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Progress Update on the U.S. Photovoltaic Manufacturing Technology Project

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PROGRESS UPDATE ON THE U.S. PHOTOVOLTAIC MANUFACTURING TECHNOLOGY PROJECT

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ABSTRACT

The Photovoltaic Manufacturing Technology (PVMaT) project is helping the U.S. photovoltaic (PV) industry extend its world leadership role in manufacturing and stimulate the commercial development of PV modules and systems. Initiated in 1990, PVMaT is being carried out in several directed and staggered phases to support industry's continued progress. Thirteen subcontracts awarded in FY 1996 under Phase 4A emphasize improvement and cost reduction in the manufacture of full-system PV products. Areas of work in Phase 4A included, but were not limited to, issues such as improving module-manufacturing processes; system and system-component packaging, integration, manufacturing, and assembly; product manufacturing flexibility; and balance-of-system development with the goal of product manufacturing improvements. These Phase 4A, product-driven manufacturing research and development (R&D) activities are now completing their second phase. Progress under these Phase 4A and remaining Phase 2B subcontracts from the earlier PVMaT solicitation are summarized in this paper. Evaluations of the success of this project have been carried out in FY 1995 and late FY 1996. This paper examines the 1997 cost/capacity data that have been collected from active PVMaT manufacturers.

INTRODUCTION

The PVMaT project was initiated in 1990 to assist the U.S. PV industry to extend its world leadership role in PV manufacturing and the commercial development of PV modules and systems. As previously described [1-5], the PVMaT project is a government/industry R&D partnership between the U.S. federal government (through the U.S. Department of Energy [DOE]) and members of the U.S. PV industry. PVMaT is designed to accomplish its purpose by helping industry improve manufacturing processes, accelerate manufacturing cost reductions for PV modules, improve commercial product performance, and lay the groundwork for a substantial scale-up in the capacity of U.S.-based PV manufacturing plants.

The PVMaT project is being carried out in six separate phases designed to address separate R&D requirements. These are Phase 1, Phase 2A, Phase 2B, Phase 3A, Phase 4A, and Phase 5A. A description of the focus and accomplishments for phases 1, 2A, 3A, and 2B have been detailed in previous papers [1-3]. The 13 subcontracts awarded under Phase 4A, Product-Driven Manufacturing, are now completing their second year of research. The objectives of these subcontracts included stimulating a broader interest in the production of PV products, encouraging and supporting risk-taking by industry to explore new manufacturing options and ideas for improved PV products or components, encouraging system and product integration, increasing module-production capacity, reducing PV module-production costs, and stimulating advances in balance-of-systems or developments in design leading to overall reduced system life-cycle costs of the PV end product. Cost reduction, improved efficiency, and manufacturing flexibility and broader market applications for PV systems as a whole were emphasized. The subcontracts awarded in Phase 4A were divided into two parts, 4A1 and 4A2, and subcontractors in both parts are now completing the second phase of their subcontracts.

Phase 4A1 addresses the product-driven system and component technology, and includes manufacturing improvements directed toward innovative, low-cost, high-return, high-impact PV products. Subcontracts under this phase are addressing manufacturing that is generally related to PV-system components such as inverters, and system integration efficiency and design improvements, with less focus on module manufacturing. Progress under these subcontracts, as well as a listing of 4A1 subcontractors, is described in another paper in these proceedings by Ward Bower of Sandia National Laboratories.

Phase 4A2 is focused on product-driven PV module manufacturing technology. Subcontracts under this phase, listed in Table 1, are directed toward manufacturing flexibility and module-manufacturing cost reductions for a wider range of PV products. These subcontracted efforts include developing large-area Silicon-Film™ panel and cell manufacturing; edge-defined, film-fed growth module manufacturing; improvements in Czochralski crystalline-silicon-based modules; the development of monolithic amorphous silicon modules on continuous-polymer substrates; and the manufacturing of extruded concentrator modules. Progress under these subcontracts toward the general PVMaT goals of accelerating manufacturing cost reductions and scale-up of U.S. PV manufacturing capacity is described below. The technical progress of the Phase 2B subcontracted activities, listed in Table 1, is also detailed below.

