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PV Manufacturing R&D Accomplishments and Status

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ABSTRACT

The U.S. Department of Energy (DOE) PV Manufacturing Research and Development Project has worked for 11 years in partnership with the U.S. photovoltaic industry to reduce manufacturing costs while significantly scaling up production capacity. Over this period, the PV Manufacturing R&D Project has issued seven solicitations for partnerships that have resulted in over 50 cost-shared R&D subcontracts that addressed the cost and capacity goals of the Project, including 10 that are currently active. The previous and current contracts have typically focused on addressing Project goals in one of two areas: module manufacturing and balance-of-systems (BOS)/systems work. The majority of the DOE investment has been targeted toward module manufacturing. The partnerships have resulted in a significant and measurable increase in PV module/systems production capacity, a decrease in PV manufacturing costs, and a subsequent return on the joint public and private investments facilitated by the Project.

1. Introduction

In 1990, DOE, working with the National Renewable Energy Laboratory and Sandia National Laboratories, initiated the Photovoltaic Manufacturing Technology (PVMaT) Project in partnership with the U.S. photovoltaic industry to accelerate PV production scale-up and cost reduction. Since the inception of PVMaT (now referred to as the PV Manufacturing R&D Project), the U.S. DOE and industry have together invested over $140M ($80M U.S. DOE share/$60M industry share) toward the goals of the Project. This has been accomplished through six procurements, including the latest and currently active procurement titled "In-line Diagnostics and Intelligent Processing (IDIP)." The details of these procurements have been described in a number of other papers [1-16] and will not be reviewed here. Generally, over the course of these procurements, subcontracts have focused on three main areas. The first, and the area that has received the majority of PV Manufacturing R&D money, is process-specific improvements for individual companies' module manufacturing products and processes. Subcontracts have also been awarded to address generic issues so that the R&D results of these efforts might be applicable to, and adopted by, a number of members of the U.S. PV industry. The third main area is related to BOS and systems integration manufacturing improvements and scale-up. The subcontracted R&D funded in the first five procurements has all been completed. The research under the IDIP solicitation is under way and will be summarized in the following section.

2. Status

The IDIP Request for Letters of Interest (LOI) was structured to solicit responses in the areas of research and development for PV System and Component Technology and Module Manufacturing Technology. The IDIP Request for LOIs received 22 responses. Of these, six responded to the System and Component category and 16 responded to the Module Manufacturing category. Table 1 lists the responders that were determined to be in the competitive range and with whom subcontracts have been entered into to this point. Negotiations are ongoing with an additional four companies not listed in Table 1, but who were in the competitive range of the IDIP solicitation.

Table 1. IDIP Subcontractors

Subcontractor	Subcontract Title
PV System and Component Category	
PowerLight Corporation	PowerGuard Lean Manufacturing
Schott Applied Power	Plug and Play Components for Building Integrated PV Systems
Specialized Technology Resources	Development of New Low-Cost, High-Performance PV Module Encapsulant/Packaging Materials
Xantrex	PV Inverter Products Manufacturing and Design Improvement for Cost Reductions and Performance Enhancement
Module Manufacturing Category	
BP Solar	Large Scale PV Module Manufacturing Using Ultrathin Polycrystalline Silicon Solar Cells
Energy Photovoltaics, Inc.	Productivity Enhancement for Manufacturing of Amorphous Silicon PV Modules
Evergreen Solar	Innovative Approaches to Low Cost Module Manufacturing of String Ribbon Si PV Modules
ITN Energy	Trajectory Oriented and Fault Tolerant Based, Intelligent Process Control for Flexible CIGS PV Module Manufacturing
RWE Schott Solar	EFG Technology and Diagnostics R&D for Large-Scale PV Manufacturing
Shell Solar Industries	PV Manufacturing R&D – Integrated CIS Thin-film Manufacturing Infrastructure
Sinton Consulting	Development of an In-Line Minority-Carrier Lifetime Monitoring Tool for Process Control During Fabrication for Crystalline Silicon Solar Cells

3. Progress Toward PV Manufacturing R&D Goals

To measure and track the progress of the PV Manufacturing R&D Project's impact on module cost and production capacity, direct module manufacturing costs and manufacturing capacity have been collected in collaboration with the Project's module manufacturing partners. In addition to supplying the most recent year's data, module manufacturing partners also supply their projections for the coming five years. Figure 1 shows the 2002 data of 15 PV Manufacturing R&D module manufacturing partners who had active manufacturing lines in 2002. (A partners in this context refers to a subcontractor with a specific technology. Within the 15 partners, there are 11 companies represented.) Figure 1 shows continued progress toward meeting the Project goals of decreasing direct manufacturing costs and increasing production capacity.

