Back-Surface Passivation for High-Efficiency Crystalline Silicon Solar Cells

Final Technical Progress Report September 2010 — May 2012

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Subcontract Report
NREL/ SR-5200-55914
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NATIONAL RENEWABLE ENERGY LABORATORY

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Executive Summary

TetraSun has enjoyed major success as a Photovoltaic Technology Incubator awardee within the U.S. Department of Energy's (DOE's) SunShot Program. All deliverables were submitted on time and passed NREL verification. Over the period of this project, the company evolved from five founders to a team of 15 scientists, engineers and technicians and has set up an R&D pilot line in Silicon Valley, California.

We have developed an advanced surface passivation and Cu-based metallization solar cell manufacturing process that results in finished cell V_{oc} values exceeding 695 mV. Further, various parts of the cell were optimized to achieve best of class conversion efficiencies and temperature coefficients competitive with those based on traditional heterojunction technology but at significantly lower cost. Also, TetraSun's high-efficiency cells are compatible with standard low-cost soldering and module manufacturing processes.

Starting the proof-of-concept with well passivated silicon wafers and 4 cm^2 R&D cells, TetraSun quickly scaled up the technology to 153 cm^2 cell area for the pilot line operation and process optimization (125 mm pseudosquare wafers). Tests on 239 cm^2 production size cells (i.e., 156 mm pseudosquare wafers) were already conducted and yielded equivalent performance. Also, we developed a metallization technology capable of 40 um line width that is replacing the commonly used screen-printed Ag paste metallization by electroplating of Cu, a much less expensive and higher efficiency process.

Collectively, these improvements have resulted in a baseline cell efficiency of 20%. Cost projections for high volume manufacturing in a 100 MW fabrication line show the potential to significantly reduce the cost of PV across the whole value chain, in accordance with the DOE SunShot Initiative.

TetraSun has partnered with commercial module manufacturers to test and qualify its cells. Modules of quality and reliability matching and exceeding those based on screen-printed Ag paste Si cells were demonstrated. Outdoor test installations have been set up and will allow monitoring the long-term benefits of TetraSun's technology.

Contents

Overview of Schedule and Deliverables

Phase 1: September 2010 – June 2011

Months After Start of Subcontract										
Task Activities	0	1	2	3	4	5	6	7	8	9
Research Focus	Δ									Δ
Task 1 – Demonstrate Cell Performance	Δ			**D1**			**D2**			Δ
Subtask 1.1.1 – Open-Circuit Voltage (Voc)	Δ			Δ						
Subtask 1.1.2 – Short-Circuit Current (Isc)	Δ			Δ						
Subtask 1.1.3 – Fill Factor (FF)	Δ			Δ						
Subtask 1.1.4 – Cell Efficiency (η)	Δ									Δ
Task 2 – Process Integration					Δ		**D3**		**D4**	**D5Δ**
Subtask 1.2.1 – Medium Area Scale-Up					Δ		Δ			
Subtask 1.2.2 – Full Area Scale-Up							Δ	Δ		
Subtask 1.2.3 – Optimization of Process Flow									Δ	Δ
Task 3 – Preliminary Reliability Testing			Δ							**D6,7,8Δ**
Subtask 1.3.1 – Temperature Testing			Δ							Δ
Subtask 1.3.2 – Pull Strength					Δ					Δ
Subtask 1.3.3 – Short Damp Heat						Δ				Δ
Quarterly Technical Progress Report				Δ			Δ			
Draft Technical Progress Report									Δ	
Stage-Gate Presentation and Review										Δ
Final Technical Progress Report										Δ

Deliverables	**Due Date**	**Delivery Date**	**Pass/Fail**
D1: >16.5% efficiency, >4 cm^2 area	Month 3	Month 1	Passed
D2: >18.5% efficiency, >4 cm^2 area	Month 6	Month 5	Passed
D3: >16.5% efficiency, >100 cm^2 area	Month 6	Month 1	Passed
D4: >17.5% efficiency, >148 cm^2 area	Month 8	Month 4	Passed
D5: >18.5% efficiency, >148 cm^2 area	Month 9	Month 7	Passed
D6: Temperature testing	Month 9	Month 7	Passed
D7: Pull strength test, F>1N/mm ribbon	Month 9	Month 9	Passed
D8: 500 h Damp heat test 85%/85°C	Month 9	Month 7	Passed

Phase 2: August 2011 – May 2012

Months After Start of Subcontract									
Task Activities	12	13	14	15	16	17	18	19	20
Research Focus	Δ								Δ
Task 4 – Advanced Cell Performance	Δ								Δ
Subtask 2.4.1 – Open-Circuit Voltage (Voc)	Δ		Δ						
Subtask 2.4.2 – Short-Circuit Current (Isc)	Δ		Δ						
Subtask 2.4.3 – Fill Factor (FF)	Δ		Δ						
Subtask 2.4.4 – Cell Efficiency (η)			Δ **D9**			**D10**			**D11**Δ
Task 5 – Pilot Production			Δ						
Subtask 2.5.1 – Production Volume			Δ		Δ	**D12**			
Subtask 2.5.2 – Production Yield					Δ				**D13** Δ
Task 6 – Module Fabrication and Reliability Testing									Δ
Subtask 2.6.1 – Module Fabrication					Δ	**D14**			
Subtask 2.6.2 – Accelerated Indoor Testing		Δ							**D15,16, 17** Δ
Subtask 2.6.3 – Outdoor Testing					Δ				**D18** Δ
Subtask 2.6.3 – Beta Customer									**D19** Δ
Task 7 – Cell and Process Cost Analysis		Δ							Δ
Quarterly Technical Progress Report			Δ			Δ			
Final Technical Progress Report (Draft/Final)								Δ	
Final Presentation and Review								Δ	Δ

