Near Term Lower Cost Solar Electric Power for US Commercial Customers

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Market Opportunities

The first market for PV electric power panels was for space satellites. While the single crystal cells used in these panels made these panels very expensive, this was unimportant for that market. That market emphasized reliability, not cost. As these panels came down to earth for off-grid remote applications, again the emphasis was on reliability and low maintenance, not cost.

Off-grid residential then led to the grid connected residential roof top market. The residential roof top market has sustained the growth of PV for the last decade. However, these select customers are not really motivated by pure economics. Solar PV for this application has the reputation of being too expensive for mass applications. There are several intrinsic economic problems for this application. On a fundamental level, the single crystal material is inherently very expensive. This problem is compounded by the fact that these residential systems are generally small with unique rooftop layout designs leading to high sales and installation costs. In addition to these problems, residential users need electricity in the evenings, not when the sun is shining.

The residential application does have one important advantage over electric utility central power stations. The utilities have to transmit and distribute electricity on power lines long distances. They generate electricity at wholesale prices and sell it to the users at the other end of the line at retail prices. Solar PV panels on homes generate higher value electricity displacing electricity at retail prices.

Solar electricity can become cost competitive for commercial customers. Commercial customers can buy and use larger PV systems. They presently pay retail prices for electricity and they need electricity during the day when the sun is shining. Power Light Corp has recognized this market and has been quite successful.

The Solar Advisor Model (SAM) has recently become available and is a very nice tool for analyzing solar PV system costs. SAM provides three current baseline cases for typical residential, commercial, and utility PV systems. This model agrees with the assessment that commercial systems have the most viable economics near term. The SAM cases show the Levelized Cost of Electricity (LCOE) for typical residential, commercial, and utility PV systems today to be approximately 32 cents, 16 cents, and 21 cents per kWh respectively.

Our company believes that there is an excellent opportunity to reduce the LCOE for commercial PV systems in three ways as follows:

1.) Using low profile solar trackers on commercial building flat rooftops will increase the number of kWh per kW installed reducing LCOE immediately.
2.) Lower cost panels can be produced now by using less of the expensive single-crystal silicon cell material in simple 3-sun mirror modules operating at low solar concentration ratios. This approach also addresses the silicon feedstock supply shortage problem.
3.) Panel efficiencies can also be dramatically improved over a longer term by using more efficient cells operating at high solar concentration ratios.

Technical Improvement Opportunities

Using SAM, we have created four commercial PV system cases as shown in Table 1. This table contains 4 columns referencing 4 commercial PV cases. The left-most column represents the SAM initial commercial baseline case. The three columns toward the right represent the three Technical Improvement Opportunities (TIOs) we have identified and that we are now developing.

The TIOs we have identified are as follows:

- TIO#1 – Rooftop-mounted low-profile carousel tracker for more electricity producing hours and standard rooftop installation.
- TIO#2 – 3-sun mirror modules, a lower cost panel using less single crystal silicon.
- TIO#3 – A Cassegrain panel using simple multi-color cells for higher 33% panel efficiency.

These TIOs will be described in more detail along with hardware prototype photographs in the subsequent section of this paper. First however, the projected system LCOE improvements associated with these TIOs are summarized along with the SAM input assumptions as enumerated in Table 1.

With reference to this table, we have used the same SAM format and the same system size and panel dimensions for all 4 cases. For simplicity, we have kept the O&M cost constant with small evolutionary changes in the inverter and installation costs. As highlighted with bold print, this paper is focused on changes in the sun tracking and panel design and efficiency parameters. As will become evident later in this discussion, changes in the indirect cost are also important. The assumptions on indirect cost are also highlighted in bold.

