Competitiveness of CIGS technology in the light of recent PV developments – Part II: Cost-reduction potential in CIGS production

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ABSTRACT

A detailed analysis of state-of-the-art CIGS technology has resulted in a direct cost of ownership (CoO) of €0.44/Wp for this PV module type. However, the reduction in production costs, although impressive, is not sufficient for CIGS to become competitive with today's c-Si technology. In order to answer the question as to whether CIGS will ever be able to challenge c-Si, the cost-reduction potential of CIGS is investigated. The impact of savings is evaluated in respect of the material segment, production equipment, energy and labour, production yield, device efficiency and absorber thickness. A total cost-reduction potential of around €0.21/Wp is identified, which would be enough to put CIGS back into the game (the direct CoO will continue to be dominated by material and equipment depreciation, adding up to 68%). These cost reductions, however, cannot be realized immediately: within the next two years, €0.03/Wp is expected to be feasible, while it will take two to four years for the next €0.107/Wp. For the final €0.073/Wp, a time frame of at least five years is predicted, with corresponding costs for the technology developments. Provided that someone is willing to spend the necessary amount of time and money, the second part of the answer regarding CIGS' competitiveness will depend on how c-Si evolves within this time period.

Introduction

In the previous edition of *Photovoltaics International* the current status of $CuIn_{1-x}Ga_x(Se_{1-y}S_y)_2$ (CIGS) production was analysed [1]. The cost of ownership (CoO) for CIGS module production, according to the author's calculations, is today around €0.44/Wp – and this is only under best-case assumptions. Fig. 1 reveals that around 70% of this cost has to be allotted to materials and depreciation. The €0.44/Wp figure signifies great progress with regard to CIGS production costs, but is still clearly above the best-in-class results of the US$0.50–0.55/Wp cost reported for c-Si module production. However, when talking about production costs, it must be borne in mind that the discussion here is about *direct* production costs. One example of all-in costs for PV module production can be taken from REC Solar ASA's first-quarter results released on April 25^{th} 2014: US$0.67/Wp including SG&A and special items.

For CIGS to become competitive, further reductions in production costs are essential; the potential for accomplishing this will therefore be evaluated in this second paper. The main cost drivers identified in the current status analysis will be examined: materials, equipment depreciation, energy and labour, and production yield. Technology improvements – such as higher device efficiencies and thinner CIGS absorber layers – will also be looked at. The discussion will focus on how potential cost reduction could be achieved, the calculation of how it would influence the direct production costs, and the probability of its being realized.

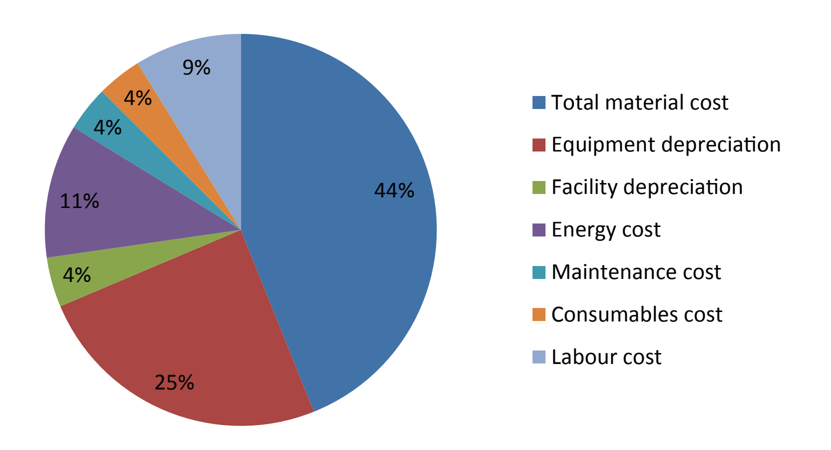

Figure 1. Relative cost contributions of various segments to the CoO for CIGS module production.

