Turning lemons into lemonade: Opportunities in the turbulent PV equipment market

Fatima Toor, Lux Research Inc. Boston, Massachusetts, USA

ABSTRACT
Production equipment is the backbone of the PV industry, but the equipment sector is suffering because of overcapacity. The 2012 global capacity utilization is at 55% for crystalline silicon (x-Si) module production, 70% for cadmium telluride (CdTe) and 80% for copper indium gallium (di)selenide (CIGS). Under these market conditions, there are almost no expected capacity expansions in the near term. The overcapacity has driven the average selling price (ASP) for modules significantly lower, resulting in hyper-competition in the PV industry, where almost all PV companies recognize the importance of product differentiation while still reducing costs. These market conditions present an opportunity for equipment manufacturers to differentiate their offerings through enabling lower production costs and higher efficiency of cells and modules.

Geographical distribution of equipment manufacturers

Lux Research surveyed, via primary and secondary research, 493 PV equipment manufacturers for various PV technologies and value chains in order to analyze global trends; it was found that 28% of PV equipment manufacturers are based in China, while 20% are based in Germany (see Fig. 1). It is important to note that, to date, the revenues of German and US equipment manufacturers have been ahead of their Chinese counterparts. This trend, however, might be changing. From conversations with equipment manufacturers, it was ascertained that the number of Chinese equipment manufacturers is growing; some of these simply replicate equipment designs, while others introduce their own and are engineering to current equipment designs to compete with Western equipment manufacturers. The Chinese will be able to sell cheap equipment, which stiffens the competition for Western equipment manufacturers. The latter will therefore need to reduce equipment costs while differentiating. Overall, there are short-term sales opportunities for equipment manufacturers when cell and module manufacturers try to differentiate their products and long-term opportunities as global solar capacity grows in dominant and emerging geographies.

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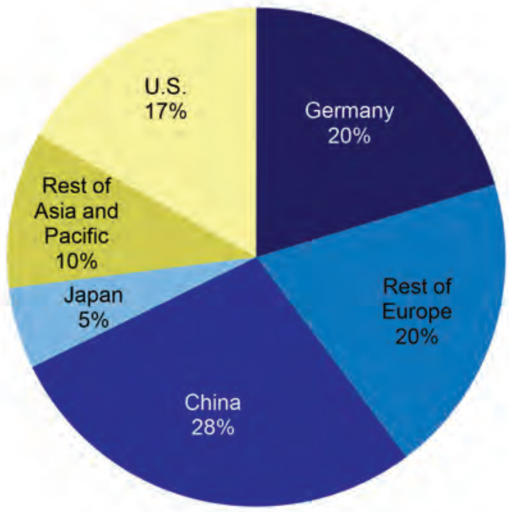

Source: Lux Research

Figure 1. Geographical distribution of 493 surveyed PV equipment manufacturers, with Asia/Pacific comprising 43%.

Room for improvement in PV manufacturing processes

The drive by the PV module producers to reduce production costs and increase efficiencies provides an opportunity for equipment manufacturers. Existing production processes across the existing PV technologies – x-Si, CIGS and CdTe – are non-optimum and there is room for significant improvement. Some of the opportunities for each technology segment are:

- Monocrystalline silicon (c-Si) ingot growth using Czochralski (Cz) pullers is too costly, too much silicon is wasted in wafer sawing, standard cell designs lose 10% to 12% of absolute efficiency from their highest efficiency potential, and module manufacturing remains unnecessarily labour intensive. The opportunity for improvement is glaringly obvious in terms of manufacturing processes and equipment to improve cell efficiencies and reduce production costs.
- CIGS and CdTe thin-film technologies rely on custom equipment because of the importance of process parameters for each individual process step. The two largest cost contributors in CIGS and CdTe production are equipment and materials costs. While CIGS and CdTe producers are aiming for high module efficiencies to maintain competition with current x-Si technologies, there is a need for reduction in capital equipment and materials costs.
- Idle capacity within PV companies allows them to upgrade polysilicon,

ingot, wafer, cell and module lines, assuming appropriate cash balances. These upgrades will enable long-term survival of the key PV industry manufacturers, since they will be able to differentiate their products from standard offerings. Those who sit idle while their equipment idles are sealing their fate.

