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Ten Years of Manufacturing R&D in PVMaT – Technical Accomplishments, Return on Investment, and Where We Go Next

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TEN YEARS OF MANUFACTURING R&D IN PVMaT – TECHNICAL ACCOMPLISHMENTS, RETURN ON INVESTMENT, AND WHERE WE GO NEXT

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ABSTRACT

The Photovoltaic Manufacturing Technology Project has been conducting cost-shared R&D with industry for ten years. Objectives of this project are to improve photovoltaic manufacturing processes and products and to lower manufacturing costs. The majority of the efforts have been module related. Results in terms of automation, yield, and throughput have provided a significant reduction in direct manufacturing costs. Some of these results are detailed, and a measure of the return due to these efforts is discussed. Finally, technical directions for future activities are identified.

INTRODUCTION

The Photovoltaic Manufacturing Technology (PVMaT) Project has been conducting cost-shared R&D with industry for ten years. Objectives of this project are to improve photovoltaic manufacturing processes and products, lower manufacturing costs, and provide a foundation for the scale-up of U.S. photovoltaic manufacturing. During that decade, 40 subcontracts were awarded. Twenty-seven are complete and the remaining 13 active subcontracts are in their last year of funding, with one exception. Twenty-five of the subcontracts primarily addressed module manufacturing. The remaining 15 addressed a variety of problems associated with power conditioning, system design and manufacture, components other than modules, and generic issues of interest to a large portion of the PV industry. The overall cost-sharing by the participants for PVMaT has been about 43%. Table 1 shows the breakout of funding by various PV technologies and provides cost-share data by technology (projected through the completion of the active subcontracts).

Table 1. Technology Share and Cost-Share by Technology

Technology	NREL Cost-Share (K$)	Subcon. Cost-Share (K$)	Subcon. Cost-Share (%)	NREL Funding - Tech. Share (%)
amorph. Si	20,244	15,147	42.8	20.9
CdTe, CIS	13,879	11,023	44.3	14.3
Conc.	6,162	1,567	20.3	6.4
crystalline Si	41,761	37,832	47.5	43.2
Generic/BOS /Systems	14,701	8,404	36.4	15.2
Totals	96,746	73,974	43.3	100

The government funding has been approximately $90 million to date, and about 85% of these funds were directed to module manufacturing R&D. Note that the most mature technology, crystalline silicon, is also the area where the highest cost-share has been afforded by the company partners and has been the technology receiving the largest share of NREL funding in this project.

Module manufacturers made improvements in many areas. Major areas addressed by thin-film manufacturers include deposition processes, deposition rates, yield, and environmental, safety and health (ES&H) issues. Crystalline-silicon improvements have also been significant and are generally related to better automation, yield, throughput, and ES&H considerations. Results in these areas are discussed and characterized in both annual and final reports by subcontractors and in many of the other papers presented at this and similar conferences (see Refs. [1-5]). These advances have provided a significant reduction in direct manufacturing costs, as described in the following sections.

COST AND CAPACITY ACHIEVEMENTS

Direct module manufacturing cost and capacity data are collected and analyzed annually in the PVMaT Project, and the most recent data show a total module manufacturing capacity of about 100 megawatts for project participants (See Fig. 1).

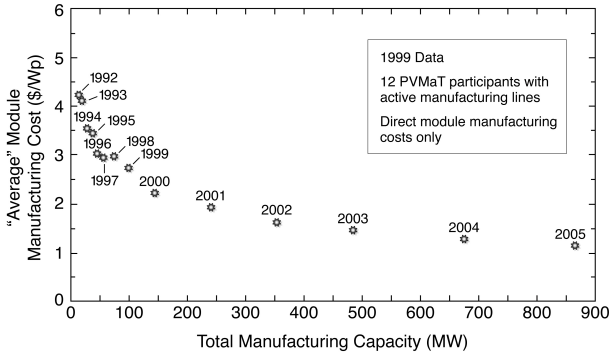

Fig. 1. PVMaT manufacturing cost/capacity.

The weighted-average (weighted by capacity) direct manufacturing cost for these companies has decreased about 35% to less than $2.75 in the past eight years during which we

have collected these data. We have also calculated cost projections out to the year 2005. The overall projection is about $1.16 per peak watt.

Other areas we have addressed in PVMaT include power conditioning, system design, encapsulation, and resource availability. Although improvements in these areas are more difficult to characterize in terms of cost reductions, the benefits in system utility, reliability, and desirability are believed to be important for increased market penetration. Examples of these benefits are AC module development and improved stabilization strategies for EVA-based encapsulants.