Cost-reduction potential: materials

The basic assumptions made here concerning target utilization and transfer coefficients show that during device deposition a significant part of the raw materials does not end up in the device. A better utilization of materials therefore reduces the costs for the coating materials.

> "During device deposition a significant part of the raw materials does not end up in the device."

To evaluate the impact on the CoO, the following improvements concerning material utilization are assumed:

- The rotatable target utilization is increased by 10%, to 85%.
- The sputter transfer coefficient is increased by 10%, to 65%.
- The evaporation transfer coefficient is increased by at least 10%.

The successful implementation of these improvements decreases the coating material costs, and consequently the direct CoO, by around €0.02/Wp; coating material costs would then amount to €0.05/Wp. However, while it is very easy to write down these numbers, it takes hard and long-drawn-out work to achieve these improvements. Furthermore, with so few ongoing CIGS activities at the moment, CIGS producers are highly dependent on technology progress induced by other products, rather than improving sputtering and evaporation technologies themselves within a relevant time window. The most significant leap forward with regard to material costs – the change from planar to rotatable targets – has already been implemented. The numbers quoted above are therefore considered a necessary but highly ambitious and long-term goal.

In arriving at these figures no account was taken of the fact that if the material utilization increases, the capacity of a given production line increases as well, which translates into lower capital expenditure. This leads to an even greater reduction in production costs, as will be shown in the next section; to what extent this occurs largely depends on the specific technology of a production line.

Current status – total material costs	30% saving	50% saving
€0.193/Wp	€0.162/Wp	€0.141/Wp

Table 1. Cost-reduction potential for the total material costs as a result of 30% and 50% procurement savings on glass, encapsulation materials and the junction box.

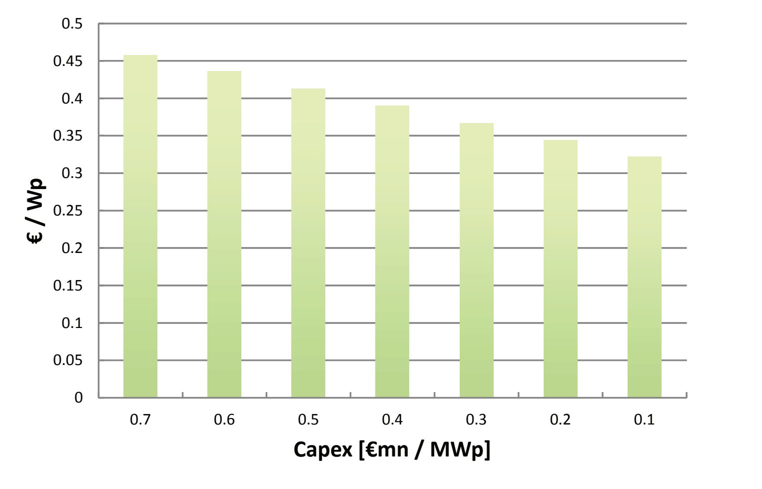

Figure 2. Impact of capital expenditure on direct CoO for CIGS module production.

Another, and much easier, way of reducing material costs is to purchase at lower prices: significant material cost reductions should be achievable by procuring glass, encapsulation materials and the junction box in Asia, and specifically China. The impact of 30% and 50% procurement savings for these items on the total material costs is shown in Table 1: more stringent procurement saves €0.03/Wp, or even €0.05/Wp. The result also impressively reconfirms the truism that "for material-intensive products, procurement is everything". A value of 30% is considered by the author to be feasible with reasonable effort, whereas 50% is (too) ambitious to be achieved within a meaningful time frame.

> "CIGS production equipment is more expensive than that for standard c-Si cell and module production."

