Low-Cost Solar
Array Project

5101-94

MASTER

Economic Analysis
of a Candidate 50¢/Wpk
Flat-Plate Photovoltaic
Manufacturing Technology

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Robert W. Aster

December 1, 1978

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ACKNOWLEDGMENT

The author gratefully acknowledges the other members of the LSA Project Analysis and Integration Area who have developed this methodology and also the members of the LSA Technology Development effort who have developed the data upon which these analyses are based.

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SECTION I

INTRODUCTION

An important milestone for the LSA Project occurred in August, 1978. The SAMICS methodology was used to analyze the first candidate manufacturing sequence that could meet the LSA Project's 1986 price goal. That goal represents a reduction in photovoltaic prices by a factor of a hundred over a 10-year period, from approximately 50 \$/Wpk in 1975 to 50 ¢/Wpk in 1986. This analysis occurred at a time when the achievability of the LSA Project's 1986 price goal was being extensively evaluated.

This document describes the results of analysis which has occurred since the original presentation of the 50 ¢/Wpk candidate factory at the 10th LSA Project Integration Meeting. Briefly, if a number of events occur, such as a high cell efficiency (14% for this technology), vertical industry integration, long periods of amortizing the initial capital investment, and full utilization of a large plant, then a price of 39.9 ¢/Wpk is possible. Non-optimal circumstances will increase this required price, and several of these circumstances are addressed in Section III of this report.

The SAMICS methodology was developed to provide a fair, consistent, reliable way of comparing manufacturing processes being developed by dozens of Low-cost Solar Array (LSA) Project subcontractors. The SAMIS III computer program, which is a part of the SAMICS methodology, is very general and is expected to be usable in virtually any manufacturing industry.

SAMIS III receives as input descriptions of manufacturing process steps. Each description provides information on the direct costs and requirements of operating that step in the manufacturing sequence. Industry size and structure, and the financial parameters of each company (e.g., return on invested capital, debt to equity ratio, etc.), can also be entered. The "price" estimates that result are actually required revenue prices, which will meet the direct and indirect costs of each company, including its specified rate of return on investment. Indirect costs such as indirect labor, facilities, and supplies are estimated from a very detailed overhead model that is driven by the direct requirements of the firm. For example, the direct requirements for the 50 ¢/Wpk factory led to 41 types of indirect equipment facilities, and 76 categories of indirect labor.

The numbers presented here are slightly different from those presented at the 10th LSA PIM. For one thing, the capital cost section of the one-time cost submodel has been modified. One-time costs include interest during construction, startup costs, and other expenses that do not occur during steady state operation of the plant. In the 250 MW case, one-time costs contributed 5.45 ¢/Wpk, about 12% of the price. While the one-time costs are not small, the change in the model turns out to have a modest effect on the required price. In this particular case, the overall change in the required price estimate is less than 0.1 ¢/Wpk. The initial capital cost figures are also different, due to the correction of an error in the

way that earlier reports were printed. Finally, the indirect requirements submodels are being examined in detail. Some items such as total support floor space and landscaping seem to be large, thus increasing the price estimate unduly. The impact of these problems is much less than 1 ¢/Wpk, but a careful review of all the indirect requirement relationships is being conducted and may lead to a release of an improved version of SAMIS III.

Another change was investigated by including a cell testing and sorting step just before cells are interconnected into strings. If this has no effect on module efficiency, then the SAMIS price estimate increases by 1.0 ¢/Wpk.

This candidate 50 ¢/Wpk technology is different in several respects from the 2 \$/Wpk strawman factories developed over the last 12 months. The strawman factories relied on ingot growth and slicing processes, where the candidate factory uses EFG ribbon growth. The ribbon growth rates and ribbon widths that are assumed here have been demonstrated experimentally. Five ribbons are pulled from each furnace, which has also been achieved in a separate experiment. This technique dramatically reduces the amount of silicon required. It also reduces the capital required for equipment in the sheet growth area. Other sheet technologies should also be considered as candidates, but this document is focused on one particular production technique.

The strawman factories used a conventional POCl process to form the cell junction, but the candidate factory assumes an advanced ion implant and pulse annealing process for junction formation. This is known to be a technically workable process, but it is not the technique used by today's manufacturers. Therefore, hardware development and demonstration are required to validate the costing data used in this analysis. There is some reason to believe that this new process will lead to increased cell efficiency, in addition to having the potential to reduce operating costs.

The strawman factories required a semiautomated version of the currently used gold/nickel plating process for metallization, but the candidate factory uses the technique of thick film printing. Printing in this manner is not fully developed. It has been shown to work experimentally, but production line reliability still requires demonstration.

The strawman modules used front and back glass covers and were filled with cells, interconnects, and polyvinyl butyral (PVB). There was an edge seal and an aluminum frame. The candidate concept is quite similar in this area. The new modules have glass front covers and Mylar back layers and are filled with cells, interconnects, and ethylene vinyl acetate (EVA). An edge seal and aluminum frame is also provided. These encapsulation materials (ignoring cells and interconnects) cost 8.28 \$/square meter of module, and this compares very well with the goal of 8 \$/square meter of module expressed in the May, 1978 version of the price allocation guidelines.

Material handling techniques are also substantially revised within the candidate factory. The 2 \$/Wpk strawman employed cassettes

to transport wafers and cells in batches from one station to the next. While this is a considerable advance from manually handling wafers one at a time, the candidate factory uses a belt transport system. Belts lead from one step to the next step, minimizing the time required to travel through the production sequence and permitting throughput rates at some stations to exceed 60 cells per minute. Total processing time from wafers to module can be as short as 1.57 hours.

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SECTION II

ASSUMPTIONS AND RESULTS

SAMIS III is a costing methodology. It is a simulation of the supply side of a market, but not of the demand side. If SAMIS is used to simulate a costly technology/industry description, then it is possible that the price required to meet costs would be too high to sell the product in a real market. Therefore it is not necessarily a predictor of what price the market will actually produce, but it is capable of describing a price at which a supplier should be willing to build and operate his plant.

