

# Thin Films and the Systems-Driven Approach

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## ABSTRACT

A systems-driven approach is used to discern tradeoffs between cost and efficiency improvements for various thin-film module technologies and designs. Prospects for reduced system cost via such strategies are enhanced as balance-of-systems costs decline, and some strategies are identified for greater research focus.

### 1. Objectives

We apply the systems-driven approach (SDA) to thin films to 1) demonstrate that SDA can make a positive contribution to our understanding of research priorities and 2) investigate some key issues in thin-film research.

### 2. Technical Approach

The technical approach is to perform a bottoms-up analysis of thin-film module technologies using 1) known materials costs, 2) published materials and equipment data, 3) information provided by sources in private companies, and 4) educated guesses. First, process steps for various thin-film technologies were defined. Information was then gathered to assemble a costs spreadsheet. In some cases, overlapping costs for substrates, superstrates, adhesives, wires, front and back contacts, mounting, and other shared components were used to minimize variation across technologies. Where needed, future cost reductions were estimated using one of two approaches: an 80% learning curve, based on projected growth in production volumes; or research-based improvements. The resulting data were assembled and analyzed. We tried to avoid comparisons that required refined data because such data were unavailable *and may never be available*. Thus, we attempted to make the conclusions robust, despite the nature of the input data.

### 3. Results and Accomplishments

Using the data for the various thin films, one can gain some insight into the current state of thin-film manufacturing costs. These are shown graphically in Fig. 1, which shows two curves: the top and bottom curves represent high- and low-cost assumptions, respectively. Neither curve is meant to represent specific technologies; they are the result of using ranges of materials, capital, energy input, labor, maintenance, and cost assumptions. However, we would expect that almost all currently manufactured thin-film modules would have a cost within or close to this envelope.

Figure 2 shows calculated *potential* extremes of cost for thin films, with everything either at the highest cost end or lowest possibility. Specifically, the lower cost curve represents where everything is optimized: the cost of the

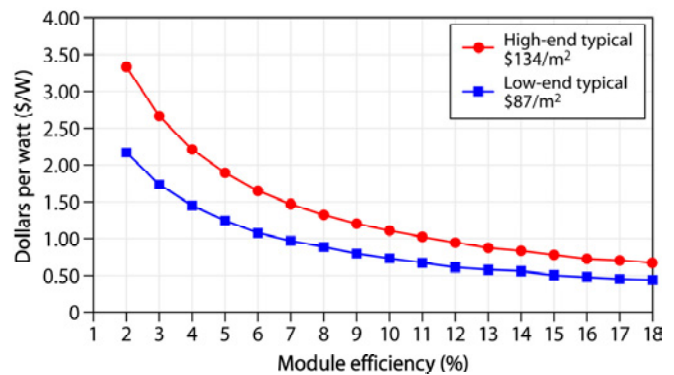


Fig. 1. Calculated ranges of thin-film module costs for today's technologies; although no technology is likely to have exactly these costs, most technologies should fall within this envelope.

semiconductor materials requires near 100% utilization rates and ultra-thin layers; their deposition is done inexpensively and with little energy input; the substrates are made using low-cost material like plastic, with minimal but inexpensive adhesive layers (*with no certainty whether such encapsulation could ever be adequately reliable*). And assumptions about volume production allowed using economies of scale such as those discussed in [1]. This is meant as a "stretch" estimate of thin-film potential.

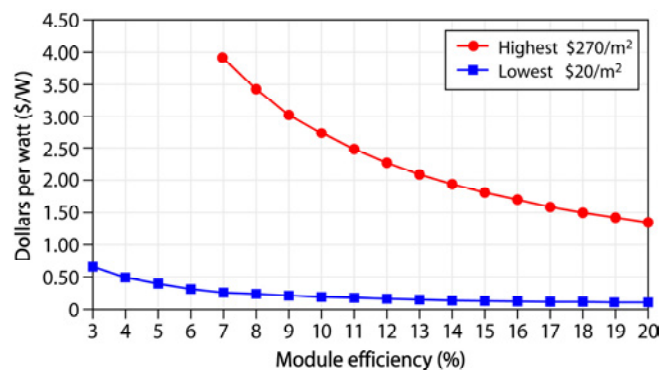


Fig. 2. Potential extremes of thin-film module costs.

To see more clearly some of the elements that go into these cost variations, we performed the following thought experiment: Start with a baseline thin film and subtract the cost saved if the semiconductor process could be optimized, i.e., if its capital and maintenance cost, energy input, material use and labor were minimal. As a second case, assume that its packaging costs could be minimized, instead, with low-cost plastics replacing glass or steel, and with low-cost adhesive replacing EVA (and other cost reductions, as

well). The following figures compare four cases: baseline thin film, lower-cost semiconductor deposition, lower-cost packaging, and both packaging and semiconductor costs reduced. In addition, the comparisons are done for two scenarios: near-term, using approximations of today's balance-of-systems (BOS) costs; and long-term, assuming much reduced BOS costs. Why? Because reduced module costs can have a greater impact if reductions are a larger fraction of total cost, and longer-term projections can elucidate this. The comparisons must also be made at the system level (not module cost itself) because this is where the tradeoffs in cost and efficiency can be seen. Table 1 shows the assumed values used as input.