Cost-reduction potential: equipment depreciation

Although the financial investment required for CIGS has come down significantly in recent years, CIGS production equipment is still more expensive, by at least a factor of six, than that for standard c-Si cell and module production. Fig. 2 indicates the impact of this difference on the direct CoO for CIGS: every €100,000 reduction in capital expenditure diminishes the depreciation and the production costs by approximately €0.022/Wp. A capital expenditure of €0.1m/MWp, equivalent to that for c-Si, would make CIGS more competitive; a value of €0.3m/MWp would be sufficient for CIGS to realize similar direct production costs to c-Si. However, considering the huge progress made in this field during the last few years, and that fairly often large-area and high-vacuum equipment is involved,

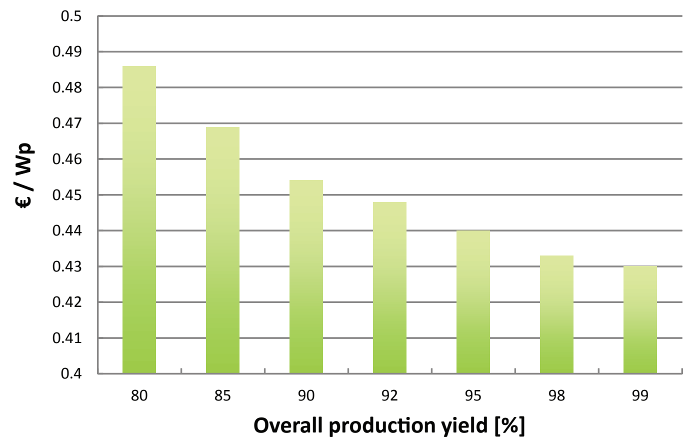

Figure 3. Impact of overall production yield on CoO.

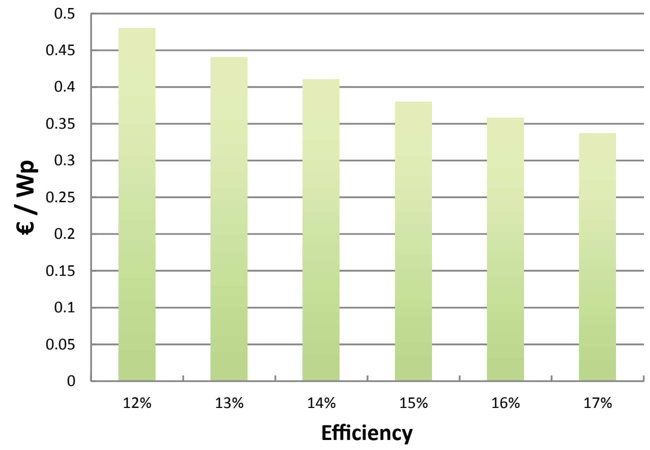

Fig. 4. Impact of module efficiency on CoO.

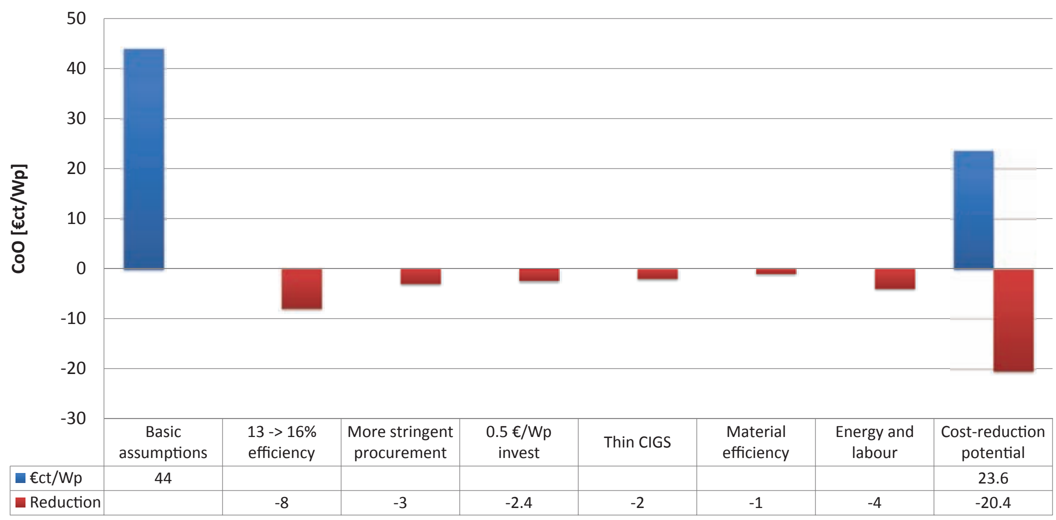

Figure 5. Contributions of the various elements to the cost-reduction potential.