Table 1

Phase 2B Subcontractors	
Golden Photon	Commercial Production of Thin-Film CdTe Photovoltaic Modules
Solar Cells, Inc.	High Throughput Manufacturing of Thin-Film CdTe PV Modules
Solarex	Cast Polycrystalline Silicon PV Manufacturing Technology Improvements
Phase 4A2 Subcontractors	
ASE Americas	Market Driven EFG Modules
AstroPower, Inc.	Large Area Silicon-Film Panels and Solar Cells
Iowa Thin Film Technologies	PVMaT Monolithic a-Si Modules on Continuous Polymer Substrates
Photovoltaics International	Manufacturing of the PVI Power Grid
Siemens Solar Industries	Photovoltaic Cz Silicon Module Improvements

An additional phase of the PVMaT project (Phase 5A) is now being initiated. This phase will also emphasize product-driven manufacturing R&D. Phase 5A has been divided into two areas (5A1 and 5A2) similar to the Phase 4A procurement, to emphasize improvements and cost reductions in the manufacture of full-system PV products.

The announcement for the Phase 5A solicitation was released in late June 1997. On September 9, 31 proposals were received in response to this solicitation—17 in the 5A1 category and 14 under category 5A2. These proposals are currently being evaluated and awards are planned for early 1998.

SUBCONTRACTOR PROGRESS

Phase 2B

The Golden Photon, Inc. (GPI) objective was to reduce the production cost of its thin-film CdTe module, increase the average module performance in production, and address an expansion of GPI's commercial production capacity. At the completion of this research, GPI has an average module output of 28 watts over 10 production-run batches, with modules as high as 31.3 watts. This has resulted in a reported 76% reduction in module-manufacturing costs and allowed GPI to bring a 2.3 MW production capacity on-line.

The Solar Cells, Inc. (SCI) objective was to reduce the module production costs on its high throughput Thin-Film CdTe module-manufacturing line, increase module performance, and provide the groundwork for expansion of its commercial production capacities. SCI has successfully demonstrated the deposition of 60x120-cm CdS/CdTe substrates in 30 seconds. Modules, which show reliability through module qualification tests and multi-year outdoor testing, are currently being fabricated from these substrates. With the installation of key equipment for a multi-megawatt line, SCI has reported reducing its module-manufacturing costs by 78% and increasing its production capacity by a factor of 4 since the start of its Phase 2B subcontract. SCI is now marketing this manufacturing technology, and offering a variety of complete CdS/CdTe (1 kW/hr, 2 kW/hr, and 3 kW/hour) production lines and plate-finishing lines as part of the product mix that it offers.

The Solarex objective was to improve its cast polycrystalline-Silicon PV manufacturing technology to reduce module production costs, increase module performance, and expand its commercial production capacity. Since 1994, Solarex has doubled its casting capacity through the redesign of equipment and modification of the process, without having to add additional equipment. The company has also transitioned its production line to include wire sawing of wafers. Solarex is incorporating wire sawing into their production line. Currently, 60% of the wafer production is wire sawn with the obvious concomitant reduction in costs. Despite problems caused by an increase in the Si feedstock costs over the past few years, Solarex has achieved a 13% reduction in module-manufacturing costs and doubled production capacity.

Phase 4A2

The ASE Americas objective under its Phase 4A2 subcontract is to reduce EFG module-production costs by 25% relative to pre-4A levels, increase average module performance of its manufacturing line, and identify and evaluate modifications for expanding its commercial production capacity. This year, ASE has reported increasing its EFG wafer production yield by 5% through improvements in crystal growth and laser cutting, resulting in a 300,000-wafers/year capacity increase. ASE has also demonstrated a new benign wafer-etching process that has lowered cell add-on production cost by 7%, and reduced fluorine ion effluent in the waste stream by 50%, hydrofluoric acid consumption by 2%, and deionized water by 20%. In addition, ASE reported a 26% reduction in module-manufacturing costs and a doubling of production capacity. Combined with the progress under its previous Phase 2A subcontract and an increase of individual cell production, ASE has achieved a 75% reduction in module-manufacturing costs and a factor of 10 increase in its production capacity from the prototype production levels in 1992.