The SAMIS price estimate could correspond to an actual market price if the following conditions are true:

- (1) The data describing the technology is accurate.
- (2) The plant is fully utilized (round-the-clock operation), and all of its product is sold.
- (3) Capital investment in the equipment and facilities is amortized over their operating lifetimes.
- (4) The return on invested capital (ROI), interest rate (I), and debt to equity ratio are reasonable inputs (in this analysis, ROI is 20%, I is 9.25%, and the debt to equity ratio is 1 to 6).
- (5) All direct and indirect production costs are met. Indirect labor, indirect facilities, and other indirect costs are modeled in a detailed manner that is representative of industry. Actual, specific firms may do better or worse than the nominal costs of this model.
- (6) Taxes are paid at normal corporate rates, on property and on taxable income, and normal tax credits are realized.

A. INITIAL CAPITAL REQUIREMENTS

The capital required to establish a new photovoltaic (PV) manufacturing facility will vary with the size of the facility and the type of technology. The numbers given in Table 1 are for three different plant sizes. Silicon material plant capital requirements are not included. The initial capital, divided by factory capacity, is 0.17 \$/Wpk for 250 MW and 0.19 \$/Wpk for 50 MW. The more conventional technology utilized in the 2 \$/Wpk strawman factory required a capital investment of approximately 1 \$/Wpk. This change is due in large part to the change in sheet technologies. In the first 2 \$/Wpk strawman, ingot pullers and slicers accounted for nearly 84% of the total equipment investment. Multiple ribbon EFG stations account for only about 45% of the equipment investment. The design concepts that keep EFG capital costs low (per unit of output) include

Table 1. Initial Capital Requirements
(in Millions of 1975 Dollars)

	Plant Size		
	30 MW	50 MW	250 MW
Equipment*	3.04	5.24	23.9
Facilities	1.94	2.91	11.6
Working Capital	0.79	1.29	6.5
Land	0.06	0.09	0.2
Total	5.83	9.53	42.2

*This does not include silicon plant equipment.

the following: five ribbons are pulled from each furnace, each ribbon is 7.5 cm wide, and each ribbon is grown at 7.5 cm per minute. A single melt replenishment device services two furnaces. The 250 MW factory requires 130 of these stations, which should reduce the equipment costs due to economies of scale. Other process steps in this sequence are highly automated, but initial capital investment divided by output is low, due to high throughput rates.

Table 2 indicates the capital requirements for equipment and facilities in the different areas of operation of the 250 MW plant.

B. REQUIRED PRICES

The range of encapsulated cell efficiencies that could be obtained from this sequence of processes is estimated to be between 12% and 14%. An actual pilot plant may be required in order to reduce the uncertainty in this sensitive parameter. The 250 megawatt factory contains eight lines of equipment throughout most of the cell and module portions of the plant. This makes it reasonable to consider the required prices of smaller plant sizes. Table 3 displays the required price for 30, 50, and 250 megawatt plant sizes at 12% cell efficiency, plus the effect of 13% and 14% efficiencies. Other factors that could increase the required prices are discussed in the next section.

A recommendation that was heard at the 10th PIM was to include a cell testing and sorting step immediately after the AR coating is applied. The sorting may reduce mismatch losses within the module, and the testing might lead to better process control. If this step is included and no credit is taken for increased module efficiency, then the required price increases from 46.45 to 47.49 ¢/Wpk, for the case of 250 MW at 12% efficiency. The other prices would also increase by about 1 ¢/Wpk.

Table 2. Breakdown of Capital Requirements Within the Factory
(in Thousands of 1975 Dollars)

250 Megawatts		
	Equipment	Facilities* (Direct and Indirect)
Packing Modules	11	62
Testing Modules	119	108
Encapsulating	1,479	1,081
Interconnecting Cells	<u>1,419</u>	<u>517</u>
Total Module Assembly	3,028	1,767
Apply AR Coating	1,097	610
Metallize Front	890	973
Metallize Back	929	972
Pulse Anneal Wafer	2,828	1,613
Ion Implant Junction	2,995	788
Etch Wafer	669	217
Apply Back Surface Field	<u>648</u>	<u>170</u>
Total Cell Fabrication	10,075	5,343
Total EFG Ribbon Growth	10,748	4,491
Total Factory	23,851	11,601

*Approximately 41 types of indirect facility are included in these costs. Also, it should be pointed out that this version of SAMIS has overestimated some of the indirect facility costs. (The "Pulse Anneal Wafer" process was particularly affected.) These problems have been identified and a new release of SAMIS III will correct this. The overall facility initial capital investment should be approximately 20% to 30% lower than the figures shown here. That would make this SAMIS price estimate high by approximately 0.5 ¢/Wpk.

Table 3. Required Prices (in 1975 ¢/Wpk)

Efficiencies	Factory Size (Megawatts)		
	30	50	250
12%	48.68	47.89	46.45
13%	44.93	44.21	42.88
14%	41.72	41.05	39.87

Table 4 describes annual cost in \$/W for each step in the 250 MW plant. These numbers are based on a 12% encapsulated cell efficiency.

C. RATIOS AND RULES OF THUMB

Another issue that was raised at the 10th PIM was that at least one company normally uses the decision rule that potential prices of its products should be at least 50% higher than the estimated direct costs. For the LSA Project, that company has calculated direct costs in the following way. Direct costs equaled direct labor costs, plus 100% of direct labor for overhead, plus materials, supplies, and utilities, plus the annual cost of replacing equipment investment. The 50% markup would cover profit, taxes, insurance, one-time costs of construction and startup, facilities, miscellaneous expenses, etc. Using this formula on the data available from the 250 MW, 12% efficiency case, a direct cost of 30.63 ¢/W can be calculated.* The detailed simulation of direct and indirect costs leads to a SAMIS price of 46.45 ¢/W, which implies a 52% markup. Using the 50 MW, 12% efficiency case, a direct cost from this formula is 30.77 ¢/W. The SAMIS price is 47.89 ¢/W, for a markup of 56%. Other technologies and plant designs would result in different indirect requirements and different implicit markups.

The ratio of gross sales to initial capital investment is estimated to be 2.75 and 2.51 for the 250 and 50 MW cases, respectively (12% efficiency).

The SAMIS printout of the ratio of net profit to price may be misleading at this time. One of the reasons for this is that a

*There are other formulas for "direct cost." Assumed overhead rates on labor may vary. One form of "markup" calculation could simply take the price calculated and divide that by the sum of the direct costs for labor, materials, supplies, by-products, and utilities. This leads to "markups" of 1.868 and 1.926 for the 250 and 50 MW plants, respectively.

