START-UP OF FIRST 100 kW SYSTEM IN SHANGHAI WITH 3-SUN PV MIRROR MODULES

L. Fraas[1], J. Avery[1], H. Huang[1], L. Minkin[1], R. Corio[2], and J. Fraas[1]
[1]JX Crystals Inc, Issaquah, WA 98027,
[2]Array Technologies, Albuquerque, NM

ABSTRACT

Thanks to funding from the Shanghai City government, Shanghai Import Export Trading Company, and Shanghai Flower Port, we have designed and fabricated in pilot production the first 3-sun 180 W (STC) mirror panels. Three of these panels were first tested in the US showing calibrated PTC ratings of 150 W. Then 24 panels were installed on two 2-axis trackers at the Flower Port in Shanghai. Then 672 panels were installed on a horizontal beam tracker on a building rooftop at the Flower Port. Test results are presented here. These systems performed as expected.

3-SUN MIRROR MODULE CONCEPT

The cost of high purity silicon feedstock today is well over \$50 / kg whereas the cost of aluminum is only about \$2 / kg. Crystal growth adds more cost to the silicon solar cells. Therefore, substituting aluminum mirrors for single crystal cell area can dramatically reduce the cost of a module. This reasoning leads us to the 3-sun module concept shown in figure 1.

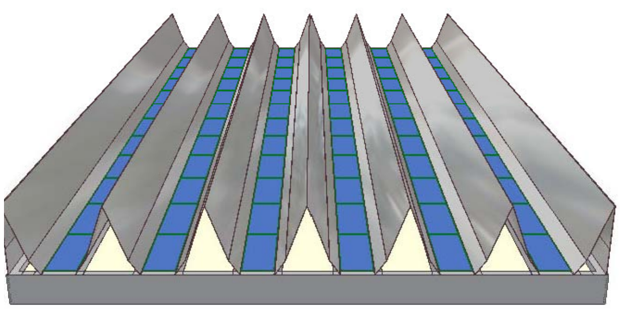

Figure 1: JXC 3-sun mirror module concept.

Our concentrator module design uses existing planar cells. As shown in figure 2, we simply cut standard 125mm x 125mm SunPower A300 cells into thirds. In addition, our module design uses standard circuit lamination procedures and equipment. However, as shown in figure 3, we add a thin aluminum sheet at the back of the laminated circuit for heat spreading. While a standard planar module contains rows of 125mm x 125mm cells, our low concentration modules consist of rows of third-cells with each row now 41.7 mm wide. We then locate linear mirrors with triangular cross sections between the cell rows (figure 1). The mirror facets deflect the sun's rays down to the cell rows.

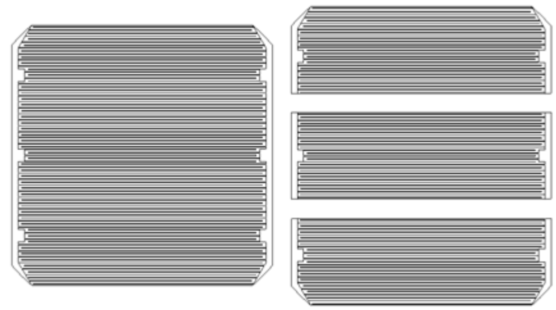

Figure 2: View from the back side of a A300 SunPower cell before and after being cut into 3rd cells.

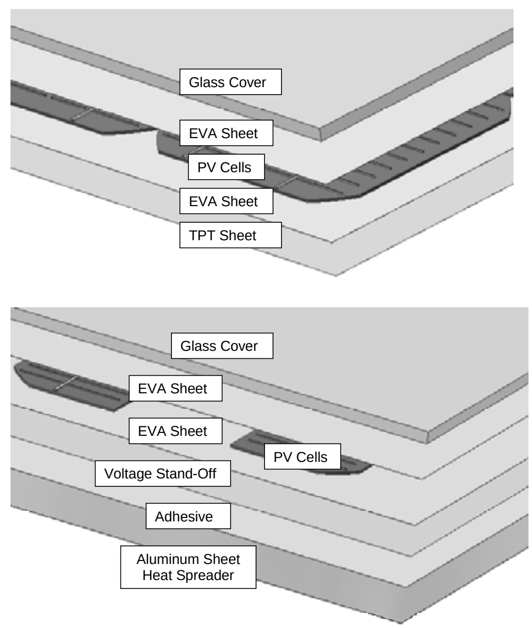

Figure 3: TOP VIEW The standard planar silicon module laminant and BOTTOM VIEW The addition of a metal sheet heat spreader to spread the heat uniformly over the whole back plane so that the air contact area for heat removal is preserved.

