

APPENDIX A

Solar Module Fabrication by the "Split" Process

1984

SOLAR CELL MODULE FABRICATION BY THE "SPLIT PROCESS

OPERATIONS

1. Receive release film in rolls 26 or 50" wide.
2. Receive substrate panels, 24" x 48", ribbed back, stacked on pallets.
3. Receive Craneglas 230 mat sheet in rolls, 24 or 48" wide.
4. Receive Epon 828 epoxy resin in tank truck.
5. Receive Versamid polyamide resin in tank truck.
6. Receive solar cell unbacked modules, 24"x 48", stacked on pallets.
7. Transfer Epon 828 to epoxy resin storage tank.
8. Transfer Versamid to polyamide resin storage tank.
9. Transfer release film rolls to stack station 2.
10. Transfer reusable spacer panel pallets to stack station 3.
11. Transfer substrate panel pallets to stack station 4.
12. Transfer Craneglas 230 rolls to stack station 5.
13. Automatically pump Epon 828 from storage tank to machine supply tank at stack station 6 as needed.
14. Automatically pump Versamid from storage tank to machine supply tank at stack station 6 as needed.
15. Transfer solar cell unbacked module pallets to stack station 7.
16. Load release film roll on unwind stand at stack station 2 after removing previous roll core.
17. Load pallet stack of reusable spacer panels on unload stand at stack station 3 after removing previous emptied pallet.
18. Load pallet stack of substrate panels on unload stand at stack station 4 after removing previous emptied pallet.
19. Load Craneglas 230 roll on unwind stand at stack station 5 after removing previous roll core.
20. Load pallet stack of solar cell unbacked modules on unload stand at stack station 7 after removing previous emptied pallet.
21. Load empty, clean wheeled stack rack on empty rack clamp at station 1 of circular 8 station stacking machine and lock rack to clamp.

22. Advance stack rack in rack clamp to station 2 and index.

23. At station 2, automatically cut a 26" x 50" sheet of release film and automatically index and place it on the stack rack.

24. Advance stack rack in rack clamp to station 3 and index.

25. At station 3, automatically take one reusable spacer panel from the panel stack and automatically index and place it on the stack rack on top of the release film, aligning one edge and one end with one edge and one end of the release film.

26. Advance stack rack in rack clamp to station 4 and index.

27. At station 4, automatically take one 24 " x 48" substrate panel, ribber side down, from the panel stack and automatically index and place it on the stack rack on top of the spacer panel, aligning one edge and one end with corresponding edges and ends of other stack components.

28. Advance stack rack in rack clamp to station 5 and index.

29. At station 5, automatically cut a 24" x 48" sheet of Craneglas 230, and automatically index and place it on the stack rack on top of the substrate panel, aligning one edge and one end with corresponding edges and ends of other stack components.

30. Advance stack rack in rack clamp to station 6 and index.

31. At station 6, automatically measure, mix and dispense Epon 828/Versamid resin mixture onto the Craneglas 230 surface in a preprogramed pattern.

32. Advance stack rack in rack clamp to station 7 and index.

33. At station 7, automatically take one 24" x 48" solar cell unbacked module, cell side up, from the module stack and automatically index and place it on the stack rack on top of the resin-impregnated Craneglas, aligning one edge and one end with corresponding edges and ends of other stack components.

34. Advance stack rack in rack clamp to station 8 and index.

35. If stack rack contains fewer than 20 assemblies, advance stack rack in rack clamp to station 1 and repeat steps 22 through 34.

36. If stack rack contains 20 assemblies, unlock fully loaded wheeled stack rack from clamp and roll rack off stacking machine.

37. Place a few 24" x 48" x 20 lb fat sheet panels on top of the panel assemblies in the rack.

38. Roll the rack to a holding area and allow the panel assemblies to stand in the rack at room temperature for a minimum of four hours to allow the Epon 828/Versamid resin adhesive mixture to harden.

39. Remove the 24" x 48" x 20 lb flat sheet panels from the rack and return them to the vicinity of station 8 of the stacking machine.

