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# Use of Manufacturing Cost Analysis During Technology Development

Chang N[1], Egan R[1], Varlamov S[1]

[1] *University of New South Wales, Sydney NSW 2052*

*E-mail: n.chang@unsw.edu.au*

**Abstract**

Manufacturing cost analysis is used to assess the potential for a technology and to direct research effort to the processes or materials offering the greatest opportunity. In this work, we report an analysis of manufacturing costs for the LPCSG technology, with a breakdown of cost detail that allows key cost drivers to be identified and their impact assessed.

For the process modelled at 110MW/yr manufacturing capacity, the estimated cost was USD 155 /module, which corresponds to USD 1.01 /Wp at 12% efficiency. Three key areas for research focus have been highlighted – replacement of BSG with SLG, reduction of the thickness of the Si absorber layer, and increase of module efficiency from the current 12% level to 15% that together would reduce the manufacturing cost to USD 0.60 / Wp.

## 1. Introduction

The manufacturing cost of photovoltaic modules is a key driver in the Levelised Cost of Electricity (LCOE) for solar power. Much research and development is focused on new materials and processes that have the potential to improve the LCOE by increasing performance and/or reducing cost.

As a new process nears commercialisation, it is essential for detailed manufacturing cost analysis to be completed. This information can then used to justify the significant investment in manufacturing facilities and equipment.

There are some published examples of this kind of analysis, such as a very detailed analysis of silicon wafer based manufacturing, that explores cost implications of future process improvements (Powell, 2012), and a cost analysis of PERC and HIP-MWT compared to Al-BSF cells (Nold, 2012).

A manufacturing cost analysis is also very beneficial at earlier stages of technology development. This analysis is by nature less accurate, as the details of the processes are not yet finalised, the efficiency and yield of the panels have not been shown and, in many cases, suitable manufacturing tools are not readily available to implement some processes.

Despite these shortcomings, early manufacturing cost analysis can be very valuable in showing the potential for a technology, as well as identifying areas of high cost or uncertainty that need further work in order to bring the technology closer to commercial reality.

As an example of this, early manufacturing cost analysis was conducted from 1999 to 2005 leading up to the commercialization of the Crystalline Silicon on Glass (CSG) technology. During this period, regular cost model updates guided process changes and improvements such as a simplified cell patterning processes (Basore, 2004), and a manufacturing scale PECVD process for silicon deposition (Basore, 2003). In 2002, the (unpublished) cost estimate was over USD 200 /module. By 2004, this had been reduced to USD 162 /module as reported by Green (2004). Shortly after this, CSG Solar entered into commercial production of this technology.

The rapid drop in manufacturing cost for silicon wafer based technologies from 2008 created many new opportunities in photovoltaics, at the same time forced many developing technologies to review their technology roadmap. CSG Solar reported its plans to introduce the liquid phase crystalline silicon on glass (LPCSG) technology (Egan, 2009) resulting in more cost-effective processing and higher efficiencies (Dore, 2014).

In this paper, a manufacturing cost analysis of the LPCSG technology is reported, and key areas of process improvement identified and assessed. This work shows by example the kind of information that can be obtained from early cost analysis, and how it can be used to focus and guide technology development efforts.

## 2. Methods

Cost modelling was completed for the LPCSG technology. Costs are calculated from input materials, utilities, labour and capital costs, along with yield and throughput.

The cost model was built within the software "Factory Commander". This simulation software is produced by Wright Williams & Kelly (www.wwk.com) which has provided Total Cost of Ownership (TCO) software for over 20 years to various industries including in particular the semiconductor industry.

The LPCSG technology is summarized by Varlamov (2013), and the structure is shown in Figure 1 below.