ECONOMIC MOTIVATION

As shown in Table I, we believe that solar PV systems using 3-sun panels and single axis trackers can eventually produce electricity at prices below 10 cents per kWh. The Solar Advisor Model (SAM) has recently become available and is a very nice tool for analyzing solar PV system costs. Using SAM in table I, we have created 3 commercial PV system cases as shown. This table contains 3 columns referencing 3 commercial PV cases.

The left-most column represents the SAM initial commercial baseline case for Phoenix assuming no tracking and today's planar silicon panels. Looking at the middle column, if we simply mount panels on a low profile I-axis tracker instead of placing them fixed on the roof, the kWh / kW increases by 2409/1820=1.32 with an immediate reduction in LCOE from 16 to 12 cents per kWh. A further reduction in the LCOE can come by reducing the panel cost and increasing its efficiency. This can be done with our 3-sun mirror modules and higher efficiency silicon cells.

For our 3-sun panels, we note that our intrinsic advantage is that mirrors are much cheaper than cells. Thus, if the real cost of cells is about \$2.10 per W at 1 sun, at 3-suns we should save about \$1.40 per W. If mirrors cost \$0.40 per W, we should save \$1 per W over standard 1-sun panels. So, our panel cost in table 1 relative to the left baseline column should then be \$2.50 / W if our panel efficiency were the same. However, using SunPower 22% cells in the future should allow an increase in panel efficiency from 13.5% to 18% with a resultant reduction in panel per W cost to (13.5/18)x\$2.5/W = \$1.88 / W. So our assumption for the 3-sun panel cost for 2010 in table 1 of \$2/W is conservative. Our problem today is that we are in low volume production and we are paying retail prices for 19% efficient cells.

Table I: SAM Commercial System Inputs and Results

Parameter	**Commercial Flat Plate System 2006**	**Commercial 3-sun with carousel tracker 2007**	**Commercial 3-sun with carousel tracker 2010**
No Changes			
System Size	150 kW	150 kW	150 kW
Panel dimensions	1.5 m x 0.8 m	1.5 m x 0.8 m	1.5 m x 0.8 m
O&M costs	\$6,365 / yr	\$6,365 / yr	\$6,365 / yr
Evolutionary Change			
Inverter Cost	\$90,000 \$0.60 / W	\$90,000 \$0.60 / W	\$75,000 \$0.50 / W
Installation	\$0.55 / W \$82,500	\$0.55 / W \$82,500	\$0.50 / W \$75,000
Changes via TIOs			
Panel Efficiency	13.5%	**13.5%**	**18%**
# Panels Required	1000	1000	750
Panel Cost	\$525 \$3.50 / W	**\$525 \$3.50 / W**	**\$400 \$2 / W**
Tracking BOS	Fixed \$0.54 / W \$81,000	**1-axis \$0.75 / W \$112,000**	**1-axis \$0.50 / W \$75,000**
Indirect (32% margin over panel cost)	\$1.10 / W \$165,000	**\$1.10 / W \$165,000**	**\$0.64 / W \$96,000**
Results			
System Cost	\$943.5k	\$975k	\$621k
Installed Cost / W	\$6.29 / W	\$6.50 / W	\$4.14 / W
LCOE cts/kWh	**15.93 cts**	**12.43 cts**	**8.3 cts**
kWh / kW Phoenix	1,820	2,409	2,409

SHANGHAI PROJECT HISTORY

We are grateful to our Shanghai colleagues for funding this project. This project has taken place in 3 phases over a 2 year period. In the 1st phase, we designed the 3-sun panels, fabricated the first 20, and tested them under calibrated conditions. In the 2nd phase, we set up 2 post-mounted 2-axis tracking systems each with 12 of our 3-sun panels. Finally, 3rd , we built the roof mounted 100 kW system. The results of these 3 activities are described in the following sections.