Table 1: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**	**Commercial 3-5 Concentrator 2015**
No Changes				
System Size	150 kW	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	1.5 m x 0.8 m
O&M costs	$6,365 / yr	$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	$75,000 $0.50 / W
Installation	$0.55 / W $82,500	$0.55 / W $82,500	$0.50 / W $75,000	$0.50 / W $75,000
Changes via TIOs				
Panel Efficiency	13.5%	**13.5%**	**18%**	**33%**
# Panels Required	1000	1000	750	450
Panel Cost	$525 $3.50 / W	**$525** **$3.50 / W**	**$400** **$2 / W**	**$400** **$1.21 / W**
Tracking BOS	Fixed $0.54 / W $81,000	**1-axis** **$0.75 / W** **$112,000**	**1-axis** **$0.50 / W $75,000**	**2-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**	**$0.39 / W** **$58,000**
Results				
System Cost	$943.5k	$975k	$621k	$463k
Installed Cost / W	$6.29 / W	$6.50 / W	$4.14 / W	$3.12 / W
LCOE cts/kWh	**15.93 cts**	**12.43 cts**	**8.3 cts**	**7.14 cts**
kWh / kW Phoenix	1,820	2,409	2,409	2,215

The 3 new columns in this table correlate with the TIOs listed earlier. The risks and benefits associated with these TIOs increase from left to right. 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 as we will describe shortly. According to SAM, this can reduce the LCOE to 8.3 cents / kWh. We view this development as a relatively low risk development.

The largest potential reduction in LCOE can come by further dramatically increasing the panel efficiency to 33%. This can be done by switching from silicon cells to multi-color cells derived from the Light-Emitting-Diode (LED) class of semiconductors but also will require high concentrating optics and more precise 2-axis trackers. This represents a higher risk path to the 2015 LCOE goal. SAM predicts a LCOE cost of 7 cents / kWh given our assumptions in table 1.

Prototype Developments

As a company with a strong R&D background in PV, JX Crystals Inc has already developed prototypes in these three areas.

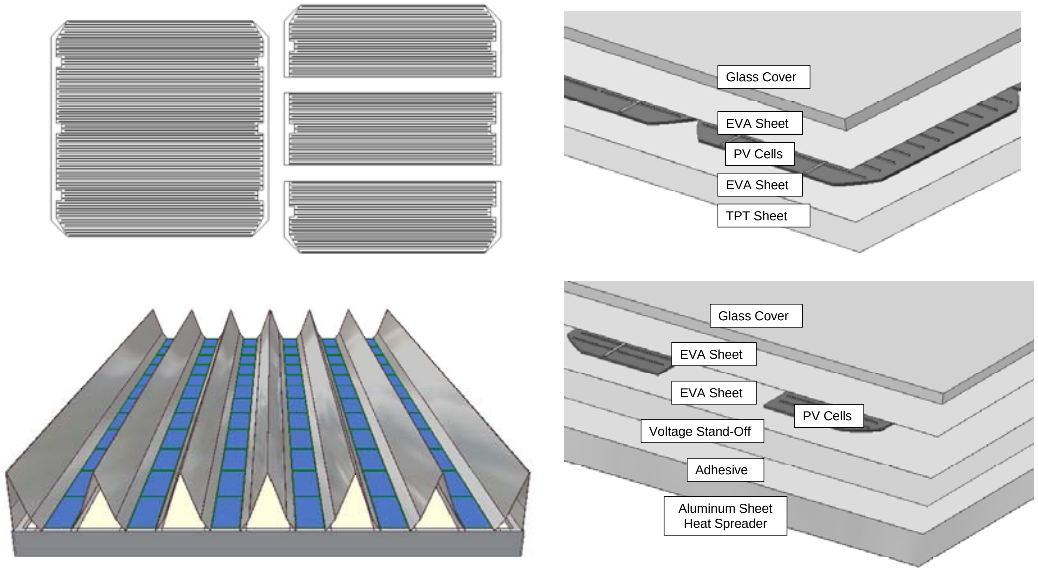
Carousel un Tracker for Commercial Building Flat Rooftops

