Considerations for selecting thin-film technologies for large-scale photovoltaic applications

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ABSTRACT

Thin-film or crystalline photovoltaic modules? One of the consequences of the rapid introduction of new photovoltaic technologies is the buzz generated in the industry. Large-scale photovoltaic applications are especially sensitive to any question connected with cost optimization. Therefore, stakeholders involved in photovoltaic project development are questioning whether the time has arrived to shift module technologies to large-scale applications. A great variety of opinions are exposed every time this question arises. This paper's aim is to uncover the key questions that should be taken into consideration in order to select the proper technology for large-scale photovoltaic applications and to provide the maximum amount of practical information for this decision.

Introduction

Photovoltaic technologies are extremely dynamic. The evolution of traditional crystalline solutions and the introduction of new materials are increasing the possibilities available for this market.

As new solutions appear on the scene, new questions are raised. The following section will concentrate on developing documented answers that may help to clear up the new market scenario, and will evaluate the feasibility of thin-film and crystalline modules in large-scale photovoltaic applications.

There are two main questions being posed by photovoltaic system developers, investors and system integrators:

1. Should we move to thin-film, or is it better to remain with crystalline-based modules for large-scale applications?
2. In case we decide to move to thin-film, what are this technology's key features for consideration?

Criteria for selecting photovoltaic modules

In order to select the optimum photovoltaic module to be implemented in an application, it is advisable to evaluate a mix of features, as outlined below. Each of these features may have a different weight, depending on the project characteristics and the investment profile.

Photovoltaic module technology

The industry currently has a range of options, from which we can select monocrystalline, polycrystalline, a-Si, Tandem or CdTe modules for large-scale applications. For ease of discussion, these options will be categorized into two groups: thin-film and crystalline.

The goal here is to simply state the main differences to be considered between the two technologies. For broader insights, please consult related specific literature of photovoltaic materials and technologies.

Thin-film photovoltaic modules are characterized by:

- Using a fraction of the material used by crystalline modules
- Implementing production lines that lower manufacturing costs
- Having a wider light spectrum sensibility
- Performing more independently of temperature variations
- Having a lesser relative power output in terms of Watt peak per square metre (Wp/m^2).

In contrast, crystalline technology features are well known among the community and are characterized by:

- Being a highly mature technology
- Being established in the market for any application size
- Broad experience; almost every large-scale system integrator has direct experience with this technology
- Having a long silicon supply chain. Margins along the chain are highly influenced by market positioning. Traditionally, the earlier the silicon stage, the higher the margin. There has recently been a sudden drop in prices (Q4 2008 – Q1 2009); this was more connected with the price negotiation of supplies than with production cost optimization.

Module power output

The previous section detailed the majority of all module features in terms of direct influence in project design and system costs. There is a power gap that separates crystalline modules from thin-film modules which, although expected to shorten in the near future, should be taken into consideration.

Standard-sized crystalline modules average 180Wp to 300Wp, while standard-sized thin-film modules average 60Wp to 120Wp. The following table shows the conversion of those absolute values into relative values.

In the case of thin-film modules, it is essential to get the power output referenced after the first degradation stage when the power output is stabilized.

It is important to understand the direct implications of one's choice of technology type. The following costs are directly influenced by the power output module decision, to a lesser or greater degree. These cost influences will be discussed in detail later in this paper.

- Cost of the land
- Fixing structure/tracking system
- Module installation
- Low tension
- Monitoring
- Security

	Wp/m^2
Crystalline	144 - 152
Thin-film	45 - 85*

Table 1. Relative photovoltaic module power output (Wp/m^2). (*At the present moment (Q1 2009), there exist CIGS thin-film modules that exceed these relative values, but for very specific applications. In this article a more general overview is presented.)

Power Generation

Product warranty

A minimum of 5 years' product warranty is advisable, despite the fact that some module manufacturers persist in offering 2 years' product warranty. The reason for their reluctance to extend their offer is simple: those manufacturers are already established in the market and are averse to competing by offering higher warranties. However, newly established manufacturers are pushing for change, so one might expect that a 5 year product warranty will become standard in the near future.

Yield warranty

The standard yield warranty has been set to guarantee 90% of module capacity from year 0 to 10, and 80% of module capacity from year 10 to 25. Again, it may be the case that some module manufacturers keep their position to guarantee yield for just 20 years. Market trends may push them to adapt those values to the new standard before long. This feature is a crucial one for the final investor, as it provides the required guarantees to make sure the module will perform as expected throughout the whole life of the investment considered in the financial simulation.