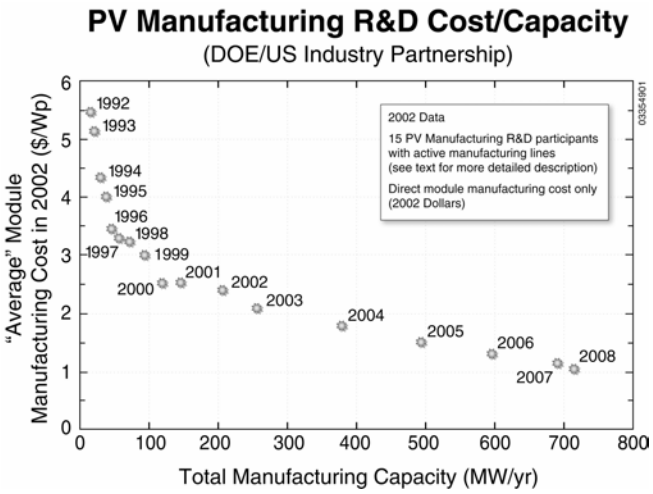

Fig. 1 PV Manufacturing R&D participants cost and capacity data.

The PV module manufacturing cost shown on the vertical axis of Figure 1 represents the weighted average of the 15 manufacturers' direct module manufacturing costs in 2002 dollars. Each manufacturer's cost was weighted in the average based on their contribution to the total manufacturing capacity. The direct costs that are included relate only to those costs directly associated with module production and do not include such costs as research, marketing/sales, or general and administrative expenses. The production capacity that is shown on the horizontal axis is the total capacity of the 15 manufacturers and does not represent the actual module production of the partners, but illustrates the *potential* production if all the plants were running at full capacity. Costs that are shown are also expected to scale with the production level, and therefore, direct costs shown are only those that are commensurate with full production.

Looking at the data through 2002, it is seen that total module production capacity has grown from 13 MW at the start of PVMaT subcontracts in 1992 to 205 MW in 2002 – a 16-fold increase or a 32% average annual growth in production capacity among these PV Manufacturing R&D participants. During the same period, direct module manufacturing costs in 2002 dollars have dropped from $5.47/Wp in 1992 to $2.42/Wp. This represents a total price reduction of about 56%, or an average *annual* drop in direct module manufacturing cost of about eight percent. In terms of technology learning curves, these data reflect an average 18% drop in direct manufacturing costs for each doubling of production capacity.

When compared to a similar graph using 2001 data [16], it should be noted that there is shift downward in production capacity and a shift upward in direct module manufacturing costs. These shifts are the result of the closure of two manufacturing plants during 2002, coupled with more conservative projections on the part of a number of manufacturers when projecting future capacity and costs. It should also be noted that the data through 2002 include 15 partners, whereas the data from 2003 to 2008 include projections without the two factories that closed.

Figure 2 shows the ratio of non-thin-film production capacity to thin-film production capacity. When compared to a previous similar graph [16], a difference can be seen in the out-year projections. A portion of this shift is related to the closure of the two plants in 2002 referenced above. The significant increase in the ratio that reflected planned thin-film capacity increases has moderated, and the ratios for projections through 2008 show a slightly more level trend.

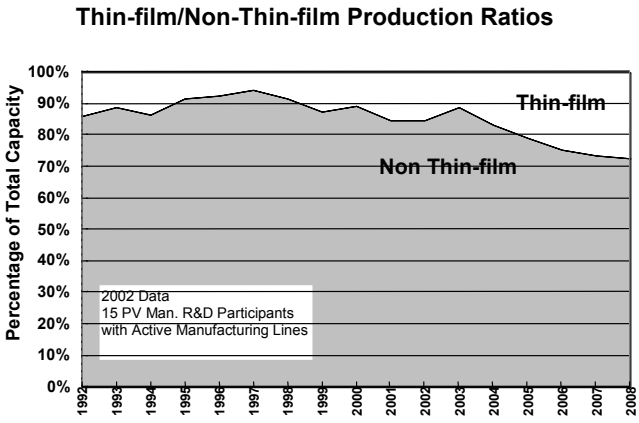

Fig. 2 Ratios of thin-film to non-thin-film production levels shown as percentage of total production.