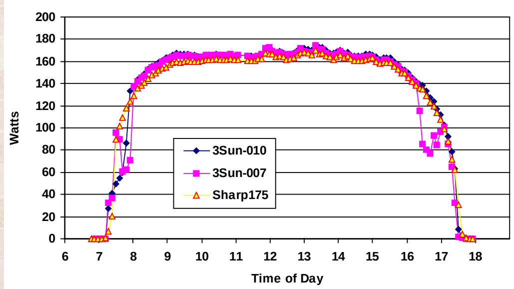
We begin with the sun tracker. Figure 1 shows photographs for a 1-axis carousel tracker that we have designed for easy deployment on commercial flat rooftops. The prototype carousel shown in this picture is mounted on a dolly so that it can be rolled out into the parking lot for testing. For reference, the top white surface of the dolly visible in the right hand photo represents the roof top surface. So, this is a low profile tracker designed to distribute its weight evenly over a large area and for low wind resistance on the roof. We believe that it can be easily lifted up to a roof and placed in position with no roof penetrations required. While this unit is shown with our 3-sun modules, it can also be deployed with standard planar modules. In summary, it weighs 120 pounds without panels and 320 pounds with panels and its projected cost in high volume and output are $235 (less panels) and 700 W STC with panels or $0.34 / W. Without panels, it fits assembled within a standard 8 ft wide shipping container.

Figure 1: Sun tracking carousel easily placed on commercial building flat rooftops.

Lower Cost Evolutionary 3-Sun PV Mirror Modules

Our second proposed innovation or TIO is shown in figure 2. This figure shows an evolutionary planar panel design. The problem today for standard planar modules is that demand has far outstripped silicon feed stock supply and therefore PV cell supply and module prices are rising. To solve this problem, JX Crystals is developing a 3-sun mirror module that uses 1/3 the cell area to triple module production at a lower cost. As shown in figure 2, our concentrator module design uses existing planar cells. We simply cut standard SunPower A300 cells into thirds. In addition, our module design uses standard circuit lamination procedures and equipment. However, we add a thin aluminum sheet at the back of the laminated circuit for heat spreading. While a standard planar module contains rows of pseudo square cells, our low concentration modules consist of rows of third-cells. We then locate linear mirrors with triangular cross sections between the cell rows. The mirror facets deflect the sun's rays down to the cell rows (patent pending). Figure 2 also shows photographs of the test systems and presents the initial outdoor test results.





	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

Figure 2: 3-sun mirror panel concept and outdoor test performance comparison.

Our 3-sun mirror module is an evolutionary design based on planar silicon cells already in high volume production. Its novelty is the use of mirrors and sun trackers. Both mirrors and trackers are already in use for other solar applications. The mirrors are available from 2 different suppliers and have been developed with weather proof coating for solar thermal applications. Single axis trackers are now baseline for the SAM utility PV case and our 3-sun panels with their linear mirror configuration will work with one axis tracking. The tracking precision required for low solar concentration is not high and does not introduce a cost or O&M problem. All of these factors make our 3-sun panel development a low risk near-term path to lower solar PV system LCOE.

On the subject of the cost of 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.

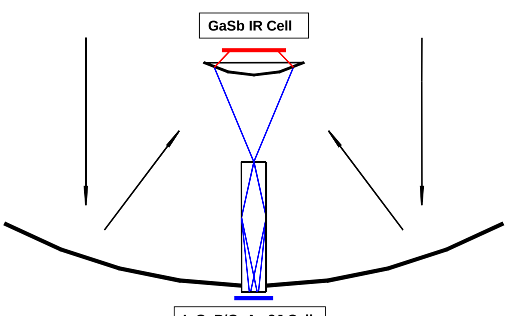
Our problem today is that we are in low volume production and we are paying retail prices for 19% efficient cells.