An interesting additional offer currently being promoted by newly established module manufacturers is a supplementary insurance policy that the module manufacturer signs with an insurance company. This guarantees that whatever occurs in the future with the manufacturer, the module yield is fully protected. It goes without saying that this is certainly a recommended feature to request from module suppliers.

Certificates

It is also important to check with the module supplier to ensure that they have passed all IEC and CE certification processes. Additional TÜV/UL/SGS certificates reinforce the quality perception.

However, there remains much more to uncover in the certificates field. For example, a buyer might be interested in knowing more about the technology used by the manufacturing line. It may be a turnkey proprietary solution, a self-engineered solution, or a mix of both, and for these reasons, it is worth asking for references.

Manufacturers' excellence and quality programs are another vein that should be investigated, bringing to mind terms such as EFQM, Malcolm Baldrige, Deming, ISO 9000, ISO 14000, Corporate Social Responsibility, Six Sigma and many other related methodologies. The adoption of some of those programs can give crucial hints complimentary to standard PV module certificates.

Lastly, due to the multiplication of manufacturers, we have identified a reinforced request coming from investors and financial institutions to perform on-site evaluations for module manufacturers in order to provide additional insights about production lines, site facilities, quality control programs and module performance.

These auditing processes are usually carried out for newly established module manufacturers, or in the case of a first-time local market entry. Once completed, both investors and financial institutions gain enough confidence to release their funds according to the project payment milestones.

> "The standard yield warranty has been set to guarantee 90% of module capacity from year 0 to 10, and 80% of module capacity from year 10 to 25."

Recycling policies

Public Administrations may be tempted to request higher tax fees and bank guarantees from those projects based on CIGS and CdTe module technologies as they may contain elements potentially dangerous to the environment. The truth is that these elements are present in a stable atomic state, but it remains an issue that must be negotiated with certain Public Administrations. In response to this concern, those affected module manufacturers have established recycling programs that show support for projects that implement their technology.

In the event that such module technologies are to be used, it is essential to have a clear understanding of the specific recycling policy in order to achieve a stronger position to negotiate with the Public Administration regarding tax fees and bank guarantees to cover potential environmental risks.

Payment terms

Module manufacturers are used to cashing their products before releasing them to their clients. As one might guess, the newly created scenario allows the buyer to have a stronger position in order to negotiate this area.

The following is a list of the indicative ranges to be negotiated:

1. Down payment: 5-15%
2. Product release: 60-75%
3. Net-90 days: 10-25% (depending on the country, the standard may go from Net-15 to Net-180 days).

Traditionally, module manufacturers only accepted discussions about payments #1 and #2, with payment #3 rarely being touched on. Payment #3 usually corresponds to the partial net margin of the module manufacturer. Consequently, module manufacturers already secure their production costs with payments #1 and #2, and once the modules are shipped, manufacturers end up just crediting part of their margin. Negotiations of module supply should include some discussion of these payment elements.

Module prices

Let's start analysing the first feature that you might consider in order to position a module supplier: price.

Location: Jaén, Spain
Nominal power: 2.1MWp
Trackers: 906
Ground area: Approx. 150,000m^2
Solar modules: Approx. 10,600 units
Electricity production: Approx. 4,000,000kWh per annum
Completion date: July 2008
Involvement: Concept, Detailed Engineering, Project Finance, Licensing, Negotiations with Public Administrations, Supply Chain, EPC, Optimization, O&M.

Figure 1. The Solar Park in Jaén, Spain. In an area of 150,000m^2, 4 million kilowatt hours of clean energy are produced annually.

Module Price Band	Crystalline (/Wp)	Thin-film (/Wp)
Low	1.70-2.10	1.45-1.60
Middle	2.15-2.40	1.65-1.80
High	2.45-2.85	1.85-2.10

Table 2. Indicative module prices for large-scale applications (Q1-Q2 2009).

