# Latest Advances in Multi-junction Photovoltaics

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**Abstract**

**High Concentration Photovoltaics (HCPV) has received significant interest in both the technical and investor communities in the last few years. The significant breakthrough by NREL and, later by Spectrolab that has shown 3-junction solar cells can reach over 40% efficiency has been the nucleus of this enthusiasm for this technology. HCPV strives to supply the utility electricity market with inexpensive photovoltaic-generated electricity and III-V multi-junction solar cells have been identified as a critical technology to reach this goal. However, the high efficiency of these cells is only a benefit if it produces a lower HCPV system cost – reducing the cost of the PV generated electricity. This paper identifies some critical aspects of HCPV that must be addressed by multi-junction cell developers.**

## INTRODUCTION

Photovoltaics have grown substantially in recent years primarily due to the government support for the technology in Germany. And yet, there are many new technological efforts currently undertaken that would not directly be applicable to the environment in northern Europe. The can be considered as a reaction to the follow-on support by Mediterranean countries such as Spain and Italy where there are much more amenable environmental conditions that make technologies for concentrated solar energy generation not only realistic but often advantageous. This has been realized by companies such as Abengoa Solar and Gauscor Foton. Further application of concentrator PV technology can be found in the south west of the US by Amonix, who have pioneered CPV (concentrator photovoltaics). Such areas are becoming increasing active in their recognition that renewable energy resources are abundant and are thus looking for appropriate technologies to furnish their electricity grid with a growing proportion of solar-generated power. CPV has a major rule in these environments due to the availability of resources and public demand for action on reducing our impact on climate change.

## ADVANTAGES OF HIGH EFFICIENCY SOLAR CELLS

For any particular PV system, there are a number of components incorporating solar cells and modules, structural and control electronics parts, installation (labor) costs and grid interconnection electronics and manufacturing labor (cost of sales, engineering, etc). Calculating the overall system cost is done assuming a model of system cost without the module and then adding either a high-efficiency, high-cost module or a low-efficiency, low-cost module; the results of the calculation for a system of fixed physical size (such as 200 1m$^2$ modules) are plotted in figure 1. The high cost, high performance modules are 12% multicrystalline silicon that cost either $4/W or $3/W and the low performance, low cost modules are 6% efficient thin film-type panels costing $2/W or $1/W. It can be seen that for high system (without the module) costs, the more efficient panels produce a lower system cost. As the cost of the system without the module reduces, there is a cross over point where the thin film-type modules reduce the finished system cost. This model can be thought to represent a residential installation in the high cost region and a 10+ MW installation for the low cost region. This model is well supported by actual installations as we see residential systems are preferentially made with higher output modules and large installations are increasingly favoring low-cost thin film modules in order to reduce the overall system cost.

As there are many regions in the world that have large differences in the amount of sun light throughout the year and the cost of labor, land, etc can differ greatly, this simple model shows that for a given location, there is generally a best fit technology. Other aspects to a flat-plate installation such as system design costs, tracking, and, the particular modules' response to varying sunlight conditions, can make a calculation of the general levelized cost of electricity (LCOE) very difficult to determine. However, the general result here is that the PV technology should match the system expense.

Taking this same model to CPV we see that there is also a variation in PV cell technology. The silicon back-contact concentrator cell has shown efficiencies over 25% and it is practically limited to less than 30%. However, due to the large silicon semiconductor industry, there is ample silicon material and manufacturing capacity/expertise to produce 500x concentrator cells in very high volumes and at low cost. The alternative to the silicon concentrator cell is the multijunction solar cell that has shown efficiencies just over 40%. However, the cost of the multijunction cells is significantly higher than silicon – the raw Ge wafers used to produce the multijunction cells are 8 times more expensive that prime grade silicon wafers, as one example. So, in recognition of the two very different technologies, Amonix was particularly interested in assessing the best direction for system development – do we aim to use these 40% multijunction or continue with our own silicon technology? The above cost models used again to assess the best-fit technology for a CPV system but with the multicrystalline and thin film PV modules replaced with silicon and multijunction cells. This direct replacement of the cells is, in the first order, valid, due to the use of the same system design and materials for both cell technologies. However, the multijunction cell has aspects to it that require manufacturing equipment and processes that are more sophisticated than is needed for silicon cells. For the purpose of simplicity, we consider these more demanding aspects of using the multijunction cells to be second order considerations and are therefore not considered for this analysis.

