# Trends and developments in the lamination process of PV modules (part 2)

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ABSTRACT

Although much of the emphasis of Part 1 of this paper (in *Photovoltaics International* ed. 5) focused on material quality issues and attention to detail on process control, high-volume manufacturing requires a concerted effort to constantly improve productivity of the lamination process and in turn the productivity of the total module manufacturing line. Such is the competitive landscape that greater attention to these factors is becoming a key differentiator for both equipment suppliers and module manufacturers. In this, the second part of the lamination process focus, we will look closely at the dynamics impacting module prices and the developments being undertaken to improve cycle-times of the lamination process, overall productivity and optimization as well as costs to ensure future competitiveness.

## The pressure on module manufacturing

A significant drop in module ASPs as a result of the global economic recession had a huge impact on the PV industry late in the third quarter of 2008. This inevitable reduction in overall demand for solar was also negatively impacted by the collapse of the Spanish market.

There seems to be a growing discrepancy between PV module production and actual installations. According to iSuppli, module production will now reach approximately 7.5GW in 2009. Although a wide range of installation forecasts have been suggested, even taking 2008's figure of 5.5GW installed as a guide, it is clear that a major disconnect is occurring.

iSuppli guided 4.2GW earlier this year, which still denotes a module overcapacity situation of over 160% for 2009, remaining above 100% through 2012. This scenario would bring silicon module prices crashing down to between US$2.50 and US$2.75 per watt. Nevertheless, concerns over module inventory build in recent quarters seems to be easing after module production has become better matched to market demand.

Module price declines have been more severe in the first half of the year than predicted by those 'in the know'. Many expected a decline in prices of between 10 and 15%, due to a combination of FiT changes in Germany and polysilicon price declines as overcapacity became apparent in the second half of 2008. REC noted in the third quarter of 2009 that it expected module prices to have fallen by 35% in 2009 as the glut in finished products continued. Module prices could yet show a 32% decline for the year, according to the latest figures produced by Photon Consulting.

The net result is mounting pressure to reduce module manufacturing costs such as materials, which represents a higher percentage of the cost of manufacture. Scaling facilities to greater economies of scale intensify along with greater need for improved productivity of the equipment.

## Laminator innovations and process optimization

The laminator equipment market has seen significant growth in recent years as it has responded to this ramp in module production. As noted in part 1 of this feature, VLSI Research's data showed that the laminator equipment market exceeded US$300 million in 2008, a CAGR of approximately 100% compared to 2007.

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Although figures are yet to be revealed for 2009, the continued capacity expansions should result in a stable market comparable to that seen in 2008. However, the module market has changed significantly, which could shape the future of the lamination market in years to come. This is perhaps part of the reason why recent new product announcements attempt to tackle the throughput and cost considerations that module manufacturers now face with rapidly declining prices.

The changing face of the laminator market is apparent in the move by some established PV equipment suppliers from other sectors to penetrate the market with new technology. One such mover is Bürkle which entered the market in 2007. From the perspective of Bürkle's Dagmar Metzger, Product Manager Photovoltaic, the laminator market was in need of a major rethink.

"Before Bürkle entered the PV market, we examined the materials to be processed and subsequently developed the corresponding machine types. Furthermore, we assumed at that time that the industry will have to get in the high-volume area and that larger capacity units would be required for this purpose."

However, Metzger was not too complimentary of what she described as 'traditional' laminators, noting that there were some fundamental issues with the equipment being used as recently as a few years ago.

"We had the impression that many of the laminators which were in use on the market at that time were mostly prototypes that have not been fully developed yet concerning many technical issues, originally intended for other purposes. Most of the lines were lacking automation and operated manually.

"Heating and vacuum systems which were in use were partly tainted with high tolerances. Consequently, the process window available for the user was highly restricted and no reproducible processes were possible." Metzger also believes that the knowledge on available materials was limited, forcing operators to carry out experiments on their own in order to obtain the necessary know-how. As soon as a process was reliable to some extent, it was frozen and not developed further.

Figure 1. Bürkle's 'Ypsator' stack system is designed for high-volume module applications.