CALIBRATED PANEL MEASUREMENTS

We fabricated twenty 3-sun modules in a first experimental pilot production run. Two of these first modules were then sent to Array Technologies in Albuquerque NM for outdoor testing. As shown in figure 4, these 2 modules were mounted along with a Sharp 175 W planar module on a 2-axis tracker. All three modules were tested and produced very similar amounts of power as shown in table II. Figure 5 shows the power outputs for the modules in Figure 4 throughout the day.

Figure 4: Two JXC 3s-180 modules and one Sharp 175 W module on 2-axis tracker in Albuquerque NM.

Table Ii: Test results for modules shown in figure 4.

	3-Sun # 10	3-Sun # 7	Sharp 175
Voc	44.51	45.25	39.95
Isc	5.75	5.74	6.11
FF	0.66	0.66	0.67
Vmax	33.82	34.39	30.36
Imax	4.98	4.98	5.35
Pmax, watts	168	171	163

Test conditions: 1.1 suns, 21oC, 12:48 pm,
8 Feb. 2006, Albuquerque NM
at Array Technologies.

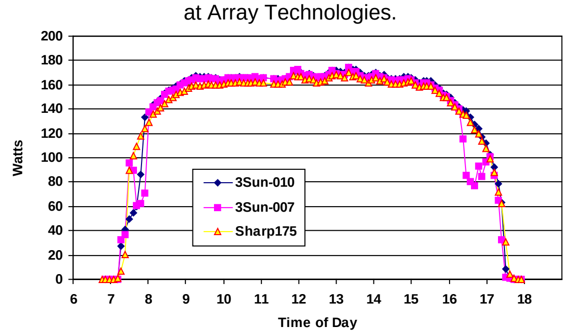

Figure 5: Power outputs for 3-sun #10 and #7 vs Sharp 175 on 2/10/2006 in Albuquerque.

A 3-sun panel was also sent to NREL for calibration measurements. The results are shown in Table III. All of these measurements are consistent with a PTC 3-sun panel rating of 150 W.

Table III: NREL PV Standardized Module Performance Test Report #2K1720 JX Crystals Low Concentration Module (Area = 1.268 m2).

	Temp (^{o}C)	Voc (V)	Isc (A)	FF (%)	Pmax (W)
11/22/06 LACSS Spectrolab X200	22.9	24.5	9.1	67.6	150.5
11/8/06 Direct Normal Outdoor 1079 W/m2	32.6	23.6	10.6	65.8	
11/8/06 Normalized & Spectrally Corrected	32.6		9.9		153.7
11/15/06 Direct Normal Outdoor 1081 W/m2	28.9	23.9	10.6	61.9	
11/15/06 Normalized & Spectrally Corrected	28.9		9.8		145.6

POST-MOUNTED 2-AXIS TRACKERS

We then supplied twenty-four 3-sun panels for mounting on 2 Array Technologies post mounted AZ225 2-axis trackers and these were installed at the Shanghai Flower Park as shown in figure 6. A SMA inverter was mounted on each post.

Figure 6: JX Crystals Inc 4 kW installation in Shanghai.

We refer to this system as a 4 kW system but this is based on the STC panel rating of 180 W. However, based on the PCT rating of 150 W, we would expect 12 x 150 W = 1.8 kW for each array. This is consistent with the power produced from an array as shown in figure 7. The peak power shown of 1.74 kW is consistent with the sun reading on that day of 0.97 suns (0.97x1.8 kW = 1.75 kW).