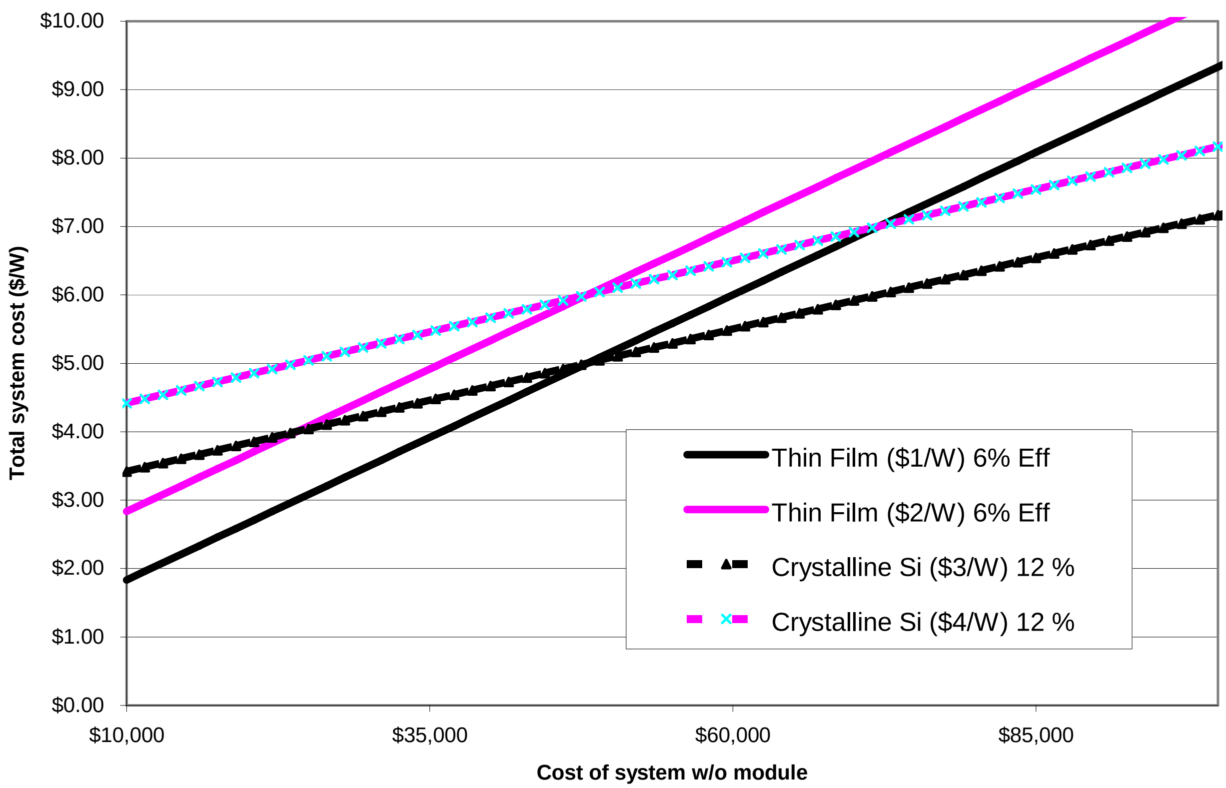


Figure 1. Calculation of system cost is presented as a function of module cost and efficiency and is plotted against the cost of the installation including all components and labor minus the PV module.

From the aforementioned conditions we have produced the same calculation for CPV system as we did for 1-sun system and plotted the data in figure 2. The data in figure 2 shows that the higher efficiency, higher cost cell reduces the system cost for more expensive installations. Once the cost of the system (without the cell) decreases, the advantage of the multijunction cell begins to diminish. Furthermore, there is also a cross over point for CPV systems where the final system cost is lower when a silicon cell is used, as was seen for the 1-sun system analysis. For near-term cell costs and efficiency levels, the cross over point is near $3/W, thereafter the overall system cost is less expensive if a silicon cell is used in place of a multijunction cell. The second group of lines shows that the cross over point is reduced to $2.50/W if both of the cell costs are reduced to the level we expect for 50 - 100 MW production.