Table 1. Assumptions used for comparison of different cost reductions (in  $\$/m^2$ )

	Baseline module	Lower semi	Lower packaging	Lower all	Area BOS	Power BOS
Near-term	90	70	74	54	80	0.5 $\$/W_p$
Long-term	40	34	29	23	25	0.2 $\$/W_p$

Figure 3 shows the results based on the near-term assumptions. The cost reductions have a minimal effect. Either reduced packaging or reduced semiconductor costs alone are worth about a 1% module-efficiency difference. Together, a near-perfect thin film (in terms of cost reduction) versus a baseline thin film would only be worth about 2% in module-efficiency difference. This means that with today's BOS costs, efficiency is so dominant that most radical changes in module design (which might lower efficiency) would not likely pay off.

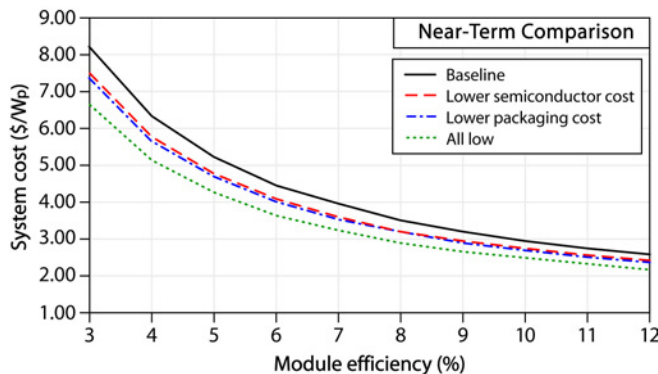


Fig. 3. Radically different assumptions about module packaging and semiconductor costs do not much alter their relative value in the near term due to high BOS costs (which outweigh the savings), causing efficiency to remain the dominant parameter.

Figure 4 shows a somewhat different picture based on much lower BOS cost assumptions from Table 1. At the very lowest cost extremes, say at a system cost of  $\$0.6/W_p$ , the allowable difference between the least expensive thin-film design (all savings) and the baseline design is 4%; in other words, a 12% module made with least-cost semiconductor deposition and packaging has the same value at the system level as a 16% baseline module (itself improved in costs from the one in Fig. 3). The lower

packaging cost reduction is worth almost twice as much as the lower-cost semiconductor fabrication, mostly because semiconductor costs are also assumed to improve in the baseline thin film. At higher-cost system levels, the differences are smaller. Over time, strategies that may cost some efficiency debit may still pay off if they result in aggressive module cost reductions. To reiterate, this is because at lower BOS costs, the module cost savings are a larger fraction of total system cost, with a larger impact.

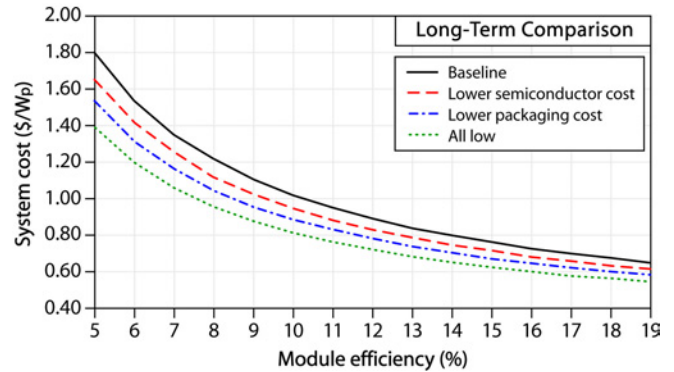


Fig. 4. A long-term comparison shows that with much lower BOS assumptions, radical cost reductions can pay off in tangible reductions in allowable module efficiency while maintaining equal system value.

The results provide some guidance about the value of cost reduction strategies, including radical approaches such as substituting low-cost plastics for glass, or using non-vacuum equipment with lower-efficiency cells to make semiconductors. It does not say whether such strategies are practical; in fact, they may not be, given reliability and efficiency challenges.

#### 4. Conclusions

Using less-than-robust input data (characteristic of the problem of studying technology options that are changing rapidly), it is still possible to make rough comparisons and suggest favorable routes for improvement. Reduced semiconductor costs (capital, maintenance, energy input, materials amounts, labor) and reduced packaging costs are attractive measures. Finer detail must be developed to bring these insights to bear on specific technologies.

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