High Concentration 33% Efficient Cassegrainian Module for Loger Term

Our TIO#3 Cassegrain panel shown in figure 3 represents a revolutionary approach to the DOE LCOE 2015 goal of 6 to 8 cents per kWh. Personnel now at JX Crystals Inc pioneered the development of high efficiency PV concentrators when at Boeing with the demonstration of a 35% efficient GaAs/GaSb tandem concentrator cell in 1989. However, there was not much interest in terrestrial concentrator system development until much more recently.

In 2003, JX Crystals finally received a contract from NREL to make terrestrial multi-color cells for terrestrial concentrator modules. This contract led to the development of the Cassegrain module shown in figure 3. In April of 2006, we measured one of these new Cassegrain modules outdoors. As shown in this figure, the cell efficiencies in this module added up to 38% and the module efficiency was measured at 30.8% at temperature including all optical and wiring losses.

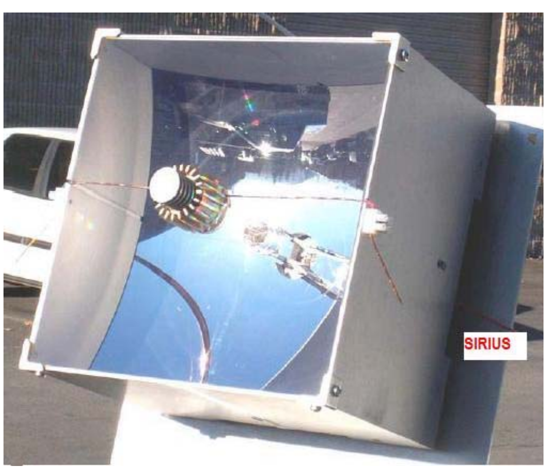
Cassegrain PV Module



33% Efficient PV Module

JX Crystals Inc
Casssegrain Module

Parts List
1. Dichroic Hyperbolic Secondary
2. Glass Window
3. Homogenizer for Dual-Junction (DJ) Cell
4. DJ Circuit
5. Homogenizer for IR Circuit
6. IR Circuit
7. Primary Mirror
8. DJ Heat Sink / Base
9. DJ Homogenizer Support
10. IR Circuit Can / Heat Sink
11. Side Wall



: Performance Summary

	Packaged Cells at STC	Projected STC with 90% Optical Effic	Measure at Operate Temp (April 28)	Measure Module at STC (April 28)
DJ Cell Power	17.4 W	15.7 W	14.4 W	15.1 W
DJ Cell Effic.	31.5%	28.4%	26.1%	27.3%
IR Cell Power	3.64 W	3.28 W	2.6 W	3.1 W
IR Cell Effic.	6.6%	5.9%	4.7%	5.6%
Sum Power	21 W	19 W	17 W	18.7 W
Sum Effic.	38.1%	34.3%	30.8%	32.9%

NIP DNI = 0.92; Area = 600 cm2; Input Power = 55.2 W

Figure 3: Cassegrain Module

System Demonstrations

3-sun panels: JX Crystals Inc has received funding from China for the development of our 3-sun mirror panels. This funding has included the first 4 kW demonstration arrays shown in figure 4. It also includes a 100 kW demonstration system using 1-axis horizontal beam trackers on a building flat rooftop in Shanghai.