The AstroPower, Inc. objective under its Phase 4A2 subcontract is to reduce the production cost of its large-area Silicon-Film™ panels and solar cells, increase average cell and module performance, and expand AstroPower's production capacity. This year the company has reported production activation of its continuous Silicon-Film growth process, generating sheet material over 10 times faster than competing processes. AstroPower has also demonstrated significant cell improvements, specifically, an NREL verified efficiency of 16.6% (compared to the project goal of 15.6%) and the fabrication of the world's largest production-silicon solar cell at 240 cm^2. These improvements have resulted in AstroPower reporting a reduction in its module-manufacturing costs during Phase 4A2 of 13%, and a factor of 4 increase in its production capacity. Combined with the progress under its previous Phase 2A subcontract, AstroPower has, to date, achieved a 23% reduction in Silicon-Film™ module manufacturing costs.

The Iowa Thin Film Technologies (ITFT) objective is to reduce its monolithic a-Si module-manufacturing cost by 68%, increase module performance, and provide the groundwork for expanding its production capacity. During the past year, ITFT has developed a new method of printing registration using active screen steering for the interconnect printing step. This development improved the registration reproducibility from 100 µm to 10 µm while increasing throughput by a factor of 6. ITFT has also developed a roll-based lamination process that increases per-machine lamination throughput from 10^2 ft/hr to 240^2 ft/hour. These developments have resulted in a 42% reduction in its module-manufacturing costs and a factor of 4 increase in production capacity.

The Photovoltaics International (PVI) objective is to reduce its linear concentrator module-manufacturing cost to $2.00/Watt, increase its module performance, and provide the groundwork for expanding its production capacity to 50 MW/yr. Further development of an in-house capability to extrude Fresnel lenses in the last year has lowered product materials cost by 37% (including performance improvements) and increased lens manufacturing capability to 5 MW/yr. Additional progress by PVI this year includes the completion of the first half of its automated receiver-assembly station development, which will lower product labor costs by 36% at an initial manufacturing rate of 5 MW per year. Advances to date under Phase 4A2 have allowed PVI to reduce its module-manufacturing costs by 41% and increase its production capacity by a factor of 5.

The Siemens Solar (SSI) Industries objective under Phase 4A2 is to reduce its Czochralski (Cz) crystalline-silicon module-manufacturing cost by 18%, increase average module performance off its manufacturing line, and address and expand commercial production capacity. SSI has reported the implementation of statistical process controls on its manufacturing line, the start up of production on its new PVMaT-developed 150-mm round cells, and initiation of a semi-automated lamination line. These have resulted in the introduction of several new lower-cost cell and module products, a reduction in module-manufacturing costs by 10%, and increased production capacity by 35% during Phase 4A alone. Combined with the progress under their previous Phase 2A subcontract, Siemens has achieved a 16% reduction in module-manufacturing costs and a factor of 2 increase in production capacity.

PROGRESS IN COST REDUCTION AND CAPACITY INCREASES

At the beginning of Phase 2A subcontracted research, information was collected to establish both the current and projected capacities and module costs for the eight participating manufacturers. Initial results [3] represented both the diverse status of a still-maturing industry and the optimistic speculation of its members regarding the effects that the PVMaT project would have after their research efforts were incorporated. Each year, the data have been updated based on information from the PV industrial participants.