40. Remove each solar cell assembly in turn from the rack.

41. Remove and discard the parting film.

42. Separate the reusable spacer panel and stack on a pallet for return to stack station 3.

43. Clean, trim, and inspect each solar cell assembly.

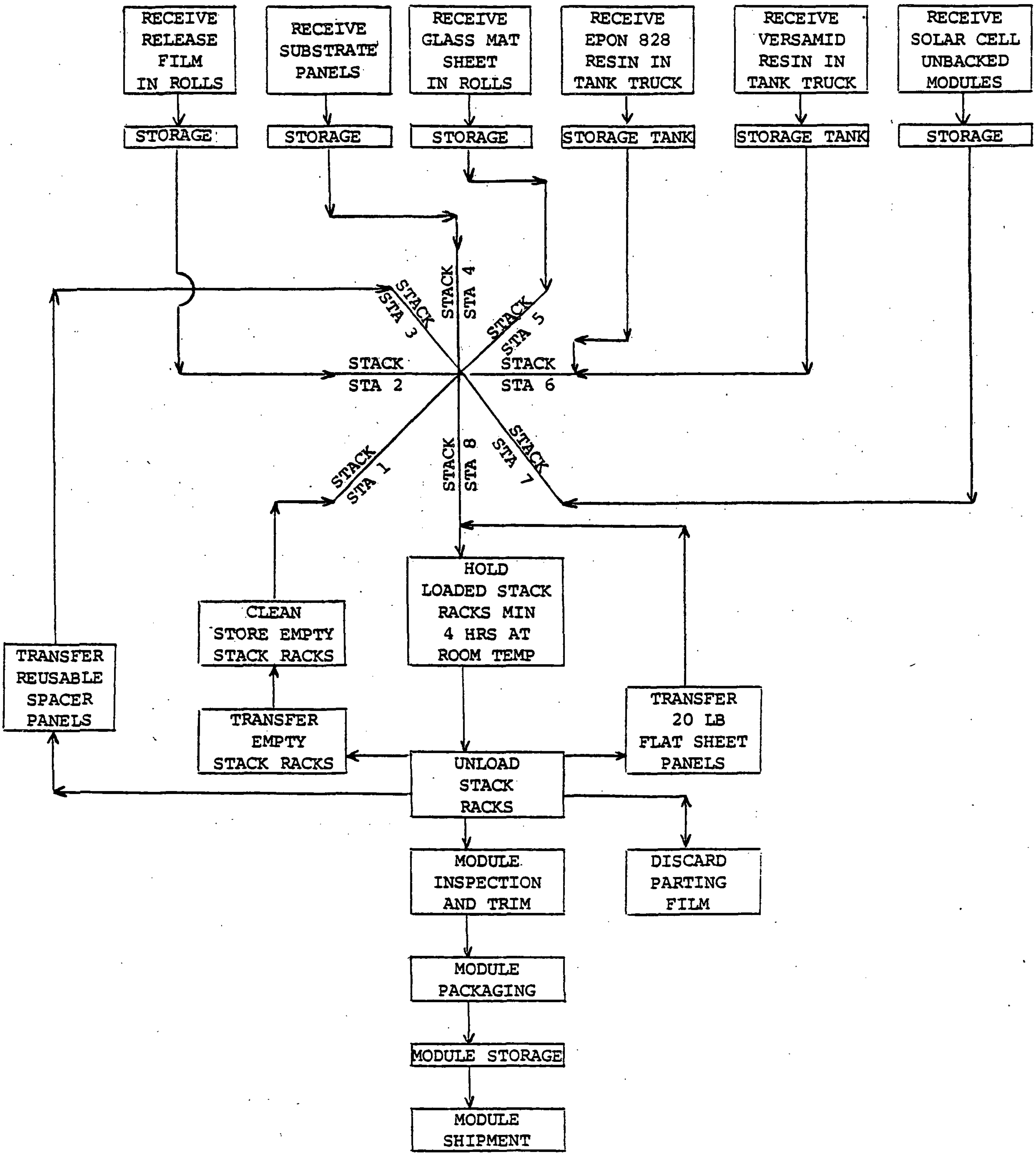
44. Pack each solar cell assembly in a corrugated shipping carton.

45. Convey the packaged solar cell assembly to a warehouse or shipping area.

46. Clean the stack rack and return it to station 1 of the stacking machine.

PRODUCTION FLOW CHART

SOLAR CELL MODULE FABRICATION BY THE "SPLIT" PROCESS



PROCESS COST ESTIMATE (1984 Estimated Costs)
SOLAR CELL MODULE FABRICATION BY THE "SPLIT" PROCESS
OUTPUT 50 MILLION SQ. FT./YR.