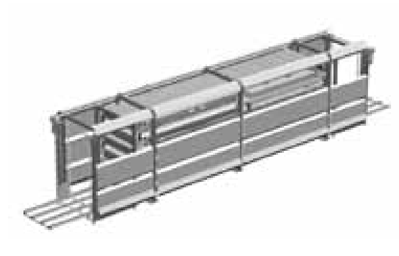

Figure 2. Komax's XLam 3L-17/34 asynchronous (independent) stack laminator.



"Moreover, the traditional laminators require quite a high maintenance effort and cause still very high wearing part costs," commented Metzger. "Currently, the traditional laminators working with membrane are also used for glass-glass modules, which were not optimal due to the overpressure which the membrane creates at the edges of the modules and due to only one-sided heating from below."

The 'Ypsator' system that Bürkle introduced laminates up to 20 modules per cycle (Fig. 1). On a surface area of 3.5m² per opening with five openings, manufacturers can produce 10 photovoltaic modules per batch simultaneously. The total annual capacity of a tool is around 500,000 modules.

Using heating platens with thermal oil, process times are reduced considerably. The lamination process is separated in order to make the processes more flexible, thus increasing productivity. In a first step, the modules are pre-laminated. This means that the moisture and the air pockets are removed from the sandwich in the vacuum, creating a vacuum-tight compound. The lamination is finished in a subsequent press. In a third step, the Ypsator cools down the solar module from 150°C to hand warmth. Due to the structure of the three lamination steps, the glass modules can be laminated with less stress, resulting in less glass breakage.

"In the case of glass-glass, modules Bürkle offers a special three-step lamination concept which avoids an overpressure at the edges and supplies the heating of the modules from both sides," added Metzger.

Bürkle would seem to have had some market success with the Ypsator system, especially with thin-film module manufacturers. Shortly after the 24th EU PVSEC in Hamburg, the company announced a tool order from Taiwan-based Jenn Feng New Energy, the sixth such order from Asia-based customers within one year.

Bürkle has also started to penetrate Germany-based module manufacturers, recently sealing a deal with the newly formed and rapidly expanding Bosch Solar Energy AG. Bosch Solar Energy will start producing a crystalline module manufacturing in Arnstadt at the beginning of 2010, using two multi-opening Ypsator laminators with four openings each for its first 75MW line. The companies plan to collaborate further to improve module manufacturing in the future.

However, other equipment suppliers are not convinced that the multi-opening laminators provide what much of the industry is demanding. One of those is Mark Willingham, VP of marketing at Spire Corporation.

"We are not pushing into stack laminators; what we have done is watch that market segment and there is no reason to spend a lot of money in that market right now, though we understand very well how to do it. The first area of adoption we see for those laminators is the thin-film market.

Figure 3. 2BG's L900A automatic laminator.

"This is a good example of risk aversion in the market as the majority of module processes we see would rather use floor space than stacks," noted Willingham. "The risk is what they are trying to get away from. It is thin-film, however, that will adopt this technology first: because there are so many laminators required per megawatt of output, the payload is less efficient with more modules per minute, requiring more laminators.

**"An aluminium heating plate with a large thermal capacity and an active pin-lifting system that does not require vacuum pumps further simplifies the tool mechanisms."**

"I think a lot of innovation is going to be pushed off until rosier times. This makes us as equipment suppliers equally as conservative in our advancements. What we are trying to do is reduce cost. Our focus is on ramp-time, temperature

