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PV Cz Silicon Manufacturing Technology Improvements

Semiannual Subcontract Report
1 April 1994 – 30 September 1994

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PREFACE

Siemens Solar Industries (SSI) began a three-year, three-phase cost shared contract in March 1992 to demonstrate significant cost reductions and improvements in manufacturing technology. The work has focused on near-term projects for implementation in the SSI Czochralski (Cz) manufacturing facility in Camarillo, California.

The work has been undertaken to increase the commercial viability and volume of photovoltaic manufacturing by evaluating the most significant cost categories and then lowering the cost of each item through experimentation, materials refinement, and better industrial engineering.

The final phase of the program has concentrated in the areas of crystal growth, wafer technology and environmental, safety and health issues.

Significant contributions have been made by the key personnel involved in the program. They include Kim Mitchell, in the crystal growth and wafer areas, and Sergio Vasquez in the environmental, safety and health area.

SUMMARY

OBJECTIVES

The objective of the program at Siemens Solar is to reduce costs in photovoltaic manufacturing by approximately 10% per year. The specific milestones are shown in Table 1. which consists of three focused tasks relating to cost reduction, the wafer, cell and module tasks. The silicon wafer itself contributes about half of the total cost and has the most potential for cost improvement. The cell processing costs are about a quarter of the total costs, with cell efficiency and yield results being most important. Module assembly and packaging costs are the balance, with the module design, both materials and labor, contributing significantly.

Table 1. Cz manufacturing technology milestones.

	Phase 1	Phase 2	Phase 3
Task 1. Silicon Crystal Growth & Thin Wafer Technology			
A. Increase Cz grower productivity by 25%	10%	15%	25%
B. Demonstrate utility of prototype wire saw	•		
Deliver 100 wire sawn wafers	•		
C. Demonstrate 0.010"-thick wire sawn wafers		•	
Deliver 100 0.010" wafers		•	
D. Reduce wafer cost by 30%		15%	30%
Task 2. Silicon Cell Processing Reduce cell cost by 30% ($/watt)	10%	20%	30%
Task 3. Silicon Module Fabrication & Environmental, Safety & Health Issues			
A. Reduce module fabrication costs by 35% Deliver modules demonstrating reduced $/watt	10%	25% 2 modules (20%)	35% 6 modules (25%)
B. Reduce caustic use and waste	Define process and equipment	10% reduction	35% reduction
C. Replace CFC's	Evaluate CFC alternatives		90% reduction in CFC usage

Task 1: Silicon Crystal Growth and Thin Wafer Technology. Crystal growing costs are driven by material growing yields and indirect manufacturing costs such as electricity and machine parts used each time an ingot is fabricated. Wafering costs are driven by labor and the number of good slices yielded per length of crystal processed.
The third year of the contract has focused on throughput of the crystal growing machines. This has been done by using larger crucibles and the implementation of wire saw machines in production to improve the yielded wafers per inch of ingot.

Task 2: Silicon Cell Processing. Cell processing costs are driven by the electrical contacts used, and the labor required for the process steps to clean the wafer, form the semiconductor junction, and apply the contacts.
The third year of this task has been focused on the improvement of automation of handling operations in the cell fabrication process, and process control at each operation to predict and improve the high quantities of cells produced.

Task 3: Silicon Module Fabrication and Environmental, Safety, and Health Issues. Module costs are highly sensitive to labor and materials. The module design tasks are driven by high reliability in the field and lower costs. Included in this task is the environmental work to eliminate chlorofluorocarbon (CFC) usage and significantly reduce the caustic waste volumes.
This year SSI has focused on lower module costs with large cell modules and the design and implementation of a lower cost junction box.

DISCUSSION AND CONCLUSIONS

During this half year (April 1994 through October 1994), several significant manufacturing technology improvements were achieved.

The crystal growing operation improved with an increase in growth capacity. Higher growing throughput has been demonstrated with larger crucibles. A new approach to larger crucibles has been taken and has successfully started in pilot production.

Wafer processing with wire saws continues to progress. The wire saws have proven to yield almost 50% more wafers per inch in production. Wire saw mechanical yields progressed from 90% to 92% with additional training of the operations personnel. An additional benefit from this conversion to wire saws has been the need for less etching to remove saw damage, resulting in lower caustic waste being produced.