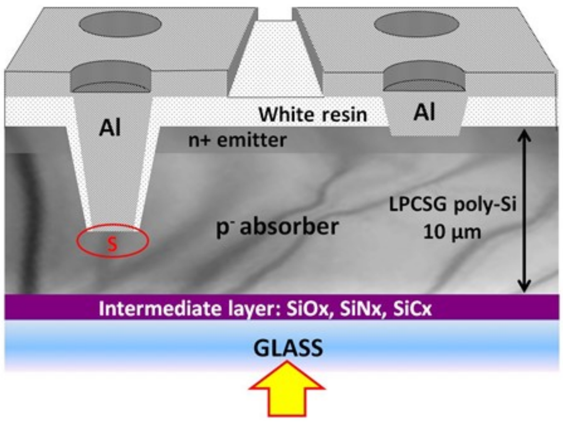


**Figure 1 – LPCSG Structure**

The main steps in the production sequence are:

- Glass Preparation
- Deposition of an intermediate layer.
- E-beam evaporation of the absorber Si layer.

- Laser crystallization.
- Emitter formation by diffusion.
- Resin coating.
- Contact formation
- Aluminium Sputter
- Encapsulation and Framing.

The LPCSG production sequence has much in common with the CSG Solar technology that was in production in 2006, and much of the cost model has been validated against actual manufacturing costs.

The key uncertainties in the costing of the LPCSG process are around the new processes and the effect of time on the cost of the unchanged processes. Some preliminary analysis of these uncertainties have been completed, with the detail to be published in the near future.

Some of the key assumptions of the model include:

- Depreciation time – 10 years for production equipment.
- Module size – 1.36m2.
- Yield – 95%
- Module efficiency – 12%
- Factory output – 720,000 modules/year (110 MW/year at 12% efficiency).
- Exchange rate USD 1.1 = EUR 1.0

## 3. Results

For the process modelled, the cost is calculated to be USD 155/module. Figure 2 shows a breakdown of cost by process step, and Figure 3 a breakdown by cost category.