RECAPTURE OF R&D FUNDING FOR PV MANUFACTURING R&D

One way to measure the benefits of PVMaT is to compare the funding invested in the R&D projects with the estimated economic benefits to the customers (e.g., reduced prices) and/or to the manufacturers (e.g., increased profits or increased available investment capital). Without detailing the form of the benefit, we have collected estimates of how manufacturers have and will distribute the savings from reduced costs between themselves and their customers. We have derived Figure 2 by comparing the savings to the customers with the government investment ("Public" curve) and the companies' savings with their cost-share investment ("Industry" curve). Dollars saved and dollars invested are calculated yearly on a to-date cumulative basis and the ratios are plotted in per-cent. It is obvious that the benefits of the project are much more than the investment. Also, because Fig. 2 is based on the 85% of PVMaT funding that has gone to module manufacturing, one can see that including the other 15% of the funding will not significantly impact the recapture, and the project as a whole is more than "paying" for itself.

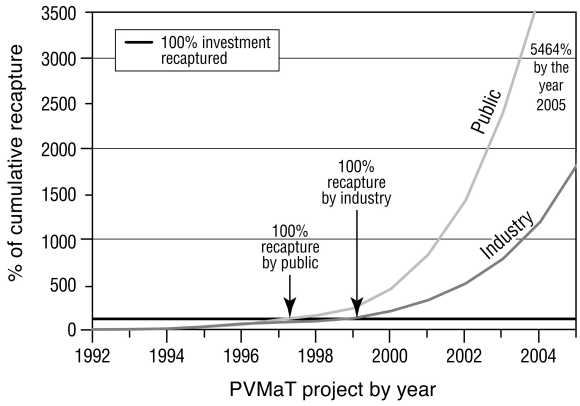

Fig. 2. Recapture of PV Manufacturing R&D Project funding.

CURRENT MANUFACTURING R&D EFFORTS

There are presently 13 active manufacturing R&D subcontracts. All, except one, will be completed during Fiscal Year 2001. Table 2 identifies the subcontract areas for the active efforts in this project.

Table 2. Current PV Manufacturing R&D Subcontractors (from FY 1998 Solicitation)

Company	Manufacturing R&D Area
Applied Power Corp. (Ascension)	Manufacture of the Advanced SunSine^{TM} 325 AC Module
ASE Americas Inc.	The EFG High-Volume PV Manufacturing Line
AstroPower	Silicon-Film^{TM} Solar Cells by a Flexible Manufacturing System
Crystal Systems, Inc.	Production of Solar-Grade Silicon by Refining of Liquid Metallurgical-Grade Silicon
Energy Conversion Devices, Inc.	Efficiency and Throughput Advances in Continuous Roll-to-Roll a-Si Alloy PV Manufacturing Technology
Evergreen Solar, Inc.	Continuous, Automated Manufacturing of String Ribbon Si PV Modules
Global Solar Energy, LLC	Throughput Improvements for Thin-Film-Based CIGS Modules
PowerLight Corporation	Advanced Powerguard^{R} Manufacturing
Siemens Solar, Inc.	R&D on Siemens Cz Silicon Product Manufacturing
First Solar, LLC	R&D on CdTe Product Manufacturing
BP Solarex	Improvements in Polycrystalline Silicon PV Module Manufacturing
Spire	Post-Lamination Manufacturing Process Automation for Photovoltaic Modules
Utility Power Group	Development of a Fully-Integrated PV System for Residential Applications

FUTURE PLANS

A new solicitation for Letters of Interest in performing PV manufacturing R&D was released August 7, 2000. The solicitation is entitled "PV Manufacturing R&D — In-Line Diagnostics and Intelligent Processing in Scale-Up Manufacturing." As in previous PVMaT solicitations, it solicits interest, from individual or teamed U.S. PV and related industries, in addressing a range of topics relating to the manufacturing of PV modules, components, and systems. It is open to all U.S. PV industry entities. And it is designed to entertain suggestions to continue efforts similar to past R&D in PVMaT. However, a primary focus is supporting approaches for intelligent processing and larger-scale manufacturing, as identified at the June 1999 U.S. Photovoltaics Industry Roadmap Workshop (see Ref. [6]). The focus of the solicitation stems from the facts that there are many issues and costs associated with translating small prototype manufacturing-line results to first-time large-scale manufacturing due to the complexity of the processes involved for making large-area, high-volume PV modules. This is further compounded by a need for the fundamental scientific and engineering base required to properly engineer

and operate manufacturing equipment. This solicitation is intended to be a first step toward a more accelerated growth in the capability of U.S. industry to produce cost-effective PV products. Responses to the solicitation are due by October 7, 2000.

CONCLUSIONS

The ten years of manufacturing R&D in PVMaT have resulted in lower module manufacturing costs and improved PV products. Estimates given by the participants also show that the costs associated with such R&D are soon recovered by both the public and the participating companies. Future efforts for manufacturing R&D will be directed to even lower costs as a result of more intelligent and sophisticated manufacturing processes based on improved real-time diagnosis and control of PV product quality.

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