Operating Costs	Annual $	$ per Module	$ per Sq. Ft.	%
Variable				
Direct labor	2,583,000	0.4133	0.0517	23.10
Fringes on direct labor, 30%	774,900	0.1240	0.0155	6.93
Utilities	1,562,500	0.2500	0.0313	13.97
Freight in and out	375,000	0.0600	0.0075	3.35
Packaging	156,300	0.0250	0.0031	1.40
Maintenance supplies, 1% of 17,688,300	176,900	0.0283	0.0035	1.58
Maintenance labor, 1% of 17,688,300	176,900	0.0283	0.0035	1.58
Other supplies	312,500	0.0500	0.0063	2.79
By-products credits	---	---	---	---
	6,118,000	0.9789	0.1224	54.70
Fixed				
Indirect labor, 0.6 x direct labor	1,549,800	0.2480	0.0310	13.86
Fringes on indirect labor, 30%	464,900	0.0744	0.0093	4.16
Depreciation	2,166,700	0.3467	0.0433	19.37
Insurance and taxes, 3% of 17,688,300	530,600	0.0849	0.0106	4.74
Maintenance supplies, 1% of 17,688,300	176,900	0.0283	0.0035	1.58
Maintenance labor, 1% of 17,688,300	176,900	0.0283	0.0035	1.58
	5,065,800	0.8105	0.1013	45.30
Manufacturing cost*	11,183,800	1.7894	0.2237	100.00
Working capital* $411,900				
ROI before tax at 20% of 17,688,300 + 411,900	3,620,000	0.5792	0.0724	
Manufacturing cost + ROI*	14,803,800	2.3686	0.2961	

Capital Equipment and Buildings	Life	Annual Depreciation
$ 800,000	3 yrs	$ 266,700
11,368,300	7 yrs	1,624,000
5,520,000	20 yrs	276,000
$17,688,300		$2,166,700

*Based on listed manufacturing cost elements only. Does not include materials.

PROCESS COST ESTIMATE (1980 Estimated Costs)
SOLAR CELL MODULE FABRICATION BY THE "SPLIT" PROCESS
OUTPUT 50 MILLION SQ. FT./YR.

Operating Costs	Annual $	$ per Module	$ per Sq. Ft.	%
Variable				
Direct labor	2,097,900	0.3357	0.0420	23.90
Fringes on direct labor, 30%	629,400	0.1007	0.0126	7.17
Utilities	1,250,000	0.2000	0.0250	14.24
Freight in and out	312,500	0.0500	0.0063	3.56
Packaging	125,000	0.0200	0.0025	1.42
Maintenance supplies, 1% of 12,897,400	129,000	0.0206	0.0026	1.47
Maintenance labor, 1% of 12,897,400	129,000	0.0206	0.0026	1.47
Other supplies	250,000	0.0400	0.0050	2.85
By-products credits	---	---	---	---
	4,922,800	0.7876	0.0985	56.09
Fixed				
Indirect labor, 0.6 x direct labor	1,258,700	0.2014	0.0252	14.34
Fringes on indirect labor, 30%	377,600	0.0604	0.0076	4.30
Depreciation	1,572,300	0.2516	0.0314	17.92
Insurance and taxes, 3% of 12,897,400	386,900	0.0619	0.0077	4.41
Maintenance supplies, 1% of 12,897,400	129,000	0.0206	0.0026	1.47
Maintenance labor, 1% of 12,897,400	129,000	0.0206	0.0026	1.47
	3,853,500	0.6166	0.0771	43.91
Manufacturing cost*	8,776,300	1.4042	0.1755	100.00
Working capital* $323,200				
ROI before tax at 20% of 12,897,400 + 323,200	2,644,100	0.4231	0.0529	
Manufacturing cost + ROI*	11,420,400	1.8273	0.2284	

Capital Equipment and Buildings	Life	Annual Depreciation
$ 600,000	3 yrs	$ 200,000
8,157,400	7 yrs	1,165,300
4,140,000	20 yrs	207,000
$12,897,400		$1,572,300

*Based on listed manufacturing cost elements only. Does not include materials.