Table 4. Annual Cost (in 1975 \$/Wpk) for Each Process Step

	Value Added	Capital Costs	Direct Labor	Materials & Supplies	Utilities	Indirect Expenses	Yield
Silicon Prep*	0.043			0.0434			
Sheet Fab	0.145	0.0630	0.0312	0.0140	0.0049	0.0320	0.800
P + Back	0.002	0.0010	0.0004	0.0002	0.0000	0.0005	0.998
Etch	0.010	0.0036	0.0018	0.0033	0.0000	0.0018	0.994
Ion Implant	0.012	0.0067	0.0018	0.0000	0.0003	0.0032	0.998
Pulse Anneal	0.006	0.0038	0.0004	0.0000	0.0003	0.0011	0.992
Back Metal	0.036	0.0108	0.0013	0.0206	0.0005	0.0030	0.980
Front Metal	0.036	0.0111	0.0013	0.0202	0.0005	0.0030	0.980
AR Coat	0.009	0.0038	0.0018	0.0014	0.0002	0.0016	0.990
Intercon	0.033	0.0104	0.0040	0.0135	0.0000	0.0054	0.999
Encapsulate & Assemble	0.130	0.0368	0.0062	0.0750	0.0001	0.0120	0.999
Test	0.001	0.0003	0.0002	0.0000	0.0000	0.0002	0.980
Package	0.001	0.0002	0.0001	0.0002	0.0000	0.0001	0.9999
Total	0.464	0.1515	0.0505	0.1918	0.0068	0.0639	-

*Based on 10 \$/kg silicon

significant portion of the revenue required to recover the amortized one-time costs consists of deferred profit and has not been included in that ratio. Although the printout figure is 2.4% of price (for the 250 MW, 12% efficiency case), the full amount is larger, and in this case may be nearly 9% of the price.

Other ratios may be of interest. The indirect labor cost is 61.3% and 62.8% of the direct labor expense for the 250 and 50 MW cases, respectively. Indirect materials and supplies is 2.3% of direct materials and supplies in both cases. Indirect utilities expense required to operate the plant is 31% of the direct utilities expense for the 50 MW plant. The energy payback period for making sheet, cells, and modules is 0.167 and 0.168 years for the 250 and 50 MW cases, respectively. This is slightly better than the most efficient 2 \$/W factory design, which has a 0.254 year energy payback period. However, none of these payback times includes the energy required for factory construction or for silicon production. But, since this technology requires about one-third the silicon required by an advanced ingot technology, the overall energy payback period should be sharply reduced.

SECTION III

SENSITIVITY ANALYSIS

A. RAPID AMORTIZATION OF CAPITAL INVESTMENT

Assumption (3) on page 5 explains that the normal SAMIS calculations assume that equipment will be operated and amortized over its normal useful lifetime. This is appropriate for a stable, on-going industry, but it is possible that the PV industry will not be stabilized by 1986. In fact, it is conceivable that some new PV technology could be developed and commercialized in the 1990's that would reduce PV market prices below the SAMIS estimate for this technology. Then it is reasonable to investigate the effect on required price of rapidly amortizing the initial capital investment.

The Rapid Amortization of Capital Investment (RACI) model is not at this time as detailed or as precise as the SAMIS model. It was developed from the simpler Interim Price Estimation Guidelines (IPEG) model, which was the first price estimation model used in SAMIS. Since IPEG gives a slightly lower price than SAMIS for this particular technology sequence by about 5%, these RACI results are increased by that amount to achieve comparability.

Table 5 shows the price required to amortize the initial capital investment in 18 months, 3 years, and 7 years, and the minimum price required after the initial capital investment has been amortized. Of course, more complicated pricing strategies could actually take place. It is interesting that 3-year amortization increases the required price by only about 16% to 17% for the candidate technology. The 2 \$/Wpk technology has a required price increase of nearly 30%. The reason for this difference is due to the different ratios of gross sales to initial capital investment, mentioned in the previous section. That ratio in the 2 \$/Wpk case was nearly twice as large as the 50 ¢/Wpk candidate factory.

Table 5 is based on a 12% encapsulated cell efficiency. Table 6 gives the same information, but for the case of 14% cell efficiency.

B. SENSITIVITY TO SILICON COST

This analysis has been focused on specific sheet, cell, and module production technologies. Silicon material currently ranges in cost from 40 to 75 \$/kg, in 1975 dollars. The variance in cost is due largely to the size of the order for silicon. The 250 megawatt plant requires 1.07 thousand metric tons of silicon, which is large enough to command the lowest prices available.* But there are also a number

*Silicon requirements of this size would require significant expansion of the high quality silicon supply industry. Any failure to expand supply could lead to increased silicon prices, with the silicon-intensive PV technology at a distinct bidding disadvantage relative to the semiconductor industry.

Table 5. Photovoltaic Required Prices for 250 MW, 50 MW, and 30 MW Plants Assuming 12% Cell Efficiency (in 1975 ¢/Wpk)

Amortization Period	Plant Size (MW)		
	250	50	30
18 Months	70	73	74
3 Years	54	56	57
7 Years	49	50	50
Minimum Price After Writeoff	35	35	35

Table 6. Photovoltaic Required Prices for 250 MW, 50 MW, and 30 MW Plants Assuming 14% Cell Efficiency (in 1975 ¢/Wpk)

Amortization Period	Plant Size (MW)		
	250	50	30
18 Months	60	63	64
3 Years	46	48	49
7 Years	42	43	43
Minimum Price After Writeoff	30	30	30

of alternative silicon technologies being developed by the Silicon Material Task of the LSA Project. These include several approaches which could achieve 7 to 10 \$/kg silicon (from new plants with one thousand metric ton capacities). A modified Siemens Process is also being investigated. It is considered to have a high probability of technical success and could lead to (1) a large expansion of current capacity and (2) prices as low as 20 \$/kg. Clearly, the actual price of high grade polycrystalline silicon could vary tremendously.

However, it should also be pointed out that this ribbon technology would require considerably less silicon than conventional ingot growth and slicing techniques. Currently, it takes 16 to 24 grams of silicon to produce 1 watt. Silicon is lost in growing ingots, in slicing wafers, in polishing off saw damage, in shaping wafers, and in yield losses. A more advanced ingot-based technology may require only 10 to 12 grams per watt. However, EFG (and other) ribbons should be thinner, and the process avoids slicing, polishing, and shaping losses. Therefore, the candidate factory required only 4 grams of silicon to produce 1 watt.