capital expenditures any lower than €0.5m/MWp are not expected to be seen in the near and mid term.

Cost-reduction potential: energy and labour

Two other fairly significant cost factors, with a contribution of around 10% each to CIGS production costs, are energy and labour. If it is assumed that both factors can be reduced by 50%, the savings in terms of direct CoO are a little over €0.02/Wp for cheaper electricity and just under €0.02/Wp for a less costly labour force. A cost reduction in both these factors can be realized by a careful and cost-aware choice of the production site; such a production site is likely to be found outside of Europe and North America.

Cost-reduction potential: production yield

So far, the production yield has only appeared as one of the assumptions for the CoO calculation. A 95% overall yield is estimated, which is mandatory for production in the semiconductor sector but is ambitiously high for thin-film PV production. It is very likely the most optimistic of the assumptions made for this CoO calculation.

Fig. 3 demonstrates how different yields influence the production costs: increasing the yield brings down the CoO in a continuous way. However, an increase in yield from 95% to 98%, which requires significant efforts on the shop floor, only results in less than €0.01/Wp cost savings. There are better opportunities elsewhere that can be exploited to reduce production costs more impressively with fewer struggles once the production has reached this level. Accordingly, no contribution is expected from this segment, and if anything, a downturn is anticipated rather than an upturn.

Cost-reduction potential: efficiency

The negative impact of the low efficiency of CIGS modules compared with c-Si modules has already been discussed in the previous paper [1]. To avoid the disadvantages due to per item costs – such as the junction box – and sealing and area penalties in the PV system, it is absolutely essential to boost the efficiency to at least 16% in order to achieve cost competitiveness for CIGS production.

Fig. 4 shows that 16% efficiency cuts the production costs to a competitive €0.36/Wp. Well, paper does not blush: it took the industry two years to increase efficiency by 1%. Even if it is assumed that this development speeds up, because consolidation turmoil irritations and timely financing procedures are now over, these higher efficiencies are not envisaged anytime soon – in any case, no earlier than four to six years from now. One has to keep in mind that the more a technology matures, the more cumbersome the implementation of the improvements becomes.

> "It is absolutely essential to boost the efficiency to at least 16% in order to achieve cost competitiveness of CIGS production."

The derivation of these figures does not take into consideration the fact that increasing the efficiency also increases the capacity of a given production line, which again translates into lower capital expenditure. As shown in a previous section, this reduces production costs even further; the extent of such reduction is highly dependent on the specific technology of a production line.

Cost-reduction potential: thinner CIGS absorber

An absorber thickness of 1.6μm was assumed for CIGS in the initial

Cost structure	€/Wp Current status		€/Wp Cost reduction potential	
Total material cost	0.193	44%	0.099	43%
Equipment depreciation	0.109	25%	0.057	25%
Facility depreciation	0.018	4%	0.015	6%
Energy cost	0.049	11%	0.022	9%
Maintenance cost	0.016	4%	0.011	5%
Consumables cost	0.016	4%	0.011	5%
Labour cost	0.039	9%	0.016	7%
Total cost	0.440		0.231	

Table 2. Absolute and relative cost contributions of various segments to the current and to the mid- to long-term CoO of CIGS.

calculation, but the absorption coefficient of this material allows even thinner absorbers. From the physical point of view, a homogeneous layer of 1.2µm is sufficient for the proper functioning of the device; the subsequent reduction in material usage translates into a cost reduction of €0.008/Wp. More important than the material savings is the increase in production capacity or the reduction in capital expenditure, since less equipment is required for co-evaporation. If a ballpark figure of a 10% reduction in capital expenditure is assumed, the reduced amount of equipment aspect adds another €0.014/Wp to the cost-reduction potential.