APPENDIX B

Supporting Calculations,
1984 Dollars

MANUFACTURING COST ESTIMATE
SOLAR CELL MODULE FABRICATION BY THE "SPLIT" PROCESS
CALCULATIONS

Desired output 50×10^6 ft^2/yr

Say operating rate $\frac{24 \text{ hrs}}{\text{day}} \times \frac{5 \text{ days}}{\text{wk}} \times \frac{50 \text{ wks}}{\text{yr}} = 6{,}000$ hrs/yr

Say 85% stream efficiency, 1% materials shrinkage, 5% reject rate

Design rate $\frac{50 \times 10^6 \text{ ft}^2}{\text{yr}} \times \frac{1 \text{ module}}{24 \times 48 \text{ in}^2} \times \frac{144 \text{ in}^2}{\text{ft}^2} = 6.25$ million modules/yr

1. Raw materials

a) Unbacked solar cell modules

$$\frac{6.25 \times 10^6 \text{ modules}}{\text{yr}} \times \frac{1.01}{0.95} = 6{,}644{,}737 \text{ modules/yr}$$

b) Substrate panels

$$\frac{6.25 \times 10^6 \text{ modules}}{\text{yr}} \times \frac{1 \text{ panel}}{\text{module}} \times \frac{1.01}{0.95} = 6{,}644{,}737 \text{ panels/yr}$$

c) Craneglass 230 mat sheet

$$\frac{6.25 \times 10^6 \text{ modules}}{\text{yr}} \times \frac{24 \times 48 \text{ in}^2}{\text{module}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 53{,}157{,}895 \text{ ft}^2\text{/yr}$$

d) Epon 828 resin

$$\frac{6.25 \times 10^6 \text{ modules}}{\text{yr}} \times \frac{0.70 \times 0.005 \times 24 \times 48 \text{ in}^3 \text{ adhesive}}{\text{module}} \times \frac{0.60 \text{ Epon 828}}{1.00 \text{ adhesive}}$$

$$\times \frac{1.11 \times 62.4 \text{ lb Epon 828}}{\text{ft}^3} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} \times \frac{1.01}{0.95} = 644{,}338 \text{ lbs/yr}$$

e) Versamid resin

$$\frac{6.25 \times 10^6 \text{ modules}}{\text{yr}} \times \frac{0.70 \times 0.005 \times 24 \times 48 \text{ in}^3 \text{ adhesive}}{\text{module}} \times \frac{0.40 \text{ Versamid}}{1.00 \text{ adhesive}}$$

$$\times \frac{1.13 \times 62.4 \text{ lb Versamid}}{\text{ft}^3} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} \times \frac{1.01}{0.95} = 437{,}299 \text{ lbs/yr}$$

f) Release film

$$\frac{6.25 \times 10^6 \text{ modules}}{\text{yr}} \times \frac{26 \times 50 \text{ in}^2}{\text{module}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 59{,}987{,}208 \text{ ft}^2\text{/yr}$$

2. Utilities

Say \$0.25 per module, estimated from previous study

3. Freight in and out

Say \$0.06 per module, estimated from previous study

4. Packaging

Say \$0.025 per module, estimated from previous study

5. Other supplies

Say \$0.05 per module, estimated from previous study

6. Production

Design rate 6.25×10^6 modules/yr

$$\frac{6.25 \times 10^6 \text{ modules}}{\text{yr}} \times \frac{1 \text{ yr}}{50 \text{ wks}} \times \frac{1 \text{ wk}}{5 \text{ days}} = 25{,}000 \text{ modules/day}$$

$$\frac{25{,}000 \text{ modules}}{\text{day}} \times \frac{1 \text{ day}}{24 \text{ hr}} = 1041.7 \text{ modules/hr}$$

$$\frac{1041.7 \text{ modules}}{\text{hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 17.36 \text{ modules/min}$$

At 95% yield, desired production rate:

$$\frac{17.36}{0.95} = 18.27 \text{ modules/min}$$

At 85% stream efficiency, desired capacity rate:

$$\frac{18.27}{0.85} = 21.50 \text{ modules/min}$$

Say stacking machine rate is 19 sec/station

Number of stacking machines required:

$$\frac{21.50 \text{ modules}}{\text{min}} \times \frac{19/60 \text{ min/stack station}}{\text{module/stack station}} = 7 \text{ machines}$$