Table 7 shows the effect of several silicon costs on the required price. As an estimate of increased costs in working capital and miscellaneous expense, a 10% burden rate was applied to the increased cost of the silicon material.

Table 7. Required Price in 1975 ¢/Wpk as a Function of Silicon Cost and Cell Efficiency

Cell Efficiency	Silicon Cost 1975 \$/kg				
	7	10	20	30	40
12%	45.1	46.5	51.3	56.1	60.9
14%	38.7	39.9	44.0	48.1	52.2

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SECTION IV

CONCLUSIONS

The analyses described in this report indicate that the manufacturing of 50 ¢/Wpk flat-plate silicon photovoltaic modules is a technically achievable goal. Factors which could make a 40 ¢/Wpk goal technically achievable are the following:

- (1) 14% encapsulated cell efficiency from the technology described here.
- (2) Large scale production, on the order of 50 to 250 megawatts.
- (3) A long-term, stable market allowing full production and permitting long-term amortization of the initial capital investment.
- (4) Vertically integrated firms.
- (5) Silicon available at 10 \$/kg.

Several factors could lead to increased costs, and would make it more difficult to achieve the 50 ¢/Wpk goal. In approximate order of sensitivity, these include:

- (1) Lower than 12% encapsulated cell efficiencies.
- (2) Amortizing capital investment over shorter periods of times. Eighteen-month amortization increases costs nearly 50% in this case.
- (3) Firms are not vertically integrated. The impact of this is highly variable and not easily predicted at this time.
- (4) Smaller firms. The cell and module manufacturing lines balance at 30 MW's, for this cell and module manufacturing sequence, and smaller plant sizes will lead to underutilized capital equipment.

APPENDIX A

INDUSTRY DESCRIPTION AND FORMAT A'S

The industry description that received the most attention was the one that produces 250 megawatts and that has an encapsulated cell efficiency of 12%. The factory floor plan presented at the 10th PIM was based on this industry description.

It was assumed that silicon material would be available at a price of 10 \$/kg. It was also assumed that the rest of the industry would have the simplest configuration possible, with all firms the same size, vertically integrated from EFG growth to module packaging. Marketing and distribution costs are not included in the SAMIS required price.

Other industry configurations are certainly possible, but they would have been equally arbitrary. This type of configuration would produce the lowest required price from the SAMIS model.

The following pages contain the Format A's that are the main source of engineering data for the SAMIS program.

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
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PROCESS DESCRIPTION

Note: Names given in brackets [] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] EFG
A2 [Descriptive Name] Edge Defined Web Growth

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] Ribbons
A4 Descriptive Name [Product Name] 7.5 cm wide, 7 mil thick grown at 7.5 cm/min, scribed & broken into 10 cm lengths, .98 scribe yield, .88 silicon mass yield.
A5 Unit Of Measure [Product Units] Ribbons

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 7.351 $7.351 = 7.5 \times .98$ Units (given on line A5) Per Operating Minute
A7 Average Time at Station 1.34 Calendar Minutes (Used only to compute in-process inventory) [Processing Time]
A8 Machine "Up" Time Fraction .643** Operating Minutes Per Minute [Usage Fraction]

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9 Component [Referent]	E-0	2 Furnaces	10 Cartridges	MP
A9a Component [Descriptive Name] (Optional)	Electro-Optical	Two Small Furnaces	10 Graphite Cartridges	1 Melt Replenisher
A10 Base Year For Equipment Prices [Price Year]	1978	1978	1978	1978
A11 Purchase Price (\$ Per Component) [Purchase Cost]	15,000	40,000	50,000	9,000*
A12 Anticipated Useful Life (Years) [Useful Life]	7	7	7	7
A13 [Salvage Value] (\$ Per Component)	300	3,000	4,500	900
A14 [Removal and Installation Cost] (\$/Component)	0	400	100	100

*Purchase prices could be higher if less than 100 work stations are purchased.

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

**Reduced from .67 to meet the 250 MW plant design.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) EFG

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16	A18	A19	A17
Catalog Number [Expense Item Referent]	Amount Required Per Machine (Per Shift) [Amount per Machine]	Units	Requirement Description
A2064D	150.4	SqFt/station	Floor Space Type A
B3736D	0.1	persons/shift	Maintenance Mechanic
B3672D	1.0	persons/shift	Chemical Operator II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20	A22	A23	A21
Catalog Number [Expense Item Referent]	Amount Required Per Machine Per Minute [Amount per Cycle]	Units	Requirement Description
E1586D	0.02587	kg/Min	Silicon (10\$/Kg)
E1120D	2.09E-5	Boat/Min	Boats
E1304D	0.3330	Cu.Ft./Min	Helium
C1032B	1.0330	kw.Hr./Min	Electricity
E1112D	1.666	Cu.Ft./Min	Argon Gas
EG801D	0.00287	Dies/Min	EFG Dies
EG803D	0.00553	\$ worth/Min	EFG Insulation Material
EG805D	0.00276	\$ worth/Min	EFG Heating Elements
EG807D	0.0144	\$ worth/Min	EFG Cartridge Material

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24	A28	A26	A27	A25
[Product Reference]	[Yield]* (%)	[Ideal Ratio]** Of Units Out/Units In	Units Of A26***	Product Name
Silicon is treated as a direct requirement.			/	
			/	
			/	

Prepared by R. W. Aster from the Mobil Tyco monthly report Date August, 1978
of Dec. 15, 1977.

* 100% minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] P + Back

A2 [Descriptive Name] Apply and fire-in aluminum power on the back of the wafer.

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] PBACKWAF

A4 Descriptive Name [Product Name] A wafer with aluminum fired into its back surface.