Cell processing improvements have focused on better handling and higher mechanical yield. The cell electrical distribution improved over this period of time, with a smaller standard deviation in the distribution.

Module designs for lower material and labor costs have continued with the focus on a new junction box, larger modules with larger cells, and less costly framing techniques. Two modules demonstrating these cost reductions have been delivered during this phase, meeting the contract deliverables. Significant reductions in the cost of caustic waste treatment has also been realized with approximately a 10% volume reduction.

The contract performance to date is shown in Table 1.

Table 1. Cost Reduction Summary for Phase III

Category	*% Reduction in Cost*
1. Crystal Growth/Thin Wafers - Large crucible - 43 vs. 29 wafers/inch - Large ingot	10%
2. Cell Improvements - 4% electrical improvement - Large Cell	5%
3. Module Improvments - Automated Assembly - Large Module	10%
Total	***25%***

CONTENTS

Figures

SECTION 1.0
CRYSTAL GROWTH AND THIN WAFER TECHNOLOGY

The Crystal Growth and Thin Wafer Technology task under this phase of the contract is focused on crucible size improvements. The additional focus of complete conversion to wire saws improved mechanical yields has further optimized the productivity of the crystal growing operation.

1.1 MACHINE HARDWARE

The graphite savings demonstrated in the previous phases continues to be confirmed this phase at greater than $300,000 annually.

Additional focus on throughput has initiated the use of larger crucibles in the existing crystal growers. Initial pilot runs were conducted with no disruption to the production process, and with comparable growth yields. The larger crucibles have demonstrated over 10% improvement in kg/day grown, with virtually no cost addition.

Problems with growing procedures on this new larger crucible have been addressed and approximately 10% of the growers currently have the larger crucible running smoothly.

The crystal growth volume has increased by 4% during this phase, and represents an overall improvement of approximately 20% from the start of the contract.

1.2 LARGER DIAMETER INGOTS

A significant cost reduction in the total module cost is realized by making larger modules, with larger cells. The development program at SSI under this phase of the contract has focused on this larger cell and larger module.

Larger diameter ingots continue to be run in large volume. The increase in yield has exceeded 10%.

1.3 WIRE SAW IMPLEMENTATION

Wire saw implementation was the focus for wafer fabrication during this phase of the contract. Production fabrication with wire saws has continued during this phase of the contract.

Wafer yield per inch has continued to improve. In addition to less material lost with each slice, the ability to slice thinner wafers has had a substantial impact. Wafer thickness has decreased by 40% with wire saws; from .021" thick as sliced with ID saws to .013" thick with wire saws. Wafer yield has improved from 29 wafers per inch of ingot with ID saws to 44 wafers per inch consistently. This has increased capacity by more than 50%. Figure 1-1. shows this improvement in yielded wafers per inch. Demonstration runs have been done exceeding 45 wafers per inch.

Slicing the larger diameter ingot discussed in section 1.2. poses no significant issues for wire sawing in the higher volumes run this phase.