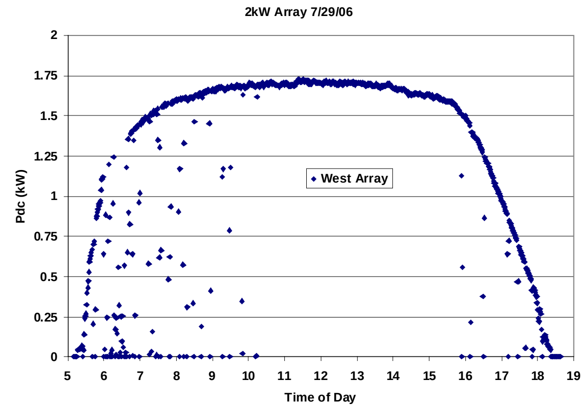

Figure 7: Power output over a day for one of the 2 kW (STC) arrays.

ROOF-MOUNTED 100 kW SYSTEM

Our customer's goal from the beginning was to mount solar panels on the roof of a utility building at the Flower Port in order to provide electric power for green houses to keep them cool in the summer and warm in the winter. So we designed a low profile horizontal beam tracking 2-sun system. The building block is a 25 kW array as shown in figure 8. It consists of 7 beams oriented in the North-South direction driven by a motor and one central drive beam. There are twenty-four 3-sun panels astride each beam.

The system we designed and built is a nominal 100 kW (PTC) system consisting of four of these building blocks. It therefore contains 4x7x24= 672 panels.

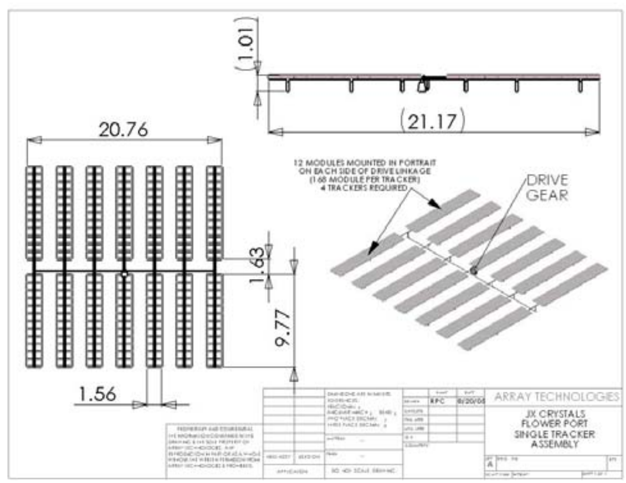

Figure 8: Design drawing for 25 kW horizontal beam tracked array consisting of 7 beams, each with 24 3-sun panels, and one drive motor and drive beam.

We actually made 750 3-sun panels and we were pleasantly surprised at the good yields and steadily improving performance as shown in the yield bar graph presented in figure 9. We used the NREL calibrated 3-sun panel as a reference panel for these flash test STC measurements.

Figures 10 & 11 then show photos of the completed roof mounted 100 kW array.

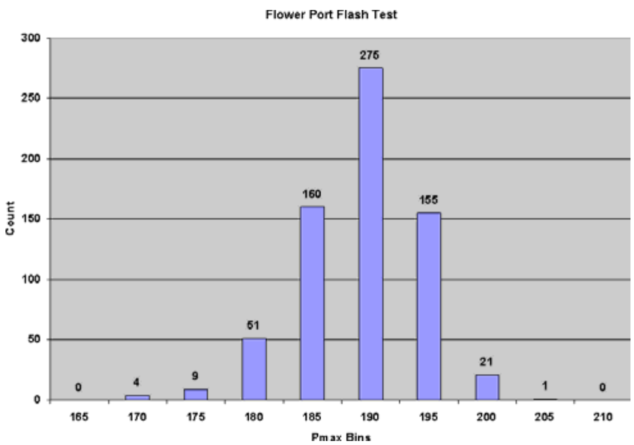

Figure 9: STC Flash test 3-sun panel power yields for 750 panels with average at 190 W and high of 205 W.


Figure 10: Photograph of 100 kW 3-sun array.