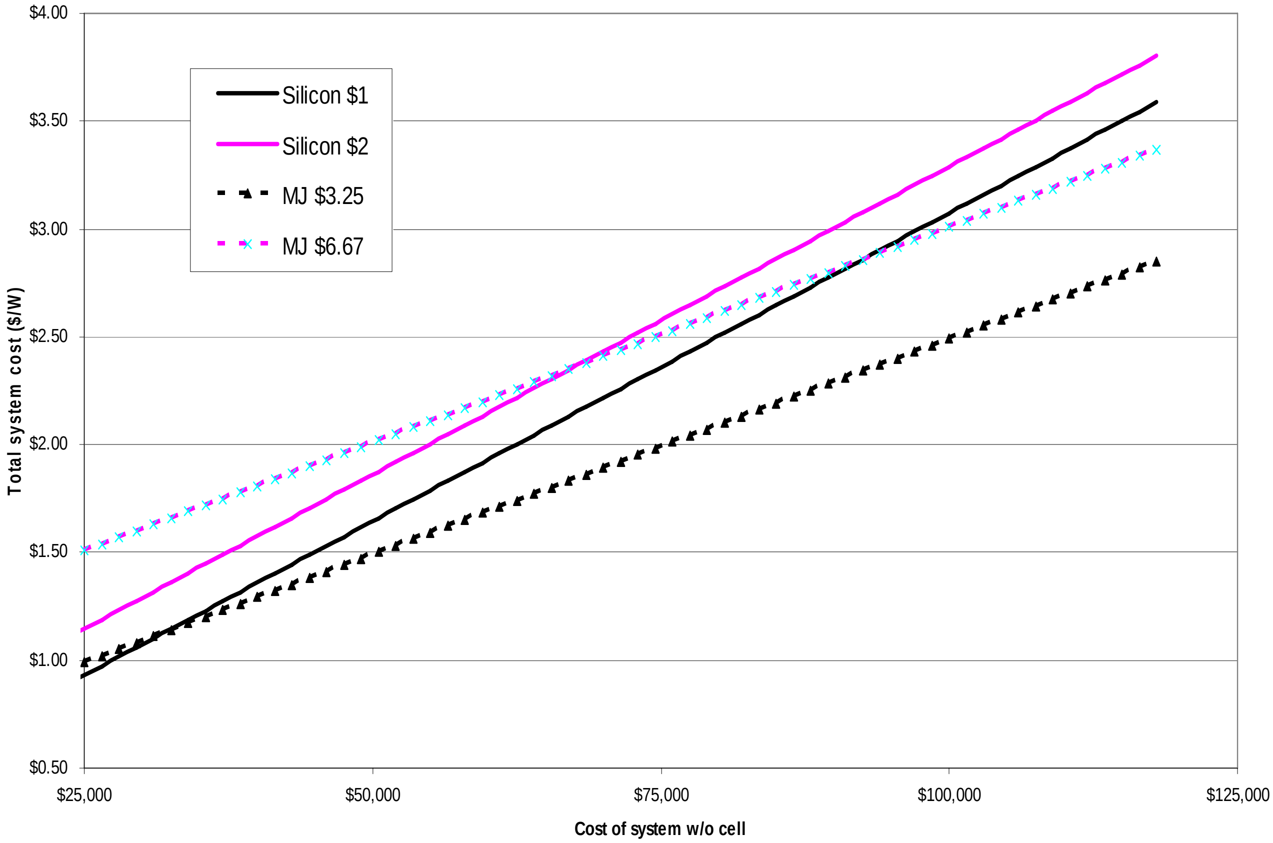


Figure 2. Calculation of system cost is presented as a function of concentrator cell cost and efficiency and is plotted against the cost of the installation including all components and labor minus the cells.

**DISCUSSION**

It has been stated many times by many burgeoning CPV companies that their mission is to reduce the cost of PV systems, relative to the established flat-plate technology. We have seen from the system-level analysis presented here that the future of low cost systems requires a low cost cell. This is somewhat in contradiction to the current enthusiasm to use a multijunction cell in CPV, as it is currently relatively expensive. However, we can see that the multijunction cell offers cost benefits to the system when the cost is in excess of $2.50-$3.00/W. This hasn't happened yet even for the established 1-sun PV industry. This being the case we could argue that the multijunction cells' main advantage is for realistic system manufacturers.

**CONCLUSION**

To produce the lowest overall cost for a PV system requires:

- Low component costs, and

- Inexpensive solar cells

However, there is motivation to use a relatively expensive, high performance solar cell technology. As an example of this, a residential PV system would benefit from using high efficiency modules whereas a very large installation in desert areas would be better designed to make use of a thin-film module. The same is true for concentrator systems that a multijunction cell will reduce the cost of an expensive system but a an inexpensive high efficiency cell is better for a CPV system if the system cost is low because the overall cost will be lower. Therefore the development of an inexpensive 40% efficient multi-junction cell will enable low cost for *all* CPV systems and thus become the dominate technology for photovoltaics as it will break down the resistance to solar energy by addressing the critical hurdle: cost.