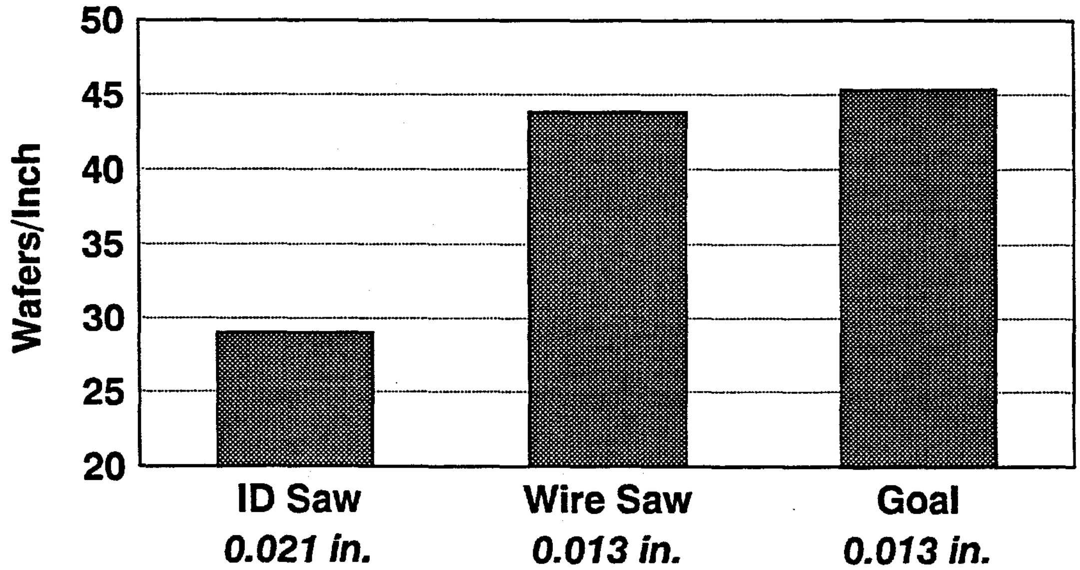

Figure 1-1. Yielded wafers per inch, ID saws compared to wire saws.

1.4 WIRE SAW YIELD

Wire saw mechanical yields also improved over this reporting period from 90% to 92%. The most recent improvements in yield have come by attention to training of the operations personnel. With multiple wire saws operating round the clock, operator interaction with the machine is a critical parameter to be focused on.

SECTION 2.0
CELL PROCESSING

The cell processing task of this contract has focused on one major item this phase: increasing mechanical yield through the cell processing line.

2.1 CELL PERFORMANCE

Improvement in the cell distribution has been consistent throughout this program. Figure 2-1. shows the electrical test amperage improvement comparing initial distribution in 1992, the comparable time frame for 1993 and 1994, and the most recent month. This electrical improvement and tightening of the distribution is credited to better process control in the diffusion area, new equipment for the anti-reflective coating process, and an additional etch step that has been added to the process. This was discussed in more detail in the annual report for Phase I. Additional increases have been obtained with the introduction of process control charting in specific areas of manufacturing. As shown in Figure 2-1, the distribution has shifted up by 5% and the standard deviation has gotten smaller as these control charts have been instituted.

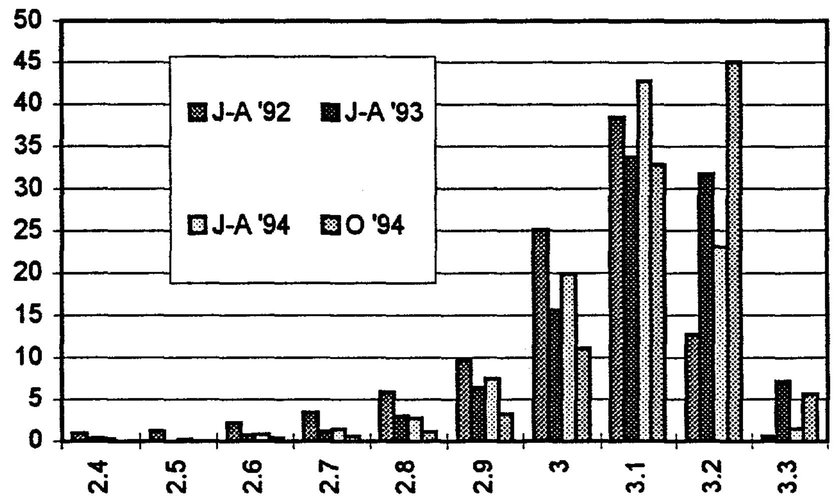

Figure 2-1. Electrical Distribution Improvement

2.2 AUTOMATED CELL PROCESSING

Automated handling systems have been debugged and implemented in production during this phase of the contract. The result has been the reduction of over 50% of the labor required in this portion of the cell process. The automated handling system begins with the anti-reflective coating process and ends with a tested cell. The transfer points are a combination robot, and pick and place mechanism system. A flowchart of the process is shown in Figure 2-2. in which the solar cells are automatically machine handled throughout this area of the production facility. The benefit comes through less handling, and has shown to improve mechanical yield by over 2%.