Deliverables	**Due Date**	**Delivery Date**	**Pass/Fail**
D9: ≥19.0% efficiency, ≥140 cm^2 area	Month 12	Month 12	Passed
D10: ≥19.5% efficiency, ≥140 cm^2 area	Month 15	Month 14	Passed
D11: ≥20.0% efficiency, ≥140 cm^2 area	Month 18	Month 17	Passed
D12: 20 cells ≥18.5% efficiency	Month 15	Month 14	Passed
D13: Report on 5 h Production Run	Month 18	Month 15	Passed
D14: 4 cell module, ≥9.8 Watts	Month 15	Month 14	Passed
D15: 1000 h Damp Heat Test 85%/85°C	Month 18	Month 16	Passed
D16: 200 Thermal Cycling Tests, -40°C/+85°C	Month 18	Month 17	Passed
D17: 15 $kWhr/m^2$ UV Test	Month 18	Month 16	Passed
D18: Outdoor Installation	Month 18	Month 18	Passed
D19: Full size module, ≥14% total area efficiency	Month 18	Month 18	Passed
D20: Preliminary CoO analysis	Month 12	Month 12	Passed
D21: CoO analysis	Month 15	Month 15	Passed

Task 1 – Demonstration of Cell Performance & Task 4 – Advanced Cell Performance

In Task 1 and Task 7, the demonstration of cell performance was the focus of the development effort. TetraSun's cell efficiency results, as measured and certified by NREL and Fraunhofer ISE, are shown in Figure 1.

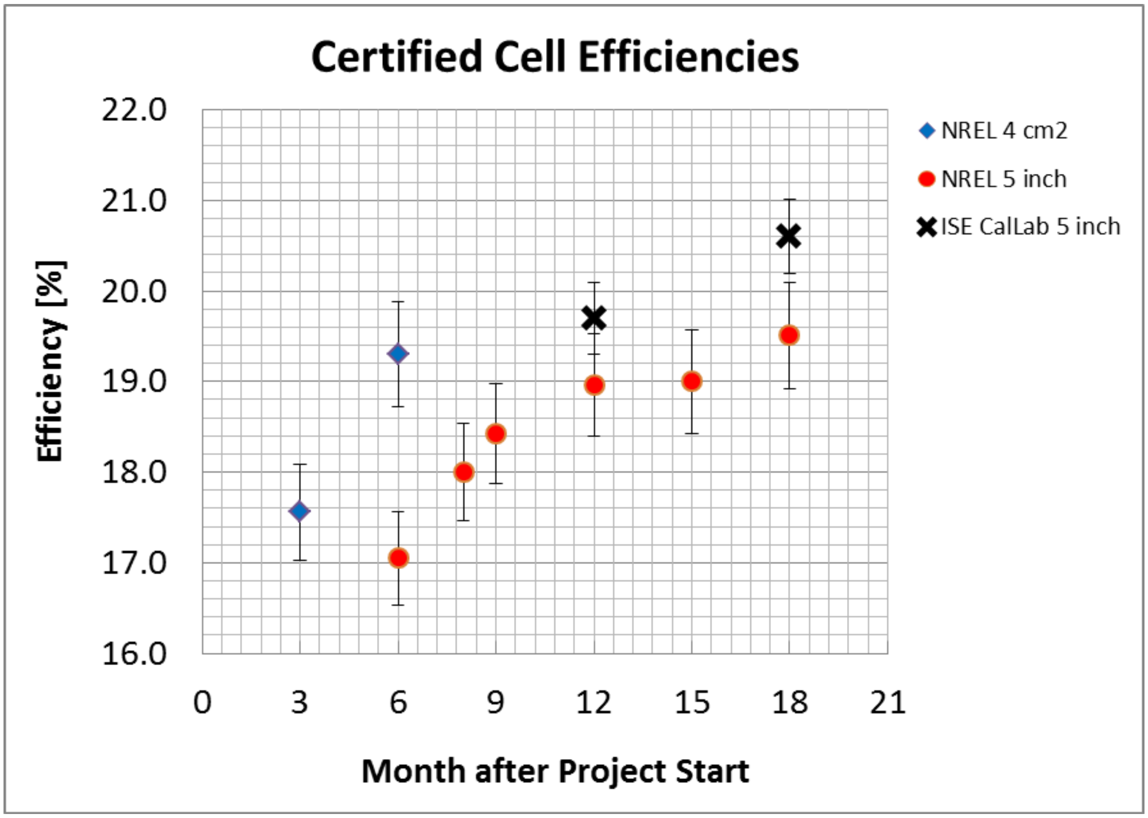

Figure 1: TetraSun's certified cell efficiencies on wafers of different size. A strong and steady upward trend was observed over the period of the project. A 3% uncertainty interval is shown for the NREL results; a 2% uncertainty interval is shown for the Fraunhofer ISE CalLab measurements.

All efficiency deliverables of this Incubator project were submitted on time, exceeded the pass/fail criteria and were met on first pass. A strong and steady upward trend was observed over the period of the project.

It is worth noting that the V_{oc} values, which are indicative of the level of surface passivation achieved, reached 696 mV on the finished cell made from phosphorus doped Cz crystalline silicon of ~170 um cell thickness. These high values were consistent between all three measurement places