A5 Unit Of Measure [Product Units] Wafers

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 80 Units (given on line A5) Per Operating Minute

A7 Average Time at Station 0.433 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction .960 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	<u>Unloader</u>	<u>Printer</u>	<u>Furnace</u>
A9a	Component [Descriptive Name] (Optional)	<u>Cassette</u>		<u>Belt</u>
		<u>Unloader</u>		<u>Furnace</u>
A10	Base Year For Equipment Prices [Price Year]	<u>1977</u>	<u>1977</u>	<u>1977</u>
A11	Purchase Price (\$ Per Component) [Purchase Cost]	<u>15,000</u>	<u>70,000</u>	<u>20,000</u>
A12	Anticipated Useful Life (Years) [Useful Life]	<u>7</u>	<u>7</u>	<u>7</u>
A13	[Salvage Value] (\$ Per Component)	<u>2,000</u>	<u>10,000</u>	<u>3,000</u>
A14	[Removal and Installation Cost] (\$/Component)	<u>500</u>	<u>1,000</u>	<u>1,000</u>

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

A15 Process Referent (From Page 1 Line A1) P + BACK

A16	A18	A19	A17
Catalog Number [Expense Item Referent]	Amount Required Per Machine (Per Shift) [Amount per Machine]	Units	Requirement Description
A2064D	300	Sq Ft.	Floor Space Type A
B3064D	0.25	persons/shift	General Assembler
B3736D	0.014	persons/shift	Maintenance Mechanic
B3688D	0.007	persons/shift	Electronics Maintenance

[illegible]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
RIBBONS	.998	1/1	Wafers/Ribbons	EFG wafers
			1	
			1	

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

Note: Names given in brackets [] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] ETCH

A2 [Descriptive Name] PLASMA Etch wafers

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] ETCHDWAF

A4 Descriptive Name [Product Name] Wafers that have had the oxide layer etched away.

A5 Unit Of Measure [Product Units] Wafers

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 85 Units (given on line A5) Per Operating Minute

A7 Average Time at Station 10 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)

A8 Machine "Up" Time Fraction .911 Operating Minutes Per Minute
[Usage Fraction]

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9 Component [Referent] Machine

A9a Component [Descriptive Name] (Optional)

A10 Base Year For Equipment Prices [Price Year] 1977

A11 Purchase Price (\$ Per Component) [Purchase Cost] 110,000

A12 Anticipated Useful Life (Years) [Useful Life] 7

A13 [Salvage Value] (\$ Per Component) 0

A14 [Removal and Installation Cost] (\$/Component) 2,750

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) Etch

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16	A18	A19	A17
Catalog Number [Expense Item Referent]	Amount Required Per Machine (Per Shift) [Amount per Machine]	Units	Requirement Description
A2064D	150	Sq.ft.	Floor Space type A
B3672D	1.0	person/shift	Chemical operator II
B3736D	0.05	person/shift	Maintenance mechanic II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20	A22	A23	A21
Catalog Number [Expense Item Referent]	Amount Required Per Machine Per Minute [Amount per Cycle]	Units	Requirement Description
EG1700D	0.0676	CF/M	Tetrafluoromethane (CF ₄)
DG1024D	1.94E-5	Gal/M	Vacuum pump oil
E1112D	0.01	CF/M	Argon
C1032B	0.106	KW/M	Electricity
C2128B	0.0087	CF/M	Ventilation

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24	A28	A26	A27	A25
[Product Reference]	[Yield]* (%)	[Ideal Ratio]** Of Units Out/Units In	Units Of A26***	Product Name
PBACKWAF	.994	1/1	Wafer/Wafer	P+Back Surface Wafer
			/	
			/	

Prepared by JPL LSA Task 4 Date August, 1978

* 100 % minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] IIAP
A2 [Descriptive Name] Ion Implant - Advanced P Type

PART 1 - PRODUCT DESCRIPTION

A3 [Product Referent] ISLP
A4 Descriptive Name [Product Name] Implanted wafer, P Type
A5 Unit Of Measure [Product Units] wafer

PART 2 - PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 80 Units (given on line A5) Per Operating Minute
A7 Average Time at Station 0.0125 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)
A8 Machine "Up" Time Fraction 0.976 Operating Minutes Per Minute
[Usage Fraction]

PART 3 - EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	<u>Implanter</u>		
A9a	Component [Descriptive Name] (Optional)	<u>High Current</u> <u>Ion Implanter</u>		
A10	Base Year For Equipment Prices [Price Year]	<u>1977</u>		
A11	Purchase Price (\$ Per Component) (Purchase Cost)	<u>500,000</u>		
A12	Anticipated Useful Life (Years) [Useful Life]	<u>7</u>		
A13	[Salvage Value] (\$ Per Component)	<u>0</u>		
A14	[Removal and Installation Cost] (\$/Component)	<u>5,000</u>		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) IIAP

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	765	Sq. Ft.	Floor Space Type A
B3672D	1.0	persons/shift	Chemical Operator II
B3736D	0.07	persons/shift	Maintenance Mechanic

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.625	Kw.Hr/Min	Electricity
C2128B	0.5	Cu.Ft./Min	Ventilation
C1080D	5E-6	Cu.Ft./Min	Nitrogen (liquid)
EG1460D	1.3E-7	Cu.Ft./Min	Phosphine Gas

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
ETCHDWAF	.998	1/1	Wafers / Wafer	Etched Wafers
			1	
			1	

Prepared by JPL LSA Task 4 Date August, 1978

* 100 % minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
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4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] ANNEALWAF

A2 [Descriptive Name] Pulse Anneal the surface of a wafer.

PART 1 - PRODUCT DESCRIPTION

A3 [Product Referent] ANELDWAF

A4 Descriptive Name [Product Name] A wafer with a P junction at the proper depth.

A5 Unit Of Measure [Product Units] Wafer

PART 2 - PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 80 Units (given on line A5) Per Operating Minute

A7 Average Time at Station 1.0 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)

A8 Machine "Up" Time Fraction .976 Operating Minutes Per Minute
[Usage Fraction]

PART 3 - EQUIPMENT COST FACTORS [Machine Description]

A9 Component [Referent] Machine

A9a Component [Descriptive Name] (Optional) Pulse
Machine
and Belt

A10 Base Year For Equipment Prices [Price Year] 1978

A11 Purchase Price (\$ Per Component) [Purchase Cost] 450,000

A12 Anticipated Useful Life (Years) [Useful Life] 7

A13 [Salvage Value] (\$ Per Component) 225,000

A14 [Removal and Installation Cost] (\$/Component) 10,000

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) ANNEALWAF

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
<u>A2064D</u>	<u>255</u>	<u>Sq.Ft.</u>	<u>Floor Space Type A</u>
<u>B3704D</u>	<u>0.25</u>	<u>persons/shift</u>	<u>Electronics Technician</u>

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
<u>C1016B</u>	<u>1.33</u>	<u>Cu.Ft./Min</u>	<u>Domestic Water</u>
<u>C1032B</u>	<u>0.3024</u>	<u>KW-Hrs/Min</u>	<u>Electricity</u>