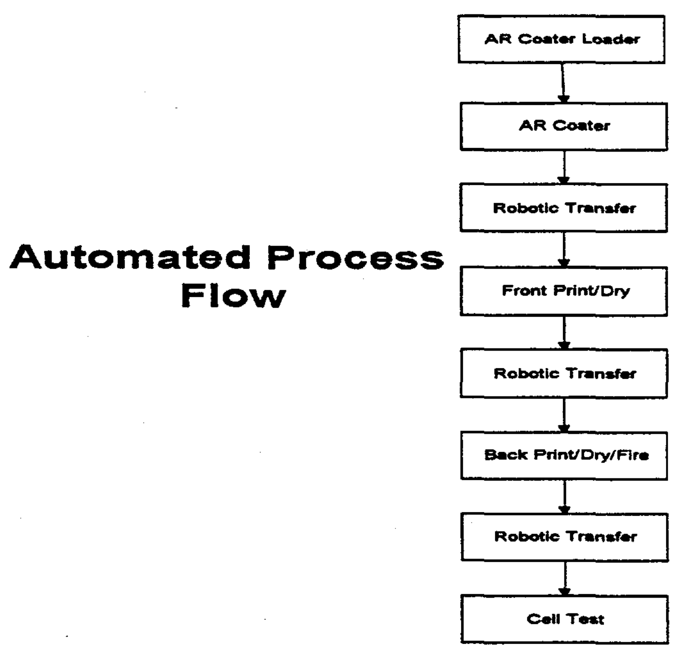

Figure 2-2. Automated Cell processing flow

SECTION 3.0
MODULE FABRICATION AND ENVIRONMENTAL, SAFETY AND HEALTH ISSUES

A majority of the module finishing costs in photovoltaics are in the materials and labor used for fabricating the modules. The requirement of reliability has driven the industry to standardize the laminate design to include glass, EVA, and various back sheet materials which provide an electrically insulating, environmentally resistant package. In working through the opportunity to reduce costs in the module design, three things became apparent during this phase of the contract: the module size has a significant impact on the dollar per watt material cost, the laminate construction is the significant contributor to the labor component of the costs, and the framing and junction box are major material contributors. During this phase of the contract, all three have been addressed.

3.1 75 WATT MODULE DESIGN

The 75 Watt modules designed last year have been fully implemented in production during this phase of the contract. The two designs, one with metal frame and junction box, and the other with plastic frames and a wire termination have been piloted in production. The metal framed module is preferred by both the production operations and the market, and over 15,000 have been made to date. The average power in manufacturing is 75.1Watts. As mentioned in the previous program summary, the savings in the plastic frame were offset by the labor and expense of the termination assembly. All around, a junction box is more versatile for this power level of module. The two designs are shown in Figure 3-1.

3.2 NEW JUNCTION BOX

A new junction box has been designed which combines the benefit of the wire termination and the large junction box. A cost reduction benefit of over 2% is expected in production. The new junction box allows for wire connections and conduit type fitting connections. The installation of this new design on the module during manufacturing has also been considered, with an open area for laminate ribbon to feed through for electrical connection and larger area contact for gluing to the module back surface. The new design is shown in Figure 3.2. This junction box has been approved by the Underwriter's Laboratory during this phase of the contract. Several slight modifications are still to be done prior to production implementation.