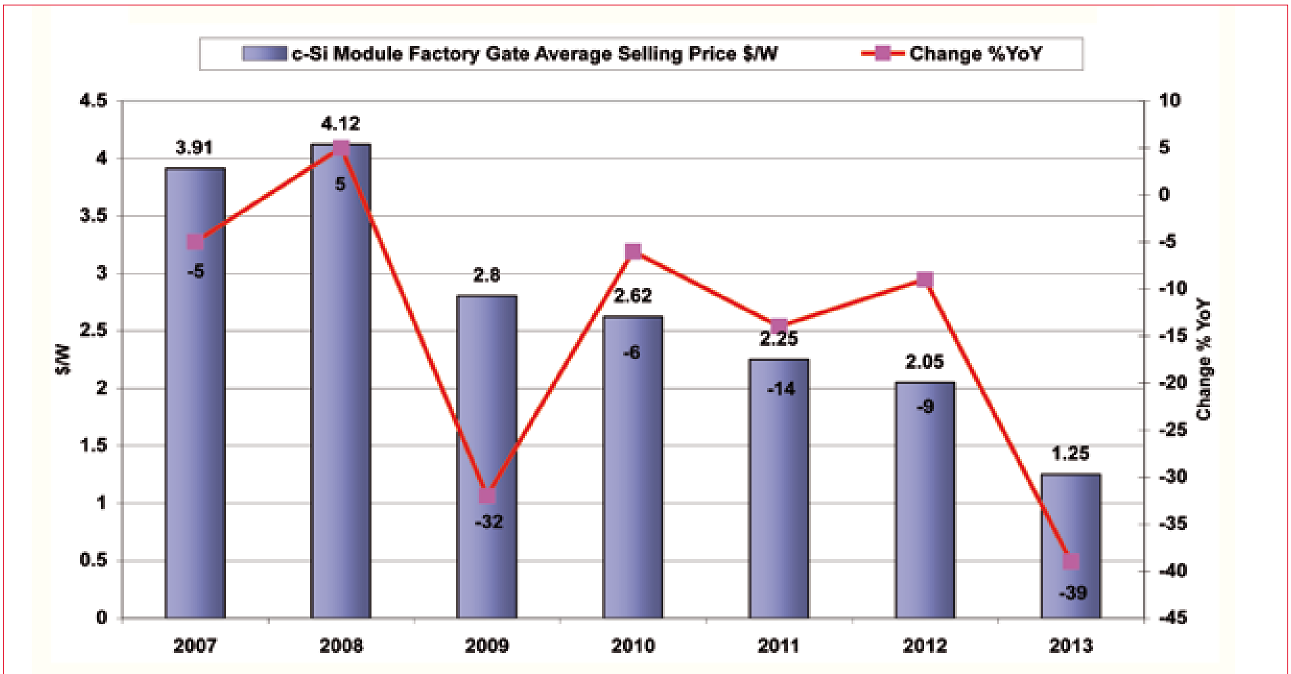


Figure 4. Photon Consulting: c-Si Module Factory Gate Average Selling Price ($/W).

uniformity and other areas that are on the cost-of-ownership side. With laminators we think the price of the tool isn't the real factor, cost of ownership is. Downtime is several magnitudes more important than the purchase price."

Willingham noted that Spire has developed a unique mechanism for removing the diaphragm and cover sheets in the laminator.

"Those are wear parts. Our system can now change diaphragms in 15 to 20 minutes. Typically this can take almost half a day!"

Another machine cost reduction program of Spire's is developing two new laminators in a lower cost region, not only from the material and labour cost perspective but also from the shipping cost perspective, especially seeing the significant market growth for equipment in Asia. Willingham remarked that it can cost US$50,000 to ship a laminator.

Komax Solar is another well-known equipment supplier that has launched a new laminator, the Xlam, as shown in Fig. 2. The tool is suitable for both crystalline module production as well as thin-film technologies and is designed from the bottom up for high volume production.

"We tried to keep the process as it exists but to improve the reliability and functionality of the machine," commented Claudio Meisser, CTO of Komax. "Looking at changing the process, you soon realise that there is a lot of work to do. A good example of this is our approach to temperature uniformity control, which is different from that of many other competitors. We are working with one temperature control loop. This enables a reduction in the complexity of the machine but retains best-in-class temperature uniformity of ±1°C."

To satisfy these requirements, the XLam platform incorporates hybrid heating featuring a unique and reliable induction heating system. An aluminium heating plate with a large thermal capacity and an active pin-lifting system that does not require vacuum pumps further simplifies the tool mechanisms and reduces machine cost, maintenance and replacement parts.

The hybrid inductive heating system integrated in the aluminium plate has meandering oil circuits that are designed to enable an ultra-high uniformity of temperature. Komax noted that it was using aluminium heating plates with larger thermal capacity than most of its competitors to achieve shorter process times.