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
<u>ISLP</u>	<u>.992</u>	<u>1/1</u>	<u>Wafers /Wafer</u>	<u>Implanted Wafer</u>
			<u>/</u>	
			<u>/</u>	

Prepared by JPL LSA Task 4 Date August, 1978

* 100% minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
3800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] BACKMETL
A2 [Descriptive Name] Screen Print Back Metalization

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] WAFERBM
A4 Descriptive Name [Product Name] A Wafer with 7% metal coverage on its back side.
A5 Unit Of Measure [Product Units] Wafers

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 26 Units (given on line A5) Per Operating Minute
A7 Average Time at Station 20 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)
A8 Machine "Up" Time Fraction .976 Operating Minutes Per Minute
[Usage Fraction]

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	<u>SPSYSB</u>		
A9a	Component [Descriptive Name] (Optional)			
A10	Base Year For Equipment Prices [Price Year]	<u>1977</u>		
A11	Purchase Price (\$ Per Component) [Purchase Cost]	<u>50,000</u>		
A12	Anticipated Useful Life (Years) [Useful Life]	<u>7</u>		
A13	[Salvage Value] (\$ Per Component)	<u>20,000</u>		
A14	[Removal and Installation Cost] (\$/Component)	<u>1,000</u>		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) BACKMETL

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2080D	275	Sq. Ft.	Floor Space Type B
B3096D	0.25	Persons/shift	Semiconductor Assembler
B3688D	0.05	Persons/shift	Electronics Maintenance

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.4202	Kw.Hr./Min	Electricity
E1576D	0.00688	Screens/Min	Screens
E1624D	0.0583	Squeegees/Min	Squeegees
EG4D	0.00132	Gal/Min	Toluene
E1696D	0.0464	\$/Min	Thermocouple
E1064D	1.82	gm/Min	Silver Paste

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
ANELDWAF	.98	1/1	Wafers/Wafer	Annealed Wafer
			/	
			/	

Prepared by JPL LSA Task 4 Date August, 1978

* 100 % minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets []
are the names of process attributes
requested by the SAMIS III
computer program.

A1 Process [Referent] FRONTMETL

A2 [Descriptive Name] Screen Print Front Metalization Grid

PART 1 - PRODUCT DESCRIPTION

A3 [Product Referent] CELLFM

A4 Descriptive Name [Product Name] A metalized cell, 7% surface coverage.

A5 Unit Of Measure [Product Units] cell

PART 2 - PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 25 Units (given on line A5) Per Operating Minute

A7 Average Time at Station 20 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)

A8 Machine "Up" Time Fraction .9760 Operating Minutes Per Minute
[Usage Fraction]

PART 3 - EQUIPMENT COST FACTORS [Machine Description]

A9 Component [Referent] SPSYSF

A9a Component [Descriptive Name] (Optional)

A10 Base Year For Equipment Prices [Price Year] 1977

A11 Purchase Price (\$ Per Component) [Purchase Cost] 50,000

A12 Anticipated Useful Life (Years) [Useful Life] 7

A13 [Salvage Value] (\$ Per Component) 20,000

A14 [Removal and Installation Cost] (\$/Component) 1,000

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) FRONTMETL

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)

[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2080D	275	Sq.Ft.	Floor Space Type B
B3096D	0.25	Persons/shift	Semiconductor Assembler
B3688D	0.05	Persons/shift	Electronics Maintenance

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE

[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	0.4202	Kw.Hr./Min	Electricity
E1576D	0.00688	Screens/Min	Screens
E1624D	0.0583	Squegees/Min	Squegees
EG4D	0.00132	Gal/Min	Toluene
E1696D	0.0464	\$/Min	Thermocouple
E1064D	1.82	gm/Min	Silver Paste

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
WAFERBM	.98	1/1	Cells/wafer	Wafer BM
			/	
			/	

Prepared by JPL LSA Task 4 Date August, 1978

* 100 % minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
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PROCESS DESCRIPTION

Note: Names given in brackets []
are the names of process attributes
requested by the SAMIS III
computer program.

A1 Process [Referent] A-R COAT
A2 [Descriptive Name] Spray an anti-reflective coating onto the metalized cell

PART 1 - PRODUCT DESCRIPTION

A3 [Product Referent] ARCELL
A4 Descriptive Name [Product Name] A cell with an A-R Coating
A5 Unit Of Measure [Product Units] cells

PART 2 - PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 75 Units (given on line A5) Per Operating Minute
A7 Average Time at Station 3 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)
A8 Machine "Up" Time Fraction .96 Operating Minutes Per Minute
[Usage Fraction]

PART 3 - EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	<u>ZICON</u>		
A9a	Component [Descriptive Name] (Optional)	<u>Zicon</u>		
		<u>A-R Coat</u>		
		<u>Sprayer</u>		
A10	Base Year For Equipment Prices [Price Year]	<u>1977</u>		
A11	Purchase Price (\$ Per Component) [Purchase Cost]	<u>185,000</u>		
A12	Anticipated Useful Life (Years) [Useful Life]	<u>7</u>		
A13	[Salvage Value] (\$ Per Component)	<u>0</u>		
A14	[Removal and Installation Cost] (\$/Component)	<u>0</u>		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) A-RCOAT

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16	A18	A19	A17
Catalog Number [Expense Item Referent]	Amount Required Per Machine (Per Shift) [Amount per Machine]	Units	Requirement Description
A2080D	450	Sq.Ft.	Floor Space Type B
B3096D	0.5	Persons/shift	Semiconductor Assembler
B3688D	0.1	Persons/shift	Electronics Maintenance
B3224B	0.1	Persons/shift	Industrial Engineer

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20	A22	A23	A21
Catalog Number [Expense Item Referent]	Amount Required Per Machine Per Minute [Amount per Cycle]	Units	Requirement Description
C1032B	.500	Kw.Hr./Min	Electricity
E1080D	.0079	\$ worth/Min	A-R Coating
E1416D	.500	CF/Min	Nitrogen Gas

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24	A28	A26	A27	A25
[Product Reference]	[Yield]* (%)	[Ideal Ratio]** Of Units Out/Units In	Units Of A26***	Product Name
CELLFM	.99	1/1	Cells/Cell	CellFM
			/	
			/	

Prepared by JPL LSA Task 4 Date August, 1978

* 100% minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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PROCESS DESCRIPTION

Note: Names given in brackets []
are the names of process attributes
requested by the SAMIS III
computer program.