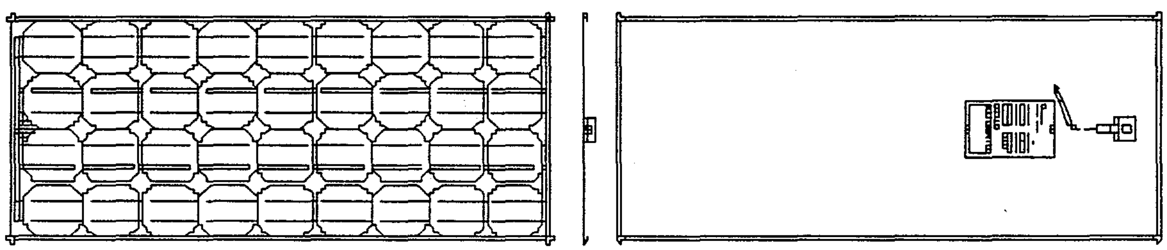

FIG 4
PLASTIC FRAME/CABLE

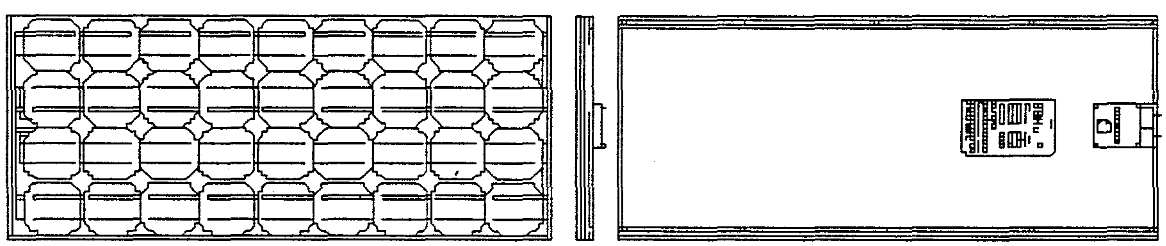

FIG 5
METAL FRAME/ J-BOX

Figure 3-1. 75 Watt module designs

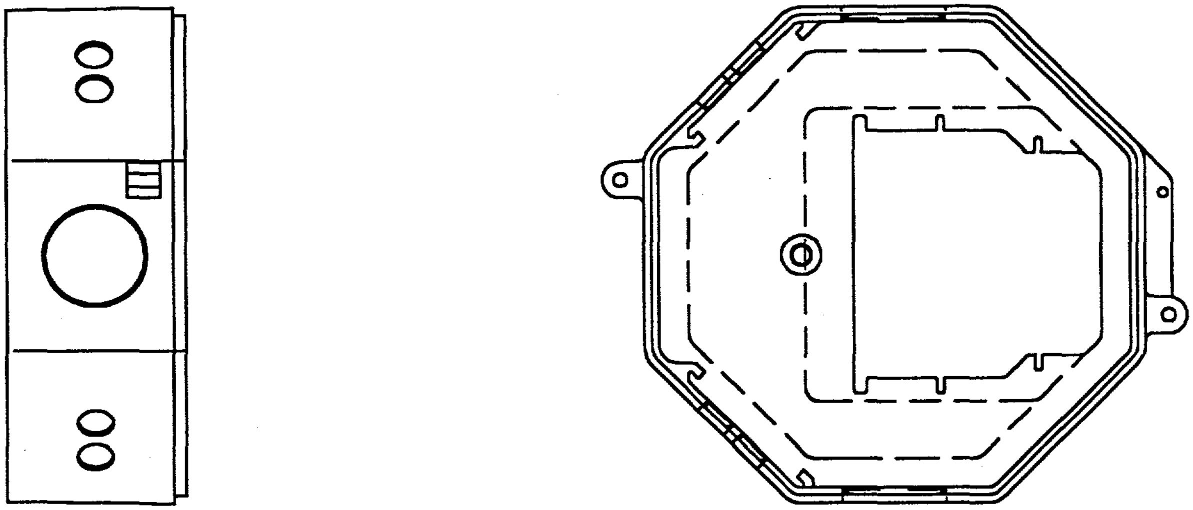

Figure 3-2. New j-box design

3.3 SEMI-AUTOMATED ASSEMBLY LINE

The semi-automated assembly line for 75 Watt laminate manufacturing has been completely implemented in manufacturing during this phase. This line has doubled the productivity and capacity of producing the 75 Watt modules. The system layout is shown in Fig. 3-3.

