Concentrator photovoltaics ramps up, as project momentum accelerates and production cells enter age of 40% efficiency

By **Tom Cheyney**

Photo by Carlos Alejandro, courtesy of Amonix

Tracking the desert sun, a 2MW array of Amonix CPV systems generates clean electricity at the science and technology park at the University of Arizona (Tucson, AZ, USA).

There are still a lot of "ifs" when it comes to concentrator photovoltaics, but it's starting to look like the question of "when" the technology will start to gain serious market traction may be sooner than some think. With tens of megawatts of projects either recently finished, under construction, or in the last phases of project development — and hundreds more MWs in the longer-term pipeline — deployment of the high-efficiency systems may reach triple digits by the end of 2011 or beginning of 2012. On the technology front, as many as a half-dozen cell companies are bringing 40%-efficient cells to market this year, which will help to further reduce CPV's increasingly compelling levelized cost of energy.

When you talk about systems companies, none is bigger than the most experienced CPV player, Amonix — both in terms of its installed base of operational power plants and the size of its massive wall of megamodules on a pylon, the 7700 platform. During a presentation at the recent CPV-7 conference in Las Vegas, company R&D director Geoff Kinsey said that the beast (my term, not his), currently rated at 60KW with 27% efficiency, has been operating in the field above both its rating and its predicted performance, with no sign of degradation. Data from a Colorado site find the system hitting 70KW in the high DNI area.

Until recently, spectrally tuned multijunction CPV cells weren't on the menu, but that's changed significantly over the past few years, he noted. There are now multiple sources of high energy yield cells that are modelled to exceed the performance of currently deployed devices. Amonix is evaluating seven incumbent and newcomer vendors, with plans to integrate some of those cells into production in 2011.

The Seal Beach, CA-based company also expects to transition from 100mm (4-inch) to 150mm (6-inch) wafers this year. With a superior "packing fraction," the 2.25× larger substrate size should yield about a 2.5× increase in the number of cells per wafer and provide a substantial cost reduction, he explained.

The already robust PMMA Fresnel lens used by Amonix will be enhanced with better UV durability and lifetime, as well as higher optical efficiency. Recent tests conducted on some 10-year-old optics pulled from the field showed the material's mean optical efficiency had dropped from 85% to 81%, when compared with a new lens of the same type — an annual degradation rate of 0.4%.

With the combination of higher performance cells, improved optics, optimized concentration levels and advanced thermal management, the next-gen modules will reach at least 32% efficiency sometime this year, according to Kinsey.

Multiple projects have just been completed, are being built, or will soon see shovels in action, including the recently energized 36 arrays making up the 2MW (AC) system on 12 acres of the Solar Zone at the University of Arizona's Science and Technology Park in Tucson. A time-lapse video (which can be found on YouTube) reveals the rapidity of the final part of the construction process, as towering cranes place a half-megawatt per day of 7700s to complete the installation.

Although he wouldn't comment on the specifics of projects under construction, CEO Brian Robertson told me that Amonix's factories are running flat out as the company ramps production to meet the demand pull. One of those sites he wouldn't discuss, the major 30MW field developed/constructed by Cogentrix Energy in Alamosa, CO, seems to be a major reason for the CPV manufacturing floor hustle and bustle.

While Amonix thinks big, Energy Innovations pursues a smaller-scale deployment approach with its dual-axis-tracked, 1200×-concentration single-module Sunflower systems. The Poway, CA-based firm has been relatively quiet of late and didn't make any presentations at CPV-7, but several members of its team were on hand at the conference, including CEO Joe Budano.

Up to almost three full work shifts at its factory, EI's first semiautomated line is fully built out and "cranking out modules," with a couple more automation production "cells" arriving soon, he said. The current 29%-efficient 270W units will be superseded by 300W models later this year; the higher-rated modules, which will be its first equipped with Spectrolab C3MJ+ cells, have been submitted for certification.