BOS costs (/Wp)	Fix Structure		1-axis tracking system		2-axis tracking system	
	Crystalline 230Wp	Thin-film 90Wp	Crystalline 230Wp	Thin-film 90Wp	Crystalline 230Wp	Thin-film 90Wp
Administrative [1]	0.0385	0.0385	0.0484	0.0484	0.0517	0.0517
Engineering [2]	0.2255	0.2255	0.2255	0.2255	0.2255	0.2255
Land [3]	0.0528	0.1194	0.0924	0.2090	0.1072	0.2424
Civil works [4]	0.0484	0.1095	0.0847	0.1916	0.0983	0.2222
Fix structure/ tracking system [5]	0.4070	0.9204	0.8987	2.0324	1.2650	2.8608
Module set-up [6]	0.0440	0.0995	0.0451	0.1020	0.0451	0.1020
High tension[7]	0.2200	0.2200	0.2200	0.2200	0.2200	0.2200
Low tension [8]	0.4620	0.6966	0.4840	0.7297	0.4840	0.7297
Monitoring [9]	0.0264	0.0398	0.0374	0.0564	0.0374	0.0564
Security [10]	0.0660	0.0995	0.1122	0.1692	0.1164	0.1755
TOTAL BOS costs	1.5906	2.5687	2.2484	3.9841	2.6505	4.8862

[1] Administrative costs include those connected to the licensing process, due-diligences, legal consultants, etc.
[2] Engineering costs include concept and detailed engineering, technical consultants, project management, etc.
[3] For the purpose of this article we have considered acquisition of the land upon which our large-scale PV park will be installed. In the event of a land-renting scenario, this cost disappears from BOS and is integrated as a variable cost into ROI simulation.
[4] Civil works include site facilities and land preparation.
[5] Fix structure/tracking system includes material supply, foundations and installation costs.
[6] Module set-up includes installation costs (module supply costs are excluded).
[7] High tension includes any equipment, civil works, installation, and manpower needed to connect the PV park to the public grid.
[8] Low tension includes all materials (wires, protection devices, inverters, etc.), civil works and related installation costs.
[9] Monitoring includes all costs connected to data network, internet access, monitoring equipment and installation.
[10] Security includes all required equipment and installation costs needed to secure the site.
All of these BOS costs are taken directly from Bioinversiones' experience in building large-scale PV parks.

Table 3. Indicative BOS costs for large-scale applications (Q1-Q2 2009).

The trend during the last 24 months (Q1 2007 – Q1 2009) has been incredibly market driven. During 2007, crystalline modules for large-scale applications were quoted in a range of 2.80€/Wp to 3.40€/Wp. (At time of publishing, the exchange rate was 1€=1.32904 USD.) This price represented a relatively stable scenario and margins across the whole supply chain were well known.

A sudden market reaction appeared in Q2 2007 led by the changes in the Spanish PV legal frame. It generated massive global pressure across the module supply chain, creating a global scenario where module manufacturers could barely meet the demand.

This situation resulted in an escalation of module prices. In Q2-Q3 2008, module for large-scale applications reached quotes in the range of 3.30 to 3.50€/Wp.

Worldwide module manufacturers were able to sell their stocks and scheduled productions until Q3 2008 at a very high price. Customers applying directly to module sales managers meant that there was no need to seek out customers, leading to an easy sale and a resulting freedom of pricing. From then until now (Q1-Q2 2009), the scenario has altered drastically.

- Spanish demand suddenly ceased in Q4 2008 due to the introduction of year caps that limited the expansion of the PV market.
- Emerging PV countries offer promising perspectives, but are still in the early stages of project development (France, Italy, USA, Greece, Bulgaria, etc.).
- New players have jumped into the arena of PV module manufacturers, especially those connected with thin-film module technologies, and have set up new production lines that have reduced manufacturing costs considerably.
- Low-quality PV modules have been almost placed out of the market. It is widely known that the quality of the Asian module was a hot question. In a scenario where offer meets demand, quality is a must. Presently, most of the surviving Asian module manufacturers are those that took quality standards seriously and successfully implemented strict quality programs.

These points generated a new scenario where module sales managers started travelling to look for clients, as the queues for quotes have died down. Additionally, high competitiveness introduced by thin-film (a-Si, CdTe, CIGS...) module manufacturers has pushed down the excellent margins across the traditional crystalline (ingot, wafer, cell, module) supply chain.

"In Q2-Q3 2008, module for large-scale applications reached quotes in the range of 3.30 to 3.50€/Wp."

Table 2 illustrates an indicative breakdown of module prices available for large-scale applications during Q1-Q2 2009. For simplicity, we will consider an average 230Wp crystalline module and an average 90Wp thin-film module. Quotes referred to are Delivered Duty Paid (DDP) incoterm.

It should be noted that the table structure does not intend to assimilate price band to quality. The following examples illustrate this point.