Requirement for new equipment to drive down production costs

There are opportunities across the entire PV value chain for optimizing production processes to reduce manufacturing costs and improve cell and module efficiencies. Fig. 2 shows a snapshot of some innovative technologies across the PV value chain that will not only enable differentiation for the PV manufacturers but also provide opportunities for equipment manufacturers. This should not be taken as a comprehensive list: Lux Research's report [1] covers many other examples of innovative technologies in addition to the ones included in Fig. 2. Each of the innovative technology areas in Fig. 2, along with the corresponding equipment opportunities they offer, will be discussed next.

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Fluidized bed reactor (FBR) polysilicon growth

According to the Lux Research Solar Supply Tracker [2], Siemens is the most popular industry process for polysilicon production, maintaining 88% of the market share; the fluidized bed reactor (FBR) maintains 6% of the market, and the rest are various UMG-Si processes. The FBR process uses only one-sixth of the energy required by the Siemens process, but current process complexity prevents it from becoming mainstream. Two major polysilicon manufacturers, MEMC and REC, use the FBR process for polysilicon production; recently GCL-Poly, the world's number one polysilicon manufacturer in terms of capacity, announced it was developing FBR technology to reduce production costs.

Three key advantages of FBR over the Siemens process are: 1) a lower energy requirement of 10kWh/kg because of a low-temperature (800°C) process; 2) continuous processing instead of batch processing as in the Siemens process; and 3) higher material yields than Siemens. The end product is polysilicon granules with a 1mm diameter, which can be packed more densely in an ingot crucible than the polysilicon chunks produced by the Siemens process.

Even with these advantages, FBR remains uncommon. There are several reasons for FBR's small market share: most notably no off-the-shelf FBR reactors are available and it suffers from process complexity in that the Si granules can be easily polluted by impurities. There is therefore an opportunity for equipment manufacturers to develop off-the-shelf FBR equipment that will enable reduced production costs for polysilicon.

Quasi-monocrystalline silicon (qc-Si) ingot growth

During recent visits to solar conferences, Lux Research observed that numerous leading wafer, cell and module manufacturers are using quasi-monocrystalline (qc-Si) wafers. The advantage of qc-Si ingots is that, with a small retrofit change to existing directional solidification (DS) furnaces, ingot manufacturers can produce wafers with a performance closer to that obtained by conventional Cz c-Si wafers but at a cost similar to that for mc-Si wafers.

In qc-Si ingot growth, c-Si seed is used for the ingot-casting process to obtain c-Si and mc-Si material consecutively. The qc-Si ingot growth process uses DS furnaces. However, a c-Si seed plate is used at the bottom of the crucible, and then the molten silicon poured into the crucible is directionally solidified with tight temperature control. The seed plate has several crystal grains on the edges, while the centre is formed of a single crystal: this occurs because it is difficult to control the temperature profile on the edges of the crucible.

The resulting ingot has mc-Si material on the edges of the ingot, while the majority of the ingot is c-Si. An advantage of this ingot growth is also that the c-Si wafers obtained from the centre of the ingot are square instead of pseudo-square, as in the traditional mono process, which typically yields a wafer with rounded corners, resulting in reduced active area in the module. According to the Lux Research cost model, qc-Si ingot growth results in around $0.10/W cost saving relative to Cz c-Si growth.

Because of all these factors, ingot and wafer manufacturers are already upgrading their existing DS furnaces used for mc-Si growth to switch to qc-Si ingot growth that enables high-quality silicon and square c-Si wafers at a fraction of the cost of Cz c-Si wafers. GT Solar and AMG Idealcast are ahead of the game, in offering qc-Si ingot growth furnaces to their customers. Other equipment manufacturers will follow, creating more sourcing options for ingot manufacturers, while placing the onus on the equipment providers to compete in price or differentiate in mono-to-multicrystalline yield ratios.

Epitaxial silicon (epi-Si) wafers and cells

Epi-Si, which is thin crystalline silicon, is becoming an increasingly popular technology: several start-ups are working on various different types of epi-Si, including epi-Si on substrates and epi-Si growth and peel. One start-up that stands out is Solexel, who recently announced a 156mm × 156mm, 20.6%-efficient cell based on its epi-Si growth-and-peel technology. Epi-Si reduces the Si costs significantly but has high capex requirements. However, it is important to note that Solexel integrates the back-contact cell design processing before the substrate attachment and then peels off the entire cell structure; this results in an overall cost saving for wafer and cell manufacturing. Solexel plans to enter the market with a 20% module efficiency by 2014, with manufacturing cost at the $0.42/W level.

Figure 2. Example innovations across the entire PV value chain providing opportunities for equipment manufacturers.

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Epi-Si techniques use a combination of standard and custom equipment, which presents an opportunity for equipment manufacturers who would like to develop differentiated equipment.