Although the company's supply chain is robust, some minor ripple effects from the Japanese earthquake/tsunami were seen, he revealed, with components like power FET devices (used in DC-DC converters) a bit tight and one robotics vendor relating that it was having trouble getting certain kinds of motors.

While "entertaining" possible 20, 40, and 60MW utility-scale installations in 2012 and beyond, he told me that the real sweet spots for his company reside within the distributed-commercial market — on warehouse and distribution center rooftops, ground-mount installations, and especially carports and truckports. If you had asked Budano two years ago what the company's primary strategy was, it would not have been carports. But he believes the segment has huge upside.

Among several projects under way, a 600kW site in Palm Desert is split 50:50 between ground-mount and carport systems. Compared to a flat-plate PV carport array which can't be tilted much beyond 5° because of wind load issues, he said the Sunflower produces 50% more energy, thanks to its higher efficiency and ability to track the sun throughout the day. Another positive aspect of the carport market that he pointed out is its relative simplicity compared to rooftops, which require more engineering and can present a host of difficulties, such as insufficient weight-bearing load factors and complex roof architectures. Almost totally turnkey, a carport deal can be sold and an installation begun with a much shorter cycle time than a rooftop project.

The chief exec said the company will have 12MW installed (mostly groundmount and carport) in the US and a few overseas locales within the next year or so. Noting the tendency in the market to label Amonix, SolFocus, and Soitec (Concentrix) as the "big three" CPV systems companies, Budano thinks it's time to expand the list to four and include Energy Innovations, given its 10 years of experience and recent success pursuing its differentiated market strategy.

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One thing all CPV systems firms have in common is the need for ever-increasing conversion efficiencies in the III-V multijunction cells at the heart of their power platforms. Even a slight increase in efficiency leads to a significant performance enhancement and reduction in the cost of overall energy production.

The company touting the top NREL-validated III-V multijunction solar cell conversion efficiency results — Solar Junction — kept a low profile at the CPV-7 conference, while just about every other cell developer and manufacturer made an appearance at the event. The newcomer's news that its "production-ready" 5.5 × 5.5mm spectrally adjustable cell hit a record-breaking 43.5% at >400 suns came on the heels of most of the other CPV cell players announcing that they were — or soon will be — at 40% efficiencies in manufacturing.

Although Solar Junction deserves kudos for cracking 43% and then some, there's a difference between what the start-up calls "production-ready" cells and other companies' cells that are actually in production and scaling. Until the new guys crank up a commercial manufacturing line (which they say will be done within a year) and get those kinds of eye-popping efficiencies consistently, at high yields and at relatively low costs, and then ship them in volume and see them perform reliably in the field, the NREL measurement lab results offer little more than bragging rights.

When it comes to the existing commercial CPV cell players, the conversation has to start with Spectrolab. The Boeing unit has more III-Vs embedded in deployed, under-sun concentrator systems than any other supplier. While Amonix, SolFocus, the newly rebranded Soitec Solar, Energy Innovations, and other systems companies may be working closely with the likes of Solar Junction, QuantaSol, Cyrium, JDS Uniphase, RFMD, and other new entrants, all of them count on Spectrolab cells for their current needs.

Russ Jones told me that the company released its 40%-efficient C4MJ cells into production in early March. Although there are not enough data available yet to analyze the efficiency distributions coming off the line, thousands of cells were qualified at 40%. The mainstreaming lattice-matched C3MJ+cell, which started production in October and has shipped since early 2011, has achieved average efficiencies of 39.2% across several hundred thousand units manufactured so far.

Since the C4MJ cells are the first employing an upright metamorphic device structure, he explained that a more extensive qualification program was needed — as in 2 million cell-hours on sun — in order to thoroughly check reliability and degradation on the widgets. As for those degradation rates, they've been found to be comparable to other cells made by the company. The business development director said that Spectrolab is taking orders for the C4MJs and has recently shipped the first batches to several customers. The new cells will likely start to show up in deployed CPV systems by the end of this year or the beginning of 2012.