Number of stack racks required:

Loading:	7 machines x 8 stations/machine	= 56
Curing:	$4 \text{ hrs} \times \frac{21.5 \text{ modules}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{1 \text{ rack}}{20 \text{ modules}}$	= 258
		314
Unloading, cleaning, spares @ 25%		79
		393
		Use 400

7. Direct labor, annual

Description		Number	Rate	Hours	Total
Raw materials handlers		2	5.00	24 x 250	60,000
Stack station attendants	3x7	21	5.50	24 x 250	693,000
Rack unloader, cleaner	1x7	7	5.50	24 x 250	231,000
Module inspector, trimmer	2x7	14	5.50	24 x 250	462,000
Module packager	1x7	7	5.00	24 x 250	210,000
Product storage, shipping		2	5.00	24 x 250	60,000
Machine supervisor	1x7	7	7.50	24 x 250	315,000
Inspection/trim supervisor		1	7.50	24 x 250	45,000
Shift supervisor		1	9.50	24 x 250	57,000
Shift mechanics		2	8.00	24 x 250	96,000
Relief operators	1x7	7	5.50	24 x 250	231,000
		71			2,460,000
Average 5% shift differential					123,000
					2,583,000

8. Capital equipment and buildings

Each circular 8-station stacking machine:

Allow 20-foot diameter around center point of machine for operating mechanism.

Allow 5 foot wide annular ring for moving stations.

Allow 5 foot wide annular ring for equipment for each stack station.

Total diameter 20+2x5+2x5 = 40 ft

Say each machine occupies a square area 40 x 40	=	1,600 ft^2
Aisles, 6 ft all around, 6 x 40 x 4	=	960 ft^2
Per machine		2,560 ft^2

Seven machines 7 x 2,560		=	$17,920 \text{ ft}^2$
Hold area for curing			
400 racks x 3 x 5 ft^2/rack =	6,000		
Aisles	6,000		
			$12,000 \text{ ft}^2$
Unload, inspection and trim area 7 x 30 x 20		=	$4,200 \text{ ft}^2$
Packaging area 7 x 20 x 20		=	$2,800 \text{ ft}^2$
Total			$36,920 \text{ ft}^2$
Raw materials storage (from previous study)			$64,000 \text{ ft}^2$
Product storage (from previous study)			$10,000 \text{ ft}^2$

Building

Manufacturing, trimming inspection, packaging	$36,920 \text{ ft}^2$
Raw materials storage	64,000
Finished product storage	10,000
	110,920
Offices (from previous study)	11,600
Locker and lunch rooms (from previous study)	11,600
Maintenance shop (from previous study)	4,000
	138,120
Use	$138,000 \text{ ft}^2$

$138,000 \text{ ft}^2 \times \$40/\text{ft}^2 = \$5,520,000$

Per machine			
Stack stations	\$70,000 x 8	=	\$ 560,000
Carrousel	100 ft x \$250/ft	=	25,000
Conveyors, inspection, trim, packaging stations		=	70,000
			655,000
Instruments and controls, spares, 40%			262,000
			917,000
Installation, 40%			366,800
			1,283,800
Engineering, 15%			192,600
Total per machine			1,476,400
Seven machines			10,334,800
Auxiliaries, 10%			1,033,500
Total machines			11,368,300
Stack racks	400 x \$2,000/rack	=	800,000
Building			5,520,000
			\$17,688,300

9. Annual Depreciation

Stack racks	$800,000/3 yrs	=	$ 266,700/yr
Machines	$11,368,300/7 yrs	=	1,624,000/yr
Building	$5,520,000/20 yrs	=	276,000/yr
			$2,166,700.yr

10. Working Capital

Based on listed manufacturing costs only.

Does not include materials.

\+ Work in process

$$\frac{1}{250} \times 11{,}183{,}800 \quad = \quad + \$ \; 44{,}700$$

\+ Finished product

$$\frac{3}{250} \times 11{,}183{,}800 \quad = \quad + \; 134{,}200$$

\+ Receivables

$$\frac{1}{12} \times \frac{11{,}183{,}800}{0.80} \quad = \quad + \; 1{,}165{,}000$$

\- Payables

$$\frac{1}{12} \times 11{,}183{,}800 \quad = \quad - \; 932{,}000$$

$$\$ \; 411{,}900$$