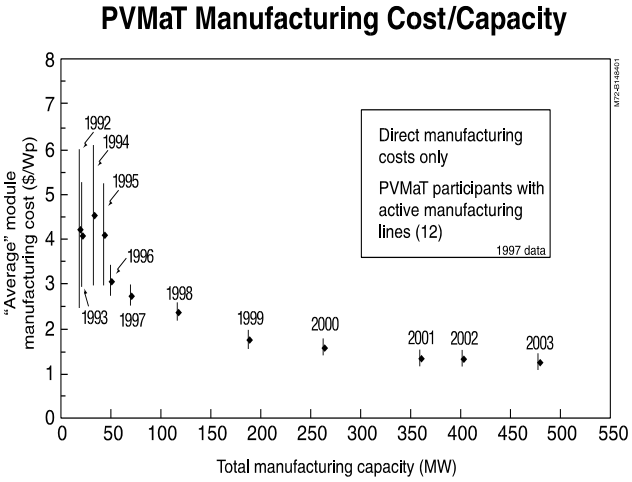

Fig.1. PVMaT Manufacturing Cost/Capacity

These most recent cost and capacity data, shown in Fig. 1, represent an update of previous projections [5] regarding these subcontracted efforts. Data in this figure are based on each manufacturer's maximum production capacity (in MW) during a given year. This year, several large manufacturers reported that they have dedicated an ever-larger portion of their production lines to cell production for shipment to other locations for module fabrication. This new aspect of PV production is, for the first time, included in the PVMaT capacity calculations. The "'average' module manufacturing cost" represents the average cost per watt of modules (weighted by each participant's capacity of both cells and modules) for these 12 PVMaT industrial participants. Module cost estimates are based on each of the manufacturers module production capacity level and include only those costs directly associated with the manufacturing of modules (i.e., not marketing, administration, or sales). It should be noted that the data associated with any particular point in time represent a potential capability. Actual manufacturing-production levels

may be less (and concomitant costs higher) due to other considerations such as market conditions or available labor. Fig. 1 indicates that PV module-manufacturing capacity (including cells for later module fabrication) has more than doubled in the last 3 years. In addition, the "average" cost for manufacturing PV modules has been reduced by more than 32%.

As in previous years, 1997 cost/capacity data provided by the active PVMaT manufacturers represent several modifications to their previous projections. Individual company cell-production volumes are now included in the module-manufacturing capacity and also impact the "weight averaging" of module production costs. Most of the effects from these inclusions come from the large module/cell manufacturers who are increasing cell production for their expanding satellite module-production plants.

The PV manufacturing industry has revised its plans for capacity increases. Data in Fig. 1 indicate the PV Industry was not able to meet its mid-1996 projections for expansion to be completed in 1996. Most of this expansion is only now being brought on line, and the previously scheduled 1997 expansion is occurring at a much slower rate than planned in 1996. Additional capacity expansion planned for completion in the next 3 years has now been projected to be spread over the next 5 years. The majority of the modifications to projected capacity increases come from the smaller, less established manufacturers, whose initial optimistic projections over the last several years are tempered with experience.

CONCLUSIONS

The PVMaT project is currently completing the second year of subcontracts under Phase 4A1 and 4A2, with research in Phase 2B approaching conclusion. Proposals received in response to the most current PVMaT procurement, Phase 5A, are currently being evaluated and awards are planned for early 1998. At this time, it is apparent from Fig. 1 that the U.S. PV industry involved in the PVMaT project has made significant progress toward reducing manufacturing costs and increasing PV module-manufacturing capacity. "Average" module-manufacturing costs have been reduced by more than 32% and total manufacturing capacity (including cells for later module fabrication) for the 12 PVMaT industrial participants with active lines has more than doubled in the last 3 years. By 1999, projections indicate module-manufacturing costs of $1.79/Wp (a 60% reduction from 1994 levels) and a production capacity increase to 187.4 MW (a factor of over 10 higher that the original 1994 level for the 12 PVMaT industrial participants). There are indications, in both the industry's future cost/capacity data and its technical projections, that long-term optimism for continuing these improvements is high—and that the near-term progress in these areas has been significant.

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