Azur Space, the European incumbent III-V cell maker and veteran of the extraterrestrial and now terrestrial sectors, has also claimed membership in the "40%-class" club. Wolfgang Guter told CPV-7 attendees that the company has had its lattice-matched 3C40S (500×) triple-junction cells in production since late 2010. Engineering samples of its upright metamorphic (UMM), current-matched 3C42S (as in 42%) devices currently in development should be available by the end of the year with commercial cells on the market by 2013. The 3C40S cells feature a high-bandgap (1.9eV) top junction, with efficiencies of up to 41.2% seen in custom designs and the best wafers averaging about 40.3% at 500×.

Tunnel diodes are a key part of Azur's high-concentration design, as well as proprietary, customizable antireflective coatings that can be adapted to the reflectivity of the glass. (Note that the company sees broadband ARCs as a critical component of its next-gen UMM cells.) Stressing the narrow distribution of the maximum power current of the in-production devices as well as their customizable form factor (a recurring theme), Guter explained that they could be provided in diced wafers or in dense arrays,

Photo courtesy of Energy Innovations

At a 600kW project in Palm Springs, CA, USA, Energy Innovations is deploying both carport and field-mounted CPV systems.

in quantities from 50 to 3000 cells per wafer.

Azur is also part of what has become a cost-saving trend in the CPV cellmaking and systems community: transitioning from 100mm (4-inch) to 150mm (6-inch) germanium wafers within the next year or so. The first to make the plunge with the larger substrates may not be one of the incumbents, but a formidable newcomer — JDS Uniphase.

No stranger to volume manufacturing of high-tech components due to its experience in the telecom and photonics markets, JDSU has been carefully developing its CPV cell assets for about 2½ years, staying in stealth mode until September 2010. The company doesn't fab its own devices, but outsources production to its foundry partner in Taiwan. The company's Robert Duval told me that while shipments of 100mm wafers have begun, the focus has been on optimizing 150mm for volume production. JDSU is leveraging its previous tech experience to help fine-tune and tailor the process, with an emphasis on dialing in the post-epitaxial steps, such as lithography, as well as wafer automation and process control/yield management strategies.

The cells (which vary in size, but are trending smaller) made on the larger wafers will be qualified during the second quarter, he said, with shipments beginning in the following quarter. To fully scale to volume, a quarter or two would be needed, with no real constraint on the amount of capacity that could be brought to bear. The challenge, he pointed out, is to know where the market is going and calibrate production levels accordingly.

Duval's colleague Jan Werthen said that JDSU's cell performance roadmap puts production efficiencies at around 39% in the first half of 2011, climbing to 40% in the second half, with 1% absolute efficiency increases forecast for 2012 and 2013, respectively. These steady improvements will be accomplished through process optimization of ARCs and grid-lines, as well as innovations in epitaxial reactor design and epi growth techniques, which he described as the primary efficiency driver. All of this will be done on what he called the "6-inch-wafer, triple-junction [InGaP/Ga(In)As/Ge, top to bottom] workhorse," but by the middle of the decade, a fourth and eventually fifth junction will be necessary for the devices to achieve efficiencies into the mid 40s and beyond.

If the CPV cell market does start to blow up and hit 100MW this year (as Werthen and others believe) and then eventually jumps to 1GW in another few years (a transition that will truly test the manufacturing prowess of the industry), there will need to be a consistent, high-volume, high-quality supply of those 150mm substrates.

With the official October opening of Umicore's new germanium wafer facility in Quapaw, OK, the industry leader has added hundreds of megawatts of production capacity to the supply chain, according to the company's Frank Boghe. Most of the current capacity is running 150mm, with much of the 100mm still in qualification. The plant could be expanded from its current level of about 400,000 100mm wafer equivalents per year to 900,000, by using the existing building equipped with additional tools. (That larger amount is equal to about 750MW; gigawatt scale looms at a bit more than 1 million wafers.)