Summary

The analysis presented in this paper regarding the cost-reduction potential of CIGS has revealed numerous segments where cost savings appear to be achievable. Better material utilization, more stringent procurement, lower capital expenditure for the production equipment, selection of low-cost production sites, higher device efficiencies, and thinner absorber layers may add up to a total potential cost saving of €0.204/Wp. Future production costs of €0.236/Wp for CIGS appear reasonable. Fig. 5 summarizes the impact of the various segments on the direct CoO.

"Future production costs of €0.236/Wp for CIGS appear reasonable."

As regards the various segments and actions within them, it is helpful to differentiate these according to technical feasibility and the corresponding timeline for achieving the cost reduction:

- *Short-term achievability, with low technical complexity.* The only action that features these properties is a more stringent procurement in the materials segment. This action can be taken immediately and is completely within the producer's control. If the time effort for sourcing, testing and recertification is considered, an impact on the cost structure can be expected within one to two years.

- *Medium-term achievability, with low to medium technical complexity*. This category includes energy and labour savings as a consequence of newly identified production sites. The setting up of new production sites will also help new generations of equipment to come online, which will also further reduce the capital expenditure. The impact of these actions is expected to become noticeable in production costs within two to four years. An increase in efficiency to 14–15% for the module in this category is also anticipated.

- *Long-term achievability, with medium to high technical complexity*. This category is where an efficiency increase to 16% and beyond belongs. Of similar technical difficulty to this are the shift to thinner absorber layers and the improvements in material utilization. In the case of the latter, only 50% of its potential was considered in the evaluation of overall cost reduction of CIGS. The impacts on production costs are expected no sooner than five years from now.

The contributions of the various segments to the mid- to long-term CoO of CIGS are listed in Table 2. To obtain these numbers, all changes were simultaneously fed into the computer model. This approach gives rise to slight differences in absolute values for some of the segments and to the even lower production costs. If their relative proportions are compared with the current status analysis, no major changes are observed.

All four major cost drivers contribute to cost-reduction potential, with the cost structure remaining dominated by the material costs. Although equipment depreciation has fallen, it has not come down sufficiently to be of low significance. Energy and labour add their share to the cost-reduction potential, but keep their relative significance. The facility depreciation, maintenance and consumables segments have not been evaluated for their cost-reduction potential separately, because of their low relative shares.

It is appreciated that the calculations to the third decimal place made here suggest more accuracy than can actually be obtained, with so many assumptions on future developments involved. Nonetheless, the accuracy of this evaluation is sufficient for illustrating the impressive cost-reduction potential of CIGS. Production costs of €0.23/Wp would help significantly in making solar electricity highly competitive worldwide; however, the road to realization is expected to be a lengthy and costly one. And one should not ignore the fact that c-Si production costs are a moving target that will continuously challenge the cost competitiveness of CIGS.

Acknowledgement

I would like to thank my colleagues Dr. S. Schuler and Ms. E. Benfares, without whose support this article would not have been written.

References

[1] Luck, I. 2014, "Competitiveness of CIGS technology in the light of recent PV developments – Part 1: The state of the art in CIGS production", *Photovoltaics International*, 24th edn, pp. 69–72.

About the Author

Dr. Ilka Luck founded PICON Solar GmbH in 2008 to provide consultancy services for the PV industry. Prior to that she was managing director of Global Solar Energy Deutschland GmbH and founder and general manager of Sulfurcell Solartechnik GmbH. She has also co-founded several other companies in the renewable energy sector. She holds a doctorate and diploma in solid-state physics and an MBA.

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