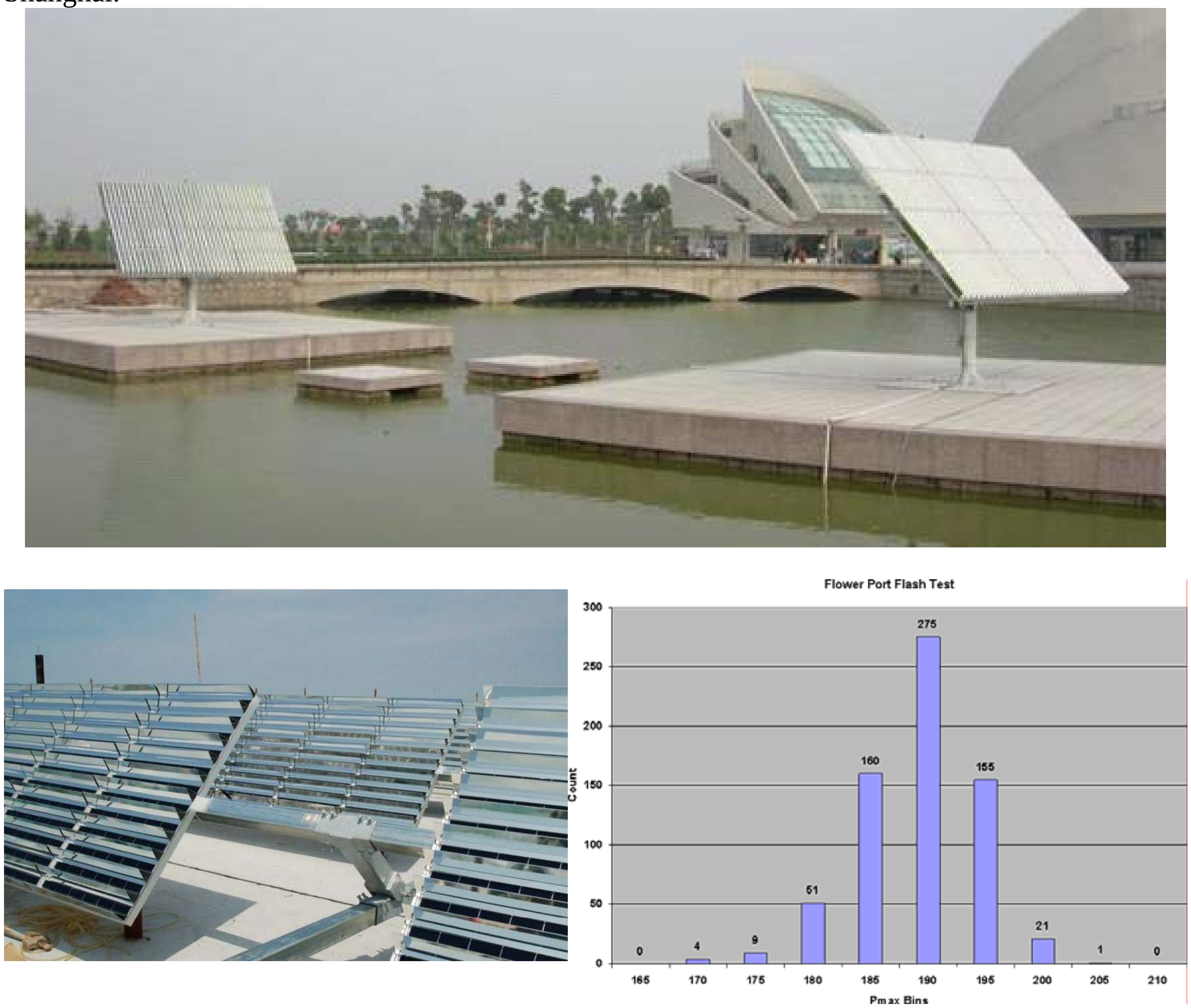


Figure 4: JX Crystals Inc 4 kW installation in Shanghai (top) with
2 Array Technologies trackers with 12 mirror panels per tracker.
(Bottom left:) Photo of panels on 100 kW installation.
(Bottom right) Panel power yields with average at 190 W and high of 205 W.

This China 100 kW project really has laid the foundation for our 3-sun mirror panel development to date. As of this writing, 800 3-sun panels have now been made in China according to a JX Crystals Inc (USA) design. This contract has now proved this 3-sun mirror panel technology.

Conclusions

Affordable solar electric power will result when panels using higher efficiency cells and lower cost materials are brought into production. No new technical breakthroughs are required. Funding is now required for manufacturing scale up of these newer technologies. The danger now is that the subsidies in place will simply promote the older planar solar panel technologies with intrinsic cost and/or efficiency limitation.