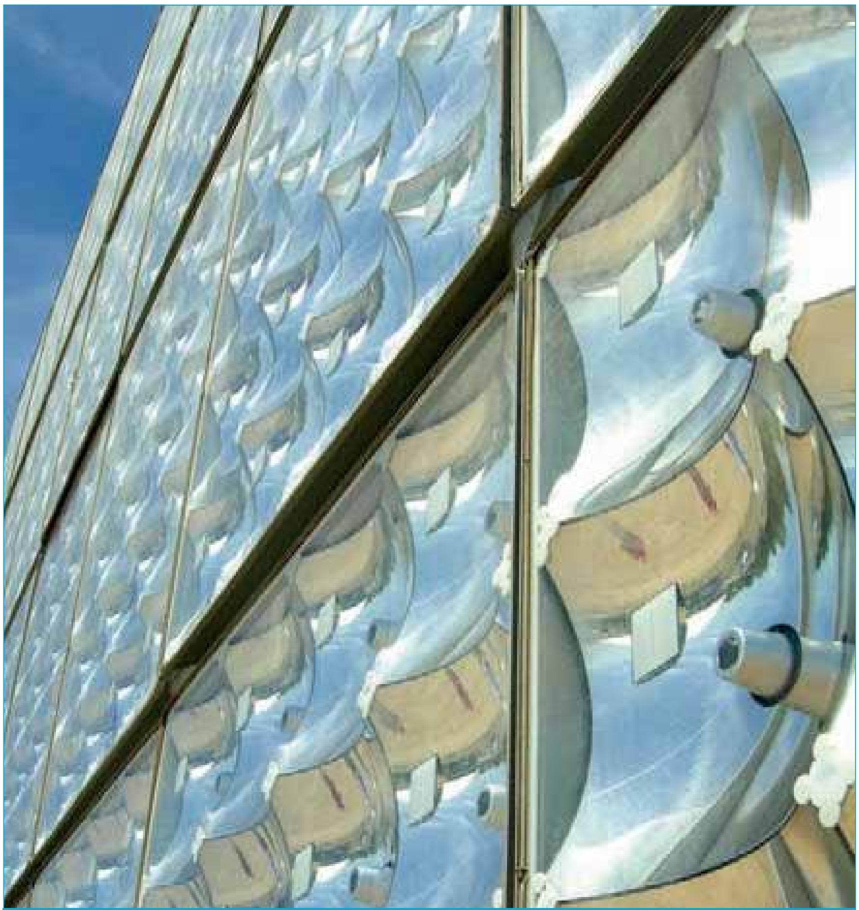

Photo by Tom Cheyney

Hundreds of Spectrolab's high-efficiency III-V solar cells are integrated into each SolFocus CPV array.

Some 70% of the wafers produced at the Oklahoma factory go for satellite projects, about 10% to CPV, and the remaining 20% to LED and other sectors. Boghe sees the concentrator PV sector as the source of future growth, with those market percentages adjusting accordingly. Umicore actually had the new facility up and running for sampling in May, with the first shipments trucked off in October. Four-inch wafers will start shipping in earnest over the next few months, as more customers get qualified.

The production flows on the two lines in Quapaw are similar to those found in more conventional silicon ingot/wafer factories. After converting the germanium oxide into Ge metal, the material is melted, grown, and pulled into ingots via the Czochralski method, resulting in a "zero EPD dislocation-free crystalline structure," according to Boghe. The ingots proceed to the wire-sawing station, where they are cut into thousands of ~175mm-thick wafers, which are laser-marked for tracking purposes as well as ground on the edge and surface areas. The substrates are cleaned before and after the sawing, and expedited to a Class 10,000 cleanroom for polishing to an "epi-ready" level. The wafers then enter a Class 100 cleanroom for a final epi-clean and inspection, with each slice getting eagle-eyed before being packaged and shipped.

Like any self-respecting wafer supplier in the semiconductor and PV sectors, Umicore closely collaborates with its customers to further optimize its substrates for the entire production flow, Boghe noted. Feedback on how the Ge wafers performed on the cellmakers' processes, including their possible impact on manufacturing yields and the like, will become even more important as those valuable slices of compound semiconducting material increase in size from 100mm to 150mm.

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