Special feature: Solyndra comes out of stealth mode with cylindrical approach to CIGS thin-film photovoltaics

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ABSTRACT

Until recently, Solyndra had been one of the stealthiest thin-film photovoltaics operators, its glistening, prominently logoed headquarters building reminding tech-savvy commuters plowing up and down the I-880 corridor near Fremont, CA, of how little they knew about the company. But Solyndra has finally let the sunshine in and come out of the closet – even if it hasn't quite changed some of its stealthy ways. After a well-planned media and analyst rollout, the public knows that for this copper-indium-gallium-(di)selenide (CIGS) thin-film PV manufacturer, the world – or at least its solar-module form factor – is not flat. Like many TFPV purveyors, Solyndra loves glass as a substrate, but the company's meter-long CIGS-coated cylindrical modules look like a fluorescent light-bulb tube, not just another rectangular slab of the smooth stuff.

Tubular PV for the commercial rooftop market

During a recent visit to Solyndra (see Figure 1), Chris Gronet and Kelly Truman, the company's CEO and VP of Marketing/Sales/Business Development, told me about Solyndra's technology and manufacturing and its plans for targeting the commercial rooftop sector. Gronet says the market potential adds up to 30 billion square feet in the U.S. alone, translating into potential electricity capacity of 150GW and a PV market of around US$650 billion. With more than a billion square feet of CoolRoof and other reflective roofing material being put down every year in the U.S., the opportunity to turn rooftop space into revenue-generating PV exists today.

Gronet showed me one of the tubular modules, the critical element that has captured the attention of venture capitalists and private equity investors who've sunk about US$600 million so

Courtesy of Tom Cheyney

Figure 1. Solyndra's Fremont, CA, headquarters sits alongside the I-880 freeway.

far into Solyndra (see Figure 2). The glass cylinder is black, about an inch or so in circumference and is actually a tube within a tube. One can see that the inner CIGS portion of the monolithically integrated device has a series of swirling helical scribe lines, differentiating the 150 cells within. Between the inner and outer glass cylinders, a common industrial liquid described by the exec as an "optical coupling agent" fills the cavity and actually creates a modest concentrator effect – about 1.5x – when struck by sunlight.

There are no moving parts, as the sunlight automatically refracts through the outer tube to the inner substrate where the absorber layers do their thing. The endcaps are the only mechanical part, which are hermetically sealed using a proprietary glass-to-metal process (with no elastomers involved) that is then helium-leak-tested, according to the CEO.

Being tubular has its advantages when it comes to PV, says Gronet. Photons are not only collected directly from all angles, a kind of "self-tracking" mechanism, but diffused light is also harvested from almost every direction, and the sun's rays that don't get absorbed by the PV cylinder at first are captured when they reflect off the white membrane underneath (see Figure 3). The circular design also provides convective cooling advantages and the tubes don't get as dirty on the roof as conventional flat-plate units.

When pressed about the thicknesses of the various film layers, Gronet claimed Solyndra "has the thinnest layers of anyone out there... the absorber layer is about a factor of two thinner" than competing technologies. Since the CIGS stack is generally in the 1.0 to 2.5 micron range, and you can't go too much thinner than a micron, it's likely Solyndra is achieving something slightly submicron with its co-evaporation process. By using less of the active materials, the company reduces its deposition process times and thus might boost throughputs and bring down overall manufacturing costs.

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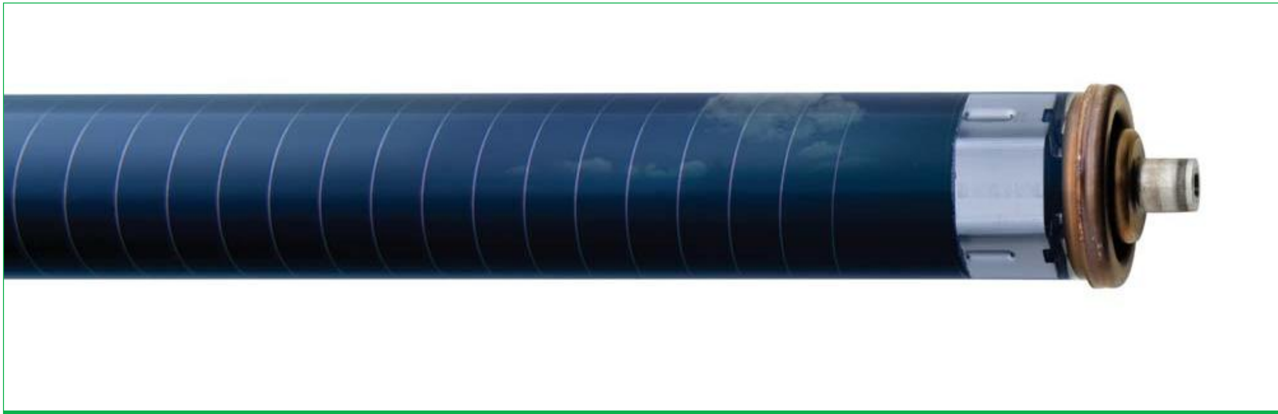
As for conversion efficiencies, the CEO cites figures in the "12-14% range" for the inner cell. But he wouldn't discuss the module- or panel-level numbers, saying that "we don't measure efficiency at the module level" because of the widely varying "rooftop efficiencies" caused by different temperature, wind and sun conditions. He also stressed the company's focus on the system as a whole, not the components therein.