A1 Process [Referent] INTERCON
A2 [Descriptive Name] Interconnect the Cells into 12 Cell Strings.

PART 1 - PRODUCT DESCRIPTION

A3 [Product Referent] INTCONSTR
A4 Descriptive Name [Product Name] Strings of 12 Cells, 1.2 M long
A5 Unit Of Measure [Product Units] Strings

PART 2 - PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 3.0 Units (given on line A5) Per Operating Minute
A7 Average Time at Station 1 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)
A8 Machine "Up" Time Fraction .683* Operating Minutes Per Minute
[Usage Fraction]

PART 3 - EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	<u>Machine</u>		
A9a	Component [Descriptive Name] (Optional)			
A10	Base Year For Equipment Prices [Price Year]	<u>1978</u>		
A11	Purchase Price (\$ Per Component) [Purchase Cost]	<u>80,000</u>		
A12	Anticipated Useful Life (Years) [Useful Life]	<u>7</u>		
A13	[Salvage Value] (\$ Per Component)	<u>15,000</u>		
A14	[Removal and Installation Cost] (\$/Component)	<u>500</u>		

* Reduced from .95 to balance the 250 MW line.

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) INTERCON

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	100	Sq. Ft.	Floor Space Type A
B3032D	1	person/shift	Electronics Assembler

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	.0417	KwHr/Min	Electricity
EP20D	36	Units/Min	Interconnects

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
ARCELL	.999	.08333/1	Strings/Cell	Cells
			1	
			1	

Prepared by JPL LSA Task 4 Date August, 1978

* 100% minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037-S R 10/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets []
are the names of process attributes
requested by the SAMIS III
computer program.

A1 Process [Referent] ENCAP&ASS

A2 [Descriptive Name] Connect Strings and Encapsulate the Module

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] MODULE

A4 Descriptive Name [Product Name] A Module, approximately 4' x 4', containing
16 strings (192 cells)

A5 Unit Of Measure [Product Units] Modules

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 0.65 Units (given on line A5) Per Operating Minute

A7 Average Time at Station 1.54 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)

A8 Machine "Up" Time Fraction 0.594* Operating Minutes Per Minute
[Usage Fraction]

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	<u>Conveyor</u>	<u>Coater</u>	<u></u>
A9a	Component [Descriptive Name] (Optional)	<u></u>	<u></u>	<u></u>
		<u></u>	<u></u>	<u></u>
A10	Base Year For Equipment Prices [Price Year]	<u>1978</u>	<u>1978</u>	<u></u>
A11	Purchase Price (\$ Per Component) [Purchase Cost]	<u>230,000</u>	<u>25,000</u>	<u></u>
A12	Anticipated Useful Life (Years) [Useful Life]	<u>20</u>	<u>20</u>	<u></u>
A13	[Salvage Value] (\$ Per Component)	<u>2,000</u>	<u>300</u>	<u></u>
A14	[Removal and Installation Cost] (\$/Component)	<u>2,500</u>	<u>1,500</u>	<u></u>

* Reduced from .95 to balance the 250 MW line.

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) ENCAP&ASS

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16	A18	A19	A17
Catalog Number [Expense Item Referent]	Amount Required Per Machine (Per Shift) [Amount per Machine]	Units	Requirement Description
A2064D	437.5	Sq.Ft.	Floor Space Type A
B3752D	4.0	persons/shift	Machine Operator

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20	A22	A23	A21
Catalog Number [Expense Item Referent]	Amount Required Per Machine Per Minute [Amount per Cycle]	Units	Requirement Description
E1812D	10.4	Sq.Ft./Min	1/8" Float Glass
E1100D	10.4	Ft./Min	Aluminum Channel
E1560D	0.0585	Lbs./Min	RTV 615 Silicone
C1032B	0.155	Kw.Hr./Min	Electricity
EG37D	7.80	Ft./Min	Terminal Bus Wire
EG39D	1.30	Sets/Min	Terminal Block Sets
EG1D	41.6	Sq.Ft./Min	10 mill thick EVA Sheets
EG30D	10.4	Sq.Ft./Min	5 mill thick Mylar

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24	A28	A26	A27	A25
[Product Reference]	[Yield]* (%)	[Ideal Ratio]** Of Units Out/Units In	Units Of A26***	Product Name
INTCONSTR	.999	0.0625	Modules/string	Strings
			/	
			/	

Prepared by JPL LSA Task 4 Date August, 1978

* 100% minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets []
are the names of process attributes
requested by the SAMIS III
computer program.

A1 Process [Referent] MODTEST

A2 [Descriptive Name] Testing Modules

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] TMODULE

A4 Descriptive Name [Product Name] Tested Module

A5 Unit Of Measure [Product Units] Modules

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 4 Units (given on line A5) Per Operating Minute

A7 Average Time at Station .25 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)

A8 Machine "Up" Time Fraction .40* Operating Minutes Per Minute
[Usage Fraction]

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9 Component [Referent] Tester

A9a Component [Descriptive Name] (Optional)

A10 Base Year For Equipment Prices [Price Year] 1977

A11 Purchase Price (\$ Per Component) [Purchase Cost] 75,000

A12 Anticipated Useful Life (Years) [Useful Life] 10

A13 [Salvage Value] (\$ Per Component) 5,000

A14 [Removal and Installation Cost] (\$/Component) 5,000

* Reduced from .95 to balance the 250 MW line.

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the
[equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context,
use 0.0, (1975, 6.0), DDB, and SL.

A15 Process Referent (From Page 1 Line A1) MODTEST

A16	A18	A19	A17
Catalog Number [Expense Item Referent]	Amount Required Per Machine (Per Shift) [Amount per Machine]	Units	Requirement Description
A2064D	450	Sq.Ft.	Floor Space Type A
B3096D	0.50	Persons/shift	Semiconductor Assembler
B3704D	0.025	Persons/shift	Electronics Technician
B3720D	0.0125	Persons/shift	Systems Inspector

[illegible]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
MODULE	.98	1/1	Modules/Module	Modules
			/	
			/	

* 100% minus percentage of required product lost.