These solutions are hugely beneficial, opening the way to high availability and low operating costs, according to Komax. With the three processing levels, operators can enjoy the benefits of continuous module production, the partial availability of the machine in the event of a malfunction at one processing level, and the adaptability of laminator capacity to less than full capacity utilization in the production line. The footprint for a specific production capacity is claimed to be much smaller than with standard laminators as it fits into a standard-sized shipping container.

"We feel we have an excellent product for continuous production requirements," added Martin Keller, Product Manager PV at Komax.

A leader in the laminator machine market is 3S Industries. Dr. Ronald Lange, Chief Innovation Officer at the company, remains enthusiastic about optimization and cycle-time reductions for laminators. Lange noted that its use of a partly transparent laminator in its complete pilot production line allows the separation of the various process variables as it allows the operator to physically see the process interactions in real-time, leading to a more cost-efficient PV module production.

Importantly, this leads to new innovations on the machine and has led to the reduction of lamination cycle time by more than a half, while increasing the quality of PV modules with a robust process window.

"Our approach may be different to others," remarked Lange. "We understand the processes and equipment to such an extent that we make productivity guarantees to our customers, eliminating long discussions on throughput, maintenance times etc. We are very confident of our processes that optimise the lamination process... our membrane clamping system is a good example of continuous product development cycles here at 3S."


**Figure 5. P.Energy's laminator has evolved into a robust workhorse for module manufacturing.**

The company developed its membrane clamping system to significantly reduce the impact of repeated stress caused by heat, cyclical stretching and chemicals on the membrane as well as to reduce the time for loading, which has been time consuming. Benefits include longer useful life for the membrane and therefore longer up-times for the machines as well as shorter handling times, boosting productivity of the laminator.

3S is not the only lamination equipment supplier that has continuous productivity improvement programs. Gabriele Pettenuzzo, President of P.Energy in Italy, noted that the company had focused attention on its laminators to reduce EVA curing times. This was being accomplished by installing larger vacuum pumps in order to reduce the required pumping time for each step. He also noted that a fast clamping system was important to productivity gains.

"We have already developed a fast clamping system in order to reduce the time for changing the silicon membrane in the laminator. At the moment, we are developing a new system in order to prevent damages in the silicon membrane and to obtain 5000 cycles before the need for replacement."

Emanuela Zecchinati from 2BG, also based in Italy, noted that, "All of our laminators are subject to continuous development in order to improve the quality of laminated product, with particular attention to time reduction, which is necessary for this process. Mechanical endurance of the structure, the compensation of delays, and the uniformity both of heating and pressure are key elements in laminator development."

Zecchinati also noted that in her opinion, the company's main effort will be geared towards further integration of process control parameters for increased overall laminator productivity.

Ecoprogetti's Lisa Hirvonen highlighted productivity improvements with the company's laminators and the route they have taken to solve certain problems with the lamination process.

"A limitation in the lamination process is that when the glass enters the laminator, it bows because of thermal dilatation. In this way, the glass touches the plate only in the centre," said Hirvonen. "During the first step of the lamination process – the so-called pumping time – the EVA starts to polymerize only in the centre, causing non-uniform gel content in the finished module."

Hirvonen said that Ecoprogetti designed their system specifically to avoid generating a uniform temperature.

"In this way we set different temperatures in different zones in the various steps of the lamination process to guarantee a uniform gel content of around 85% over the complete surface," remarked Hirvonen. "In this way we take advantage of being able to increase the temperature around the module, but most important of all, we can reduce the cycle time, thus improving our productivity."

## Material developments and optimization

As noted in Part 1 of this feature, EVA has the longest track record of encapsulant material usage for modules, which have been dominated by crystalline technologies. As noted by Birgit Wernicke, Managing Director of Etimex Solar, the widest choice of lamination equipment is available for EVA.

"EVA is being offered in at least three different types concerning curing time, resulting in longer or shorter lamination cycle times," commented Wernicke. "A key requirement is the control of the process of the lamination and the resulting gel contents. Etimex UFC [ultra-fast cure] EVA is even suitable for a stack lamination process, thus resulting in the highest output of modules per time and laminator area."

Indeed, faster curing times have had an impact on lamination cycle-times. Alessio Maiocchi, Product Manager at 3S, noted that lamination process times about five years ago would typically take 40 to 50 minutes using a standard conventional EVA material. This can now be reduced to between 15 and 16 minutes with the range of fast-cure materials now available.