While much of the solar industry uses "module" and "panel" interchangeably, Solyndra has instituted its own differentiating nomenclature. Forty of the tubes or "modules" are mounted in what Solyndra calls its "panel," a 1.8 meter long by 1.08 meter wide, relatively simple non-penetrating framework that sits flat about a foot off the roof. The whole unit weighs about 32kg (70lbs).

Traditionally, the total expense of installed PV comes about half from the price of the manufactured panel and half from the cost of installation. While Gronet would not disclose Solyndra's current or projected cost per manufactured watt for its modules and panels, he did tout the system's simple design, ease of installation and superior electricity output per rooftop (see Figure 4).

He says that customers have validated that the Solyndra racks can be installed in one-third the time of a normal flat plate PV system, at about half the cost. The panels seem easy to carry and the proprietary mount hardware can be bolted down with simple hand or power tools. It doesn't take much time to place the panels, plug in the DC connectors and set up the ground strap. To connect one panel to another, a clip does the trick.



Courtesy of Solyndra

Figure 2. Solyndra's cylinidrical PV modules include 150 CIGS cells and a proprietary glass-to-metal endcap seal.

Each non-penetrating system is self-ballasted. The mounting design follows the contours of the average not-so-flat flat roof, Truman told me, and allows the panels to sit over most low-lying obstructions. A team of five workers can install about 40KW of Solyndra panels in a day, according to Gronet, and the system is as easy to take apart as it is to put together, offering mobility and flexibility for those who might want to move the PV to another location or do some work on the roof itself.

A highly automated manufacturing facility

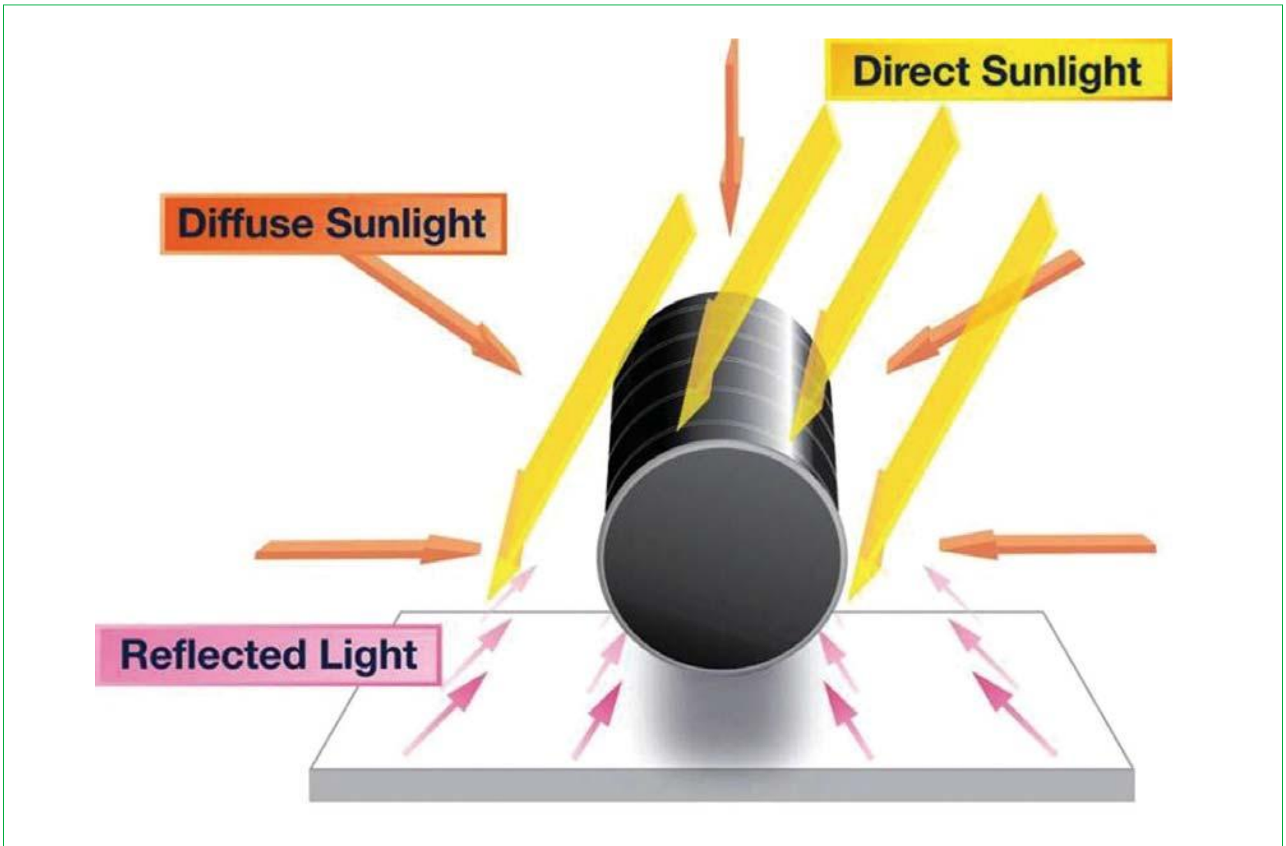
When you enter Solyndra's Fab 1, you notice a few things right off the bat. It's a biggish facility, but not mega-scale, with about 180,000 square feet of factory floor and related manufacturing space. Floor space is at a premium, with little room left for more tools. The conditions are tidy, but not ultraclean, nowhere near the stringent contamination control specs of a semiconductor or a hard-disk-drive fab.