The installation of this system was completed in the middle of November of 2006. A SMA Sunny Central inverter was used along with string monitors to read the outputs from each of the 28 strings corresponding with the 28 beams. Its performance is documented in figure 12 where the current for one of the typical 28 strings is shown along with the system output voltage over a day in November. The system performance is as expected. Since the sun is at 50 degrees off normal toward the South in the winter time for this horizontal beam system, the current reading of 5 Amps per string needs to be divided by cos(50)= 0.64 to predict peak summer time operation. From this data, the system peak AC power in the summer should then be (5x28 / 0.64 A) x 430 V = 94 kW. Given an inverter efficiency of 94%, this then equates to 100 kW (PTC) and this is consistent with 672 x 150 W = 100.8 kW.

CONCLUSIONS

Thanks to funding from a launch customer in Shanghai, China, we have designed, built, and characterized 3-sun panels with an STC rating of 180 W and a PTC rating of 150 W. We then built in a first production run these panels for installation in two demonstration systems at the Shanghai Flower Port. These systems are performing and operating as per expectation.

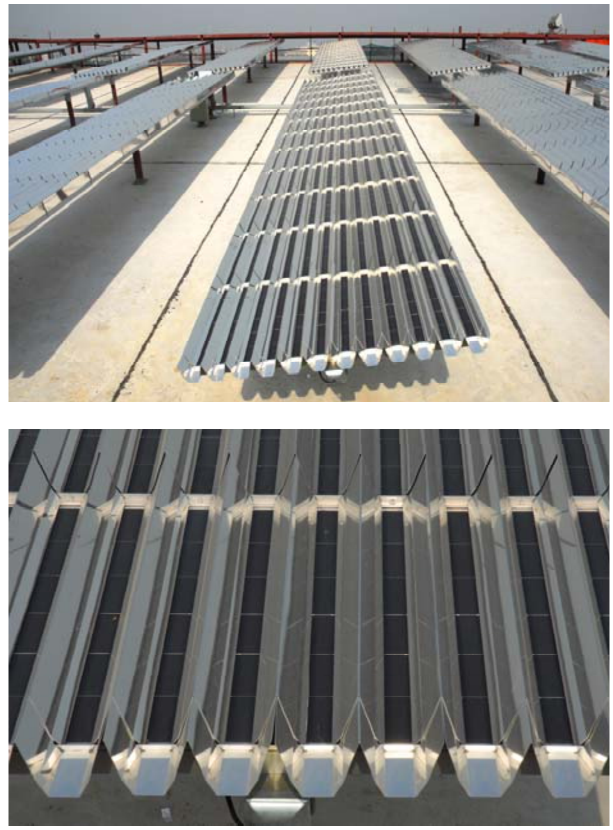
Figure 11: Close-up photos of 3-sun panels and tracker.

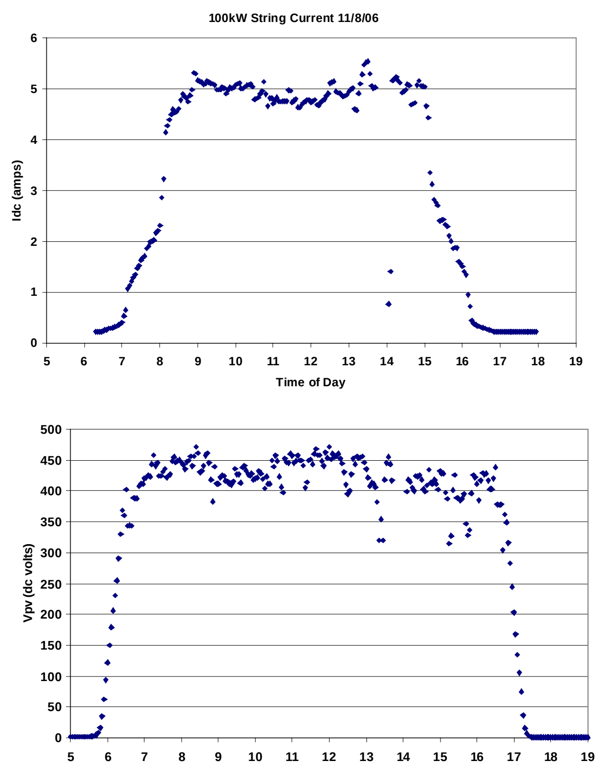

Figure 12: Typical string current and system voltage for 100 kW (PTC) 3-sun system in winter of 2006.