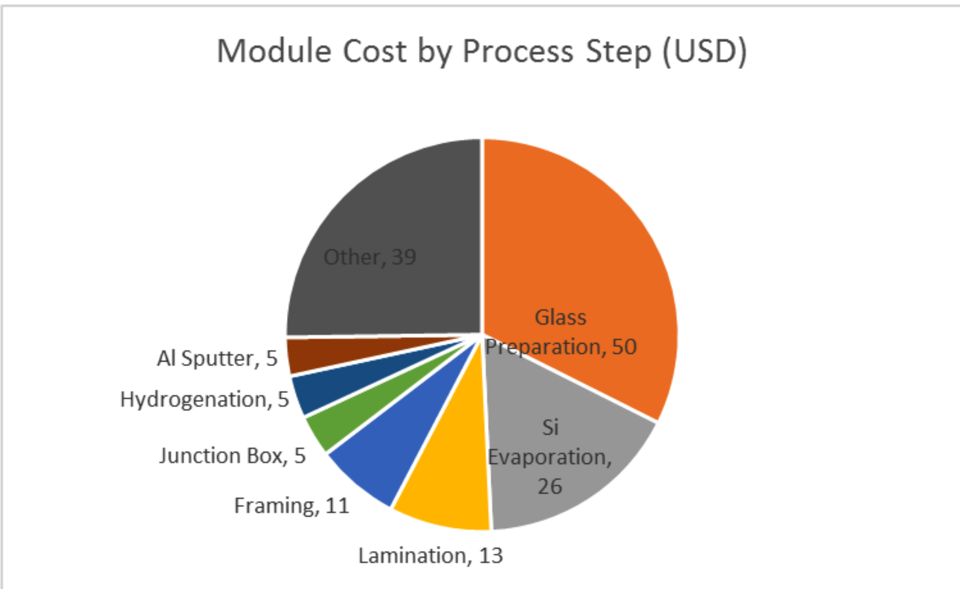


**Figure 2. Module Cost allocated to Process Steps**

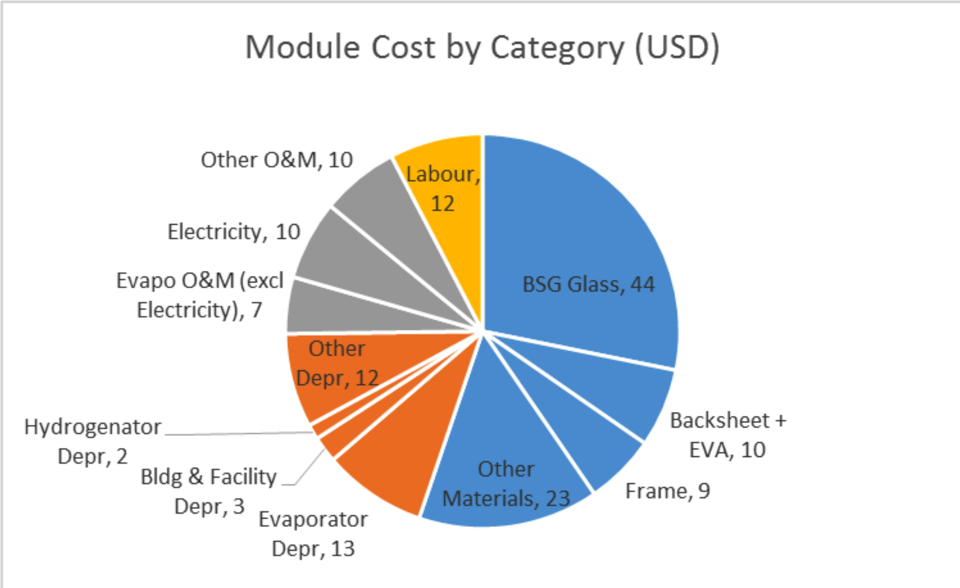


**Figure 3. Module Cost by Cost Category**

The process costs for the LPCSG approach are dominated by glass preparation, followed by silicon evaporation while, by cost category materials costs (glass, backsheet, frame+other) account for over 50% of the module costs. Notably, capital depreciation accounts for nearly 25% of total costs.

Assuming an efficiency of 12% this analysis gives a cost of USD 1.01 /Wp. Note that Varlamov (2013) reported 11.7% efficiency on lab devices, with expected >13% efficiency with optimization.

## 4. Discussion

The analysis reveals cost drivers that could be improved through technology development. The most significant of these are:

- The cost of the substrate material; boro-silicate glass (BSG) - this constitutes over 25% of the total cost. A sensitivity analysis reveals that if this glass can be replaced with cheaper soda-lime glass (SLG), it would reduce the manufacturing cost to USD 122 /module (EUR 0.80 / Wp at 12% efficiency).
- E-beam evaporation of silicon - This step by itself is around 17% of the total cost. The cost of the deposition process is proportional to the thickness of the evaporated silicon layer. Reducing the layer thickness to 7um in addition to using SLG would reduce the manufacturing cost further to USD 115 /module (USD 0.75 /Wp at 12% efficiency)
- A higher module efficiency would make a significant difference to the cost per Wp. For example, increasing the efficiency to 15% in addition to the above changes would reduce the cost to USD 0.60 /W.

## 5. Conclusions

For the process modelled at 110MW/yr manufacturing capacity, the estimated cost was USD 155 /module, which corresponds to USD 1.01 /Wp at 12% efficiency. Three key areas for research focus have been highlighted – a shift to a lower cost glass substrate, a reduction of the thickness of the Si absorber layer, and increase of module efficiency from the current 12% level to 15%. With developments in these areas the cost could be reduced to USD 0.60 / Wp.

This type of early manufacturing cost analysis is very useful in giving an indication of the current state of the technology, identifying areas of high cost or uncertainty that need further work in order to bring the technology closer to commercial reality, and indicating the potential of a technology should certain barriers be overcome.

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