High-efficiency crystalline silicon cell designs

Standard crystalline silicon (x-Si) cells are sub-optimal in terms of their design, because they suffer from shading losses due to the front metallization, and recombination losses in the bulk, front and back surfaces of the x-Si cell. These effects result in almost 10–12% absolute efficiency loss (assuming an x-Si efficiency potential of 27–29%). Given the significant room for improvement, several companies are working on improving cell efficiencies using various designs that reduce shading and recombination losses. These cell designs include heterojunction with intrinsic (HIT), passivated-emitter rear cell (PERC), selective emitter (SE), interdigitated back contact (IBC) and metal wrap-through (MWT). All of these designs offer an opportunity for equipment manufacturers to develop equipment that enables high performance, but at the same time a reduction in cost.

Some companies already have a lead in providing equipment for manufacturing high-efficiency cell designs, including Meyer Burger and Applied Materials, and others are following suit. Among cell designs that will see growth in their market share will be PERC, HIT and SE because these do not require different module packaging from that for standard cells. Equipment manufacturers should therefore target their equipment offerings to facilitate the implementation of these cell designs. Most of the designs require upgrades to existing production lines, presenting a short-term revenue-generating opportunity for equipment manufacturers.

EVA-free vacuum encapsulation of PV modules

In PV technology it is not just about the $/W but also the $/kWh: in other words, module cost and lifetime are both critical. The most common encapsulant in module packaging is ethylene vinyl acetate (EVA), which is known to yellow over time and decompose to acetic acid, causing corrosion of metal contacts and an overall reduction in module performance. EVA-free vacuum encapsulation can eliminate these issues and prolong the life of modules.

Apollon Solar is one equipment manufacturer developing an EVA-free vacuum encapsulation technology, dubbed 'new industrial solar cell encapsulation,' or NICE. Traditional modules encapsulate the cells between two layers of EVA, which is then protected by the front glass and a backsheet. Taking advantage of technology used by insulating glass manufacturers, Apollon Solar vacuum-seals the cells between two sheets of glass using a sealing process requiring 120°C of localized heat. A thermoplastic spacer (TPS) is placed between the sheets of glass to hermetically seal the module and keep the glass sheets from crushing the cells; the TPS is placed only along the edges of the module and also acts as an edge sealant.

The resulting modules have passed International Electrotechnical Commission (IEC) environmental and degradation tests, and further testing has been carried out to prove that these modules are more robust than traditional modules. Apollon Solar claims cost-of-ownership savings between $0.13/W and $0.16/W. Innovative module packaging technologies, which reduce costs while improving module lifetimes, therefore provide an opportunity for equipment manufacturers.

Near- and long-term outlook for PV equipment industry

The overcapacity in the PV industry has reduced utilization to an all-time low. Contrary to the general consensus, idle capacity is an opportunity in the near and long term for PV manufacturers to upgrade to high-performance products, assuming that funding is available. The current low capacity utilization in the PV industry should and will trigger equipment upgrades across the entire value chain, starting from high-purity polysilicon production upgrades to upgrades for high-efficiency cell and module designs. These upgrades will grow demand for differentiated PV equipment, enabling the long-term survival of innovative PV industry manufacturers and the equipment providers that help them to do so.

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Moreover, while there may be tremendous overcapacity in China, as PV demand grows in emerging markets such as India, South America and the Middle East, PV equipment manufacturers will sell equipment to these markets to an increasing extent. Equipment manufacturers' business development operations should look to these geographies now while their sales teams should renew their passports or start scouting for local talent to position for growth.

References

[1] Lux Research 2012, State of the Market Report [available online at https://portal.luxresearchinc.com/research/report/11731].

[2] Lux Research 2012, Solar Supply Tracker [available online at https://portal.luxresearchinc.com/data_trackers/6].

About the Author

Fatima Toor is an analyst at Lux Research and leads the Solar Components Intelligence Service. Along with her team she helps clients – Innovation 1000 corporations, leading institutional investors, utilities and public policy makers – make better strategic decisions and monitor the ever-changing global solar market. Prior to joining Lux Research, she was a postdoctoral researcher in the Silicon Materials and Devices group at the National Renewable Energy Lab (NREL). Fatima obtained her Ph.D. and M.A. in electrical engineering from Princeton University.

Enquiries

Lux Research Inc.
234 Congress St.
5th Floor
Boston, MA 02110
USA

Email: fatima.toor@luxresearchinc.com
Website: www.luxresearchinc.com