**** Assume 100% yield here.**

*** Examples: Modules/Cell or Cells/Wafer.

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

Note: Names given in brackets [] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] PACKAGE

A2 [Descriptive Name] Packing Modules into Crates

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] PMODULE

A4 Descriptive Name [Product Name] A Packaged Module, Ten per Crate.

A5 Unit Of Measure [Product Units] Crates

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 2.4 Units (given on line A5) Per Operating Minute

A7 Average Time at Station 10 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)

A8 Machine "Up" Time Fraction .95 Operating Minutes Per Minute
[Usage Fraction]

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9 Component [Referent] Machine

A9a Component [Descriptive Name] (Optional)

A10 Base Year For Equipment Prices [Price Year] 1978

A11 Purchase Price (\$ Per Component) (Purchase Cost) 15,000

A12 Anticipated Useful Life (Years) [Useful Life] 7

A13 [Salvage Value] (\$ Per Component) 1,500

A14 [Removal and Installation Cost] (\$/Component) 1,000

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) PACKAGE

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16	A18	A19	A17
Catalog Number [Expense Item Referent]	Amount Required Per Machine (Per Shift) [Amount per Machine]	Units	Requirement Description
A2064D	900	Sq.Ft.	Floor Space Type A
B3656D	4	Persons/shift	Packager

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20	A22	A23	A21
Catalog Number [Expense Item Referent]	Amount Required Per Machine Per Minute [Amount per Cycle]	Units	Requirement Description
E1180D	8	Cu.Ft./Min	Crates, Wooden
C1032B	.016	Kw.Hr./Min	Electricity

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24	A28	A26	A27	A25
[Product Reference]	[Yield]* (%)	[Ideal Ratio]** Of Units Out/Units In	Units Of A26***	Product Name
TMODULE	.9999	1/10	Crates/Modules	Tested Modules
			1	
			1	

Prepared by JPL LSA Task 4 Date August, 1978

* 100 % minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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PROCESS DESCRIPTION

Note: Names given in brackets []
are the names of process attributes
requested by the SAMIS III
computer program.

A1 Process [Referent] TESTCELL
A2 [Descriptive Name] Tests and Sorts Individual Cells. Not Used in the Original
Candidate Factory

PART 1 - PRODUCT DESCRIPTION

A3 [Product Referent] ETC
A4 Descriptive Name [Product Name] Electrically Tested Cells
A5 Unit Of Measure [Product Units] Cells

PART 2 - PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 40 Units (given on line A5) Per Operating Minute
A7 Average Time at Station 2.5 Calendar Minutes (Used only to compute
[Processing Time] in-process inventory)
A8 Machine "Up" Time Fraction .95 Operating Minutes Per Minute
[Usage Fraction]

PART 3 - EQUIPMENT COST FACTORS (Machine Description)

A9	Component [Referent]	<u>Tester</u>		
A9a	Component [Descriptive Name] (Optional)			
A10	Base Year For Equipment Prices [Price Year]	<u>1977</u>		
A11	Purchase Price (\$ Per Component) [Purchase Cost]	<u>50,000</u>		
A12	Anticipated Useful Life (Years) [Useful Life]	<u>7</u>		
A13	[Salvage Value] (\$ Per Component)	<u>5,000</u>		
A14	[Removal and Installation Cost] (\$/Component)	<u>500</u>		

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) TESTCELL

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
(Facilities and Personnel Requirements)

A16	A18	A19	A17
Catalog Number (Expense Item Referent)	Amount Required Per Machine (Per Shift) (Amount per Machine)	Units	Requirement Description
<u>A2064D</u>	<u>175</u>	<u>Sq.Ft.</u>	<u>Floor Space Type A</u>
<u>B3768D</u>	<u>0.5</u>	<u>Persons/shift</u>	<u>Electronic Tester</u>
<u>B3688D</u>	<u>0.05</u>	<u>Persons/shift</u>	<u>Electronics Maintenance</u>
<u>B3736D</u>	<u>0.05</u>	<u>Persons/shift</u>	<u>Maintenance Mechanic</u>

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
 [Byproduct Outputs] and [Utilities and Commodities Requirements]

[illegible]**PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]**

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
ARCELL	.99	1/1	Cells/Cell	Cells

Prepared by JPL LSA Task 4 Date August, 1978

* 100% minus percentage of required product lost.

** Assume 100% yield here.

*** Examples: Modules/Cell or Cells/Wafer.

APPENDIX B

COMPARISON OF THE 50 ¢/Wpk CANDIDATE FACTORY WITH THE MAY, 1978 PRICE ALLOCATION GUIDELINES

The Price Allocation Guidelines (PAG) are a set of internally consistent targets by which the LSA Project might achieve its overall goal. It is revised and updated from time to time as new knowledge is developed or as breakthroughs occur. The most recent PAG was published in May, 1978, approximately three months prior to the work that led to the candidate factory.

The candidate factory was developed from process descriptions and is an example of a "bottom up" cost analysis. The PAG is a "top down" analysis technique, starting with an overall objective and working down to specific areas. Table B-1 shows how the candidate technology compares with project goals.

This table shows that nearly all of the task goals appear to be feasible, especially if this technology is capable of the higher cell efficiency. One problem area is that overall yields of this technology simulation are not quite as high as they are in the PAG. However, this is more than offset by the strong performance in the cell and module production areas of the candidate factory.

Table B-1. The 1986 PAG and Candidate Technology Simulation Results
(All Dollars Are 1975 Dollars)

Production Area	1986 Goal (Value Added)	Candidate Technology (Value Added)
Sheet Production Area		
• Non-Ingot Technology		
12% enc. cell efficiency	11.1 $\$/\text{m}^2$ sheet	15.8 $\$/\text{m}^2$ sheet
14% enc. cell efficiency	17.4 $\$/\text{m}^2$ sheet	15.8 $\$/\text{m}^2$ sheet
Cell Production Area	22 $\$/\text{m}^2$ cells	14.8 $\$/\text{m}^2$ cells
Encapsulation Materials	8 $\$/\text{m}^2$ module	8.3 $\$/\text{m}^2$ module
Module Production Area (not including encapsulation materials)	15.5 $\$/\text{m}^2$ module	10.0 $\$/\text{m}^2$ module
Overall Silicon Yield		
12% enc. cell efficiency	4.0 kg/kW	4.3 kg/kW
14% enc. cell efficiency	3.5 kg/kW	3.7 kg/kW