The fab is highly automated with robots and conveyor systems of various sizes and shapes--from AGVs scurrying past on the floor to large, strong-armed palletizing robots, their limbs moving around with that mindless yet almost anthropomorphic precision of the industrial robot class (see Figure 5). Scores of 25-high stacks of tube-module trays, each holding 48 CIGS PV cylinders, are grouped on the floor in various spots.

The company took the keys to the Fremont facility in February 2007, and after some construction and equipment installation, had its first PV tube modules coming off the line by late summer of that year, according to Truman. Over the next year, the team focused on improving tube performance and enhancing yields.

Gronet told me that the first volume shipments of Solyndra's panels began in July 2008. At least 15 beta sites are running in the U.S. and Europe to validate the system's performance.

The company puts a nameplate capacity of 110MW on what it calls its "front-end" fab. It has borrowed this terminology from the chipmaking realm to differentiate its core CIGS tube production from the "back-end" processing down the road in Milpitas, where an outer tube sheaths the inner one, the unit's endcaps are plugged in and sealed, the optical coupling liquid is injected between the inner and outer tubes and the finished cylinder modules are inserted in the panel arrays, 40 at a time.



Courtesy of Solyndra

Figure 3. The tubular design of Solyndra's modules optimizes the collection of direct, diffuse, and reflected sunlight.

Because Solyndra's front-end fab building once housed a succession of HDD fabs, it was not purpose built for the company's process. The floor plan isn't bad, especially with the level of automation helping out, but the flow is less than optimal. Truman told me that in the second factory, they "will do the layout optimally for the logistics."

He leads me around to the large, multi-dunk-tank cleaning equipment where the incoming soda-lime glass tubes are cleaned and prepped for process. Truman pointed out that there's quite a bit of worldwide capacity with this kind of glass since the medtech/pharma crowd has been switching over to plastic for their test tubes and vials. "We actually have a segment of the glass industry where there's an excess of supply," he related.

The robots transport the tubes to the molybdenum deposition tool, where, like with CIGS done on flat glass or flexible foil, the metallic back contacts are put down on the glass substrates. The individually RFIDed tubes are rotated, with careful attention to film uniformity. The Solyndra fab boasts a proprietary manufacturing control system with an arsenal of sensors, creating a closed-loop metrology system reminiscent of a flat-panel display or chipmaking plant.

"We have alot of custom metrology in these things," Truman explained. "At every step of the way every tube is tested, whether it's in deposition or scribing for the monolithic integration. Even during our monolithic integration steps, there are metrology devices on the head of the scribing machines measuring a variety of properties as we go along. Every tube is tracked through the automation system and through every aspect of the deposition – each tube has its own identifier."

After the moly layers are deposited and a quick patterning-step is completed, the PV cylinders are robotically transported to the most important equipment set on the floor – the CIGS absorber tool. Solyndra designed and built (with the help of subcontractors) the 45MW system, which boasts an impressive footprint, stretching about 100 feet. The company uses the co-evaporation approach to lay down its copper, indium, gallium and (di)selenide because, as Gronet reminded me, the highest conversion efficiencies for CIGS have been achieved using that type of deposition.