In this context, the knowledge and understanding of EVA materials is most comprehensive, and the widest range of material requirements can often be better met with EVA derivatives. This allows for focus on the all-important reliability requirements, but can also tackle the needs for short cycle times, overall improved productivity and the ultimate goal of cost reduction.

"Material cost – specifically EVA films – can be reduced to a certain extent by quantity and standardization of module dimensions," remarked Wernicke. "Thickness reduction has already been achieved with current standards as you have to consider technical limits for the mechanical strength required in modules."

Although not a technical innovation in the true sense, Wernicke also sees an opportunity for material cost reductions, simply from the point of industry standards, which would help to optimize output in the whole supply chain. EVA remains a very cost-effective solution.

> "Optimization of materials will continue only for the next several years and will definitely improve the productivity of the module production line."

While polyvinyl butyral (PVB) has been in use for decades in laminated glass applications, recent technology developments have made it a material of choice for certain PV module designs. This includes many thin-film technologies, which has over time become more robust to moisture absorption.

According to Christopher Reed, Global Business Director of Saflex, a unit of Solutia, Inc., a key attraction for thin-film manufacturers adopting PVB over EVA was not only the potential for cost savings but also the ability for suppliers to scale production quantities quickly. Furthermore, the material can be produced in long roll lengths (to minimize roll handling cost) and wide sheet widths. Such dimensions are necessary for the non-standardized nature of the thin-film module market, which also requires the capability to handle larger module sizes. According to Reed, PVB seems to be better suited to new processes.

In the case of large-area modules, a pre-nip oven heats and softens the PVB sheet before the de-airing process using nip rollers. The PVB is then baked to a higher temperature in the sequential ovens and pressed by a second set of nip rollers to seal the front and back glass panels. The autoclave process therefore evenly dissolves residual air into PVB.

However, it is not all plain sailing when new formulations are developed. Reed noted that to effectively evaluate material improvements for customers, it can often be challenging to arrange for time on the customer's production floor to test out the materials. This is compounded by the fact that even with the so-called thin-film 'turnkey' lines, nearly all of these lines operate and perform differently.

"This is not a simple recipe that can be acquired and dialled in. We try and discuss with customers requirements in productivity, in an effort to optimise the lines as well as long-term resistivity and longevity of the module.

"They have to open up the module design books to deal with the current cost competitiveness of crystalline modules. However, although polyvinyl butyral has a cost advantage over EVA, it also comes down to making the film more active compared to its traditional passive role."

Like others interviewed for this feature, Reed believes that optimization of materials will continue only for the next several years and will definitely improve the productivity of the module production line, such as film relaxation due to roll-handling tension generation. Reed also conforms to the argument that only the development of new materials and processes will see a step-function improvement in the laminator's ability to significantly lower costs.

A firm steeped in optimization of materials and processes for volume production environments is Mettler Toledo. While speaking with Michael Zemo, Market Manager for Materials Characterization at the company, it soon became apparent that with the continued process optimization work being carried out, there is a need for characterization tools – especially in the field of thermal analysis – that would aid both equipment suppliers and module manufacturers.

Zemo noted that by using differential scanning calorimetry (DSC) to provide structural information about the encapsulant material being processed, greater understanding of process parameters would enable improved process optimization.

"The most common question we are asked is 'I want to fully cure this material in the shortest time possible – how do I do this?' We end up taking engineers step-by-step through the process of how to go about modelling that approach using a DSC."

Gaining the correct curing profile of the material is the first step, according to Zemo, followed by correlating that information to your process flow and tool.

"When you are in a conservative industry and you chose a coating that allows for a reasonably wide process window, it can give you a false sense of security, especially in relation to overall product reliability once in the field."

Ultimately, what is required is a complete drill-down on process optimization that eliminates all variability that could impact quality of process, while providing the lowest manufacturing cost.

## Conclusion

Currently, machine and material innovation is ongoing, especially in respect to optimization of the lamination process, which is inline with the conservative approach of module manufacturers. It would seem that this strategy has several more years to continue to boost productivity and reduce costs. However, a step-function improvement will be required to deal with falling module prices and continued conformance with lifetime module guarantees.