1) High-band crystalline modules may correspond to certain manufacturers, usually positioned in the highest ranks for quality. However, this is not the

/Wp	Fix Structure				1-axis tracking system				2-axis tracking system			
Module Price Band	Crystalline 230Wp		Thin-film 90Wp		Crystalline 230Wp		Thin-film 90Wp		Crystalline 230Wp		Thin-film 90Wp	
Low	3.2906	3.6906	4.0187	4.1687	3.9484	4.3484	5.4341	5.5841	4.3505	4.7505	6.3362	6.4862
Middle	3.7406	3.9906	4.2187	4.3687	4.3984	4.6484	5.6341	5.7841	4.8005	5.0505	6.5362	6.6862
High	4.0406	4.4406	4.4187	4.6687	4.6984	5.0984	5.8341	6.0841	5.1005	5.5005	6.7362	6.9862

Table 4. Indicative integrated photovoltaic system costs for large-scale applications (Q1-Q2 2009).

only real fact that drives them to quote their modules so high: certain supply constraints with their cell supplier can have a major effect on the price. In the past, these manufacturers had signed long-term cell supply contracts and as a result, cannot adjust their prices down to follow the market trend simply because they are buying cells at much higher prices than the market standard.

2) Many of the module manufacturers included in the low price band insisted that their clients should audit their products, manufacturing site and quality control program. It should be taken as a positive sign when manufacturers are so confident of their quality that they encourage their clients to check it.

The above examples suggest that there is no direct correlation between price and quality; but rather that many other factors have a relevant weight.

Balance-of-system costs

Balance-of-System (BOS) costs include the rest of the costs that one might find while developing photovoltaic systems.

Table 3 includes indicative prices for each of the BOS items during Q1-Q2 2009. As before, we will consider an average 230Wp crystalline module and a 90Wp thin-film module. Quotes referred to are Delivered Duty Paid (DDP) incoterm.

> "High-band crystalline modules may correspond to certain manufacturers, usually positioned in the highest ranks for quality."

Table 4 shows BOS costs integrated with module prices, and reveals some points of interest. While a vague idea of costs can be garnered from a focus on photovoltaic module prices or BOS costs alone, Table 4 allows the prospective buyer to observe how the photovoltaic system costs are balanced when all the costs are considered.

Conclusions

In the months and years to come, the photovoltaic market will perform a self-regulation of prices. As emerging photovoltaic countries increase their demand for modules, the down-pricing trend may freeze for some time. Nevertheless, global module manufacturing capacity is increasing at a fast rate, which is bound to decrease the likelihood of seeing module shortage and scarcity for some time.

Location: Almería, Spain
Nominal power: Phase 1: 2.1MWp; Phase 2: 1.1MWp
Free-standing
Ground area: Approx. 50,000m^2
Solar modules: Approx. 8,000 units
Electricity production: Approx. 2,600,000kWh per annum
Completion date: September 2008
Involvement: Concept, Detailed Engineering, Project Finance, Licensing, Negotiations with Public Administrations, Supply Chain, EPC, Optimization, O&M.

Figure 2. The Solar Park in Almería, Spain. In an area of 5,000m^2, 2.6 million kilowatt hours of clean energy are produced annually.

Returning to the questions asked earlier in the paper, we can now review and answer them based on the lessons learned from our findings.

1) *Should we move to thin-film, or is it better to remain with crystalline-based modules for large-scale applications?*

There is no definitive answer to this question.

Due to the lesser relative power output, perhaps thin-film module technology should be considered for mounting in free-standing PV parks where land availability is not a constraint, and land costs have a minor influence on the overall system price. Highly cost-optimized foundations and supporting metallic structures can also prove profitable in lowering related costs as much as possible and bringing costs closer to those associated with crystalline BOS costs. From a cost-effectiveness perspective, tracking solutions remain the only available option as a reserved application for crystalline modules.

2) *And in case we decide to move to thin-film, what are this technology's key features for consideration?*

One should definitely consider the highest relatively powered thin-film modules available in the market. The higher the relative photovoltaic module power output (Wp/m^2), the lesser the BOS costs associated with that particular solution.

Regardless of the application, it is advisable to check all of the key features exposed in this article. BioInversiones develops tailor-made photovoltaic systems, which are fully optimized to run under their specific environments, and designed to generate the highest returns to investors and the local community. Consequently, please take note that the above guidelines and costs must be properly evaluated for each individual project.

About the Author

Pedro M. Fernández, founder of BioInversiones, is an experienced photovoltaic business developer committed to providing conscious profitable green business solutions. Pedro has successfully led a vertical integration from module manufacturing towards investments in turnkey PV power plants. He has also held technical and management positions in Gas Natural SDG. He graduated with a degree in electricity engineering and an M.B.A. from Universitat Rovira i Virgili in Tarragona, Spain.

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