4. Recapture of Research Funding

Along with cost and capacity data, PV Manufacturing R&D module manufacturing partners have also provided the Project with manufacturing cost reductions that can be directly attributed to the efforts completed under their cost-shared subcontracts. In addition to the raw cost-savings data, manufacturers have also provided information related to how those cost reductions will be allocated. The recapture of the money invested by both the U.S. DOE and the companies themselves can be determined by analyzing how much of the cost reductions will be passed on to consumers through lower prices and how much will be retained by the company as increased profits, debt reduction, or capital investment. Figures 3 and 4 show the breakeven points for both the public and participating

companies. The breakeven point is defined as the point at which the cumulative manufacturing cost savings equals the total amount invested (in 2002 dollars). The industry recovery as shown in Figure 4 reflects the total investment and recapture of R&D funding in 2002 dollars for all participating module manufacturers and is not a reflection of the investment recapture for an individual company. As can be seen in Figure 3, accounting for the investment through the end of calendar year 2002, the benefit to the public through cumulative lower pricing exceeded the U.S. DOE (public) investment in 1999. As of the end of 2002, the simple return on the public's investment stands at 366% since the project's inception.

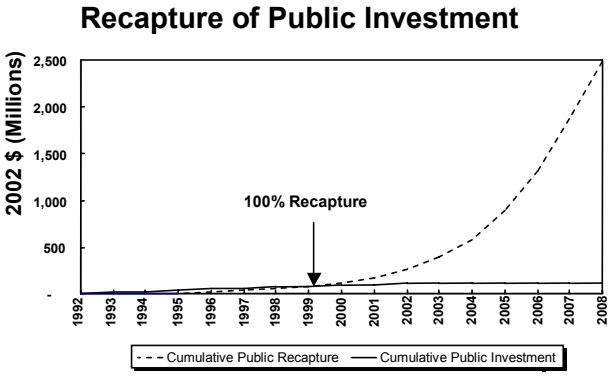

Fig. 3 Recapture of the public's investment in the PV Manufacturing R&D Project.

Figure 4 illustrates that the industry reached a breakeven for their investment in 1998. As of the end of 2002, the simply return on the industry's investment stands at 319 percent. In addition to breakeven points for both the public and private sectors, Figures 3 and 4 also depict, based on projections of the participating module manufactures, that the cumulative benefits will continue to accrue well into the future.

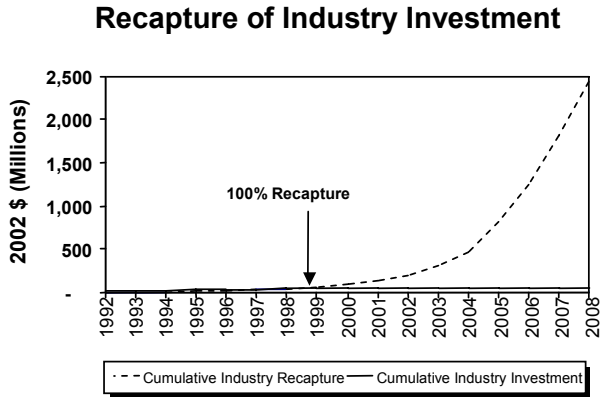

Fig. 4 Recapture of industry's investment in PV Manufacturing R&D improvements.

5. Conclusions

Work on subcontracted R&D under the IDIP solicitation of the PV Manufacturing R&D Project is currently under way. Interest on the part of the U.S. PV industry has remained very strong throughout the Project, with 22 LOIs received for the latest solicitation. The Project has continued to address its goals of reducing direct manufacturing costs and increasing production capacity. Average direct manufacturing costs (in 2002 dollars) have been reduced 56% since the first subcontracts were issued in 1992, while production capacity has increased 16-fold, assisting the industry in meeting the demands of a rapidly growing market. Projections from the Project's partners show this trend continuing, with projections through 2008 for further direct manufacturing cost reductions to $1.07 per peak watt accompanied by an increase in production capacity to over 700 MW. As work on the IDIP procurement continues, investigation is under way to determine future activities that will support research in product quality and facilitate the further acceleration of the Project's cost reduction and increased capacity goals.

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