Once the CIGS film stack has been put down, the tubes move to the junction partner/buffer layer tool. The company uses a proprietary wet solution process here, in which the tubes are spray-coated with nanometer-scale layers of cadmium sulfide (although there's apparently work going on to make the buffer cadmium-free). Finally, the transparent conductive oxide (TCO) topcoat, reportedly an optimized i-ZnO/Al:ZnO cocktail, is sputtered on.

Then the tubes are moved to Solyndra's proprietary laser-scribing tools for the monolithic integration process. Truman told me that the scribes, done six tubes at a time, are mostly helical, with "one linear scribe done at the very end to define each cell." He showed me how the individual cells, rather than being cylindrical per se, are slightly curved in a croissant-like shape.

Before the cylinders are sent down to the back-end facility for packaging and paneling, each one is tested for its performance, electrical output and the like on a tool familiar to any PV manufacturer – the solar simulator and its pulsing bright lights.

Impressive debut, but questions remain

Solyndra's launch story may be impressive, but there remain several areas of concern in need of clarification so that the company's prospects for success can be more comprehensively evaluated.

Aside from the difficulties facing any manufacturer seeking capital during the emerging global recession, Solyndra could be more open about the actual retail or wholesale price tags of the panels and systems. There's been ample lip service paid to the company's ability to drive toward a variety of definitions of unsubsidized grid parity, but without those dollar figures, we have to take their word for it.

They also aren't ready to talk about their current cost-per-watt manufacturing metric, let alone the roadmap to getting to that buck-a-watt sweetspot and beyond. They may have a fully

Courtesy of Solyndra

Figure 4. Solyndra claims installation of its rooftop PV panels can be done in about one-third the time and one-half the cost of traditional flat-plate module systems.

Courtesy of Solyndra

Figure 5. Solyndra's highly automated fab features a proprietary manufacturing and process control system.

automated, highly controlled, even high yielding factory and a proprietary process that uses less absorber materials than other CIGS schemes, but what was on the fab floor did not strike me as a disruptively inexpensive approach. Three out of the four main process steps use vacuum deposition, the other (for the junction partner/buffer layer) employs a wet-spray technique – none of which screams "low-cost manufacturing solution."

The claimed 12-14% conversion efficiencies for Solyndra's tube modules are certainly competitive with other CIGS, CdTe and amorphous-silicon TFPV players and even match up well with the low end of the crystalline silicon module spectrum. But what's lacking is a third-party, NREL or NREL-like evaluation of the cylinders' efficiencies, let alone any efficiency numbers for the panels or reporting on the tightness of their product's overall efficiency distribution curve.

Of course, the actual geographics and climatic placement of the PV systems have a big impact on their ultimate efficiencies and at the end of the day, it's about the electricity produced by the panels, not just how well they convert those photons to electrons. But there's a bit of gamesmanship in Solyndra's refusal to play by the established rules of stated conversion efficiencies.

The ingenious glass-to-metal sealed end-cap on each tube seems to be an elegant, robust approach to keeping CIGS-killing moisture out. But can the hermetically sealed caps survive the necessary 20 to 25 years and demonstrate the level of reliability needed to compete with silicon and other thin-film PV? The Solyndra systems have all been run through their testing paces and they apparently passed with flying colors. But testing's one thing, actual field life is another.

Then there's the question of scalability. The initial 40MW line in Fab 1 is running close to capacity, I'm told. The second line – the to-be-standard 70MW – is still a work in progress, with a limited amount of product coming off of it and heading for the back-end facility. Some tools remain in what Truman called "various stages of startup." The plan is to build out capacity in the second fab (and future ones) in increments of 70MW, cookie cutter-style.

Before building out the new factory, the Solyndra crew has to crank up the initial 70MW line in a timely, high-yielding manner. Some CIGS aficionados question the ultimate ability of a co-evaporation-style process like that in use at the Fremont fab to scale economically to high volume. At the end of the day, nameplate is not the same as run rate. PV factories of many flavors are notorious for their low capacity utilization numbers, and CIGS companies still have yet to prove their high-volume, 100MW-plus production mettle.

Despite these questions, with US$1.2 billion in orders already booked, the likes of customers Phoenix Solar, Solar Power Inc. and GeckoLogic must obviously believe in the company and its product. Solyndra must now demonstrate a First Solar-like focus on executing the remaining ramp of its first fab and then building, equipping, and scaling its planned six-line, 420MW factory up in order to take its place in the photovoltaic pantheon.

This feature is an abridged/edited version of a three-part blog series on Solyndra that originally appeared on PV-Tech.org.