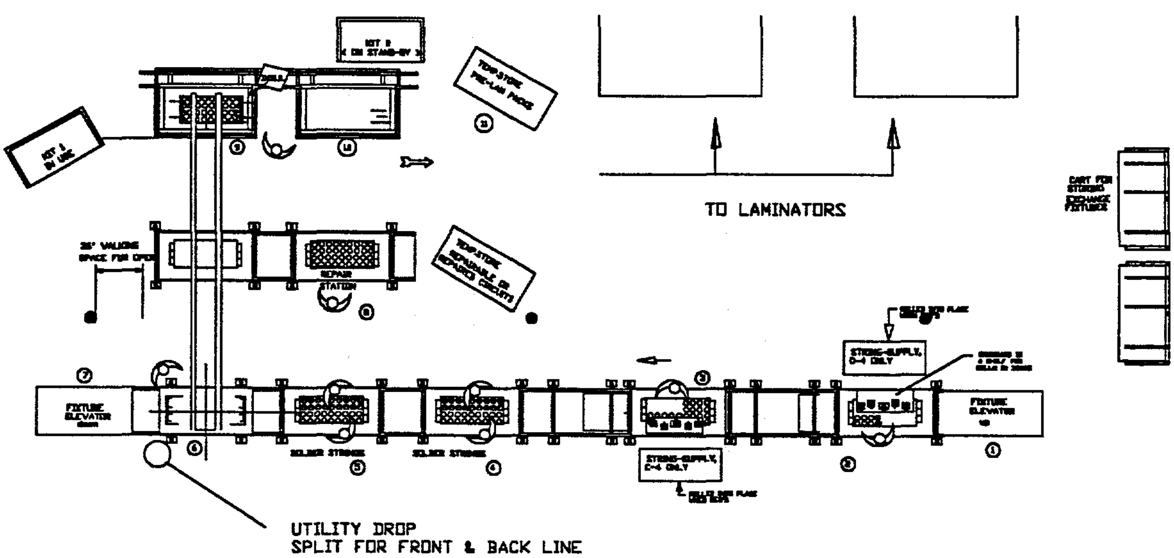

Figure 3-3. Layout of semi-automated assembly line.

3.4 ENVIRONMENTAL, SAFETY & HEALTH

For the Module Fabrication and Environmental, Safety and Health Issues task, the focus during this reporting period was the complete elimination of CFC usage in the manufacturing process, and the reduction in the amount of caustic waste produced.

CFC usage was discontinued during May of last year by the implementation of a no-clean flux solder paste. The development of the use of this paste was done during the first phase of the contract (Phase 1), with the implementation of its use last year. Complete elimination of CFC use was accomplished, one and a half years ahead of the contract schedule.

The second focus on reducing caustic waste has been attacked using two methods. The first method is the reduction of waste created per cell processed. This has been accomplished mainly with the use of wire sawn wafers which require less etching to remove saw damage. This reduction in caustic waste per wafer is over 12% for the reporting period of this contract. The second focus has shifted from treating caustic waste here to working on the cost of removing the waste. The treatment of the waste requires several difficult environmental permits, and there have emerged opportunities to remove our waste through companies which use the caustic to neutralize acidic waste streams. This has been chosen as the business approach to the problem with encouraging results. The cost of waste per cell has dropped by almost 50% in the last two years. The volume and cost reduction are shown in Figure 3-4.

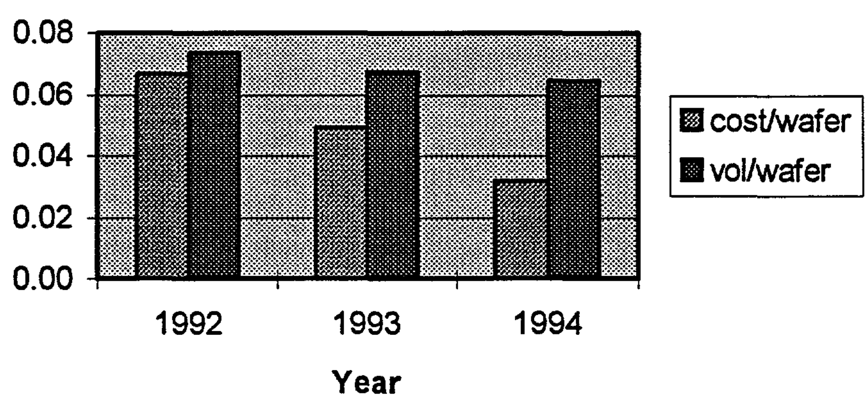

Figure 3-4. Caustic Waste Reduction in volume and cost

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13. ABSTRACT *(Maximum 200 words)*

This report describes work performed by Siemens Solar Industries (SSI) under the final phase of a 3-year, three-phase, cost-shared contract to demonstrate significant cost reductions and improvements in manufacturing technology. The work focused on near-term projects for implementation in the SSI Czochralski (Cz) manufacturing facility in Camarillo, California. The final phase of the program was concentrated in the areas of crystal growth, wafer technology, and environmental, safety, and health issues. During this reporting period, several significant accomplishments were achieved: (1) The crystal-growing operation improved with an increase in growth capacity. (2) Wafer processing with wire saws continued to progress. The wire saws yielded almost 50% more wafers per inch in production. An additional benefit of the conversion to wire saws is less etching to remove saw damage, which results in lower caustic waste. (3) Cell processing improvements focused on better handling and higher mechanical yield. The cell electrical distribution improved, with a smaller standard deviation in the distribution. (4) Module designs for lower material and labor costs continued, with the focus on a new junction box, larger modules with larger cells, and less costly framing techniques. Two modules demonstrating these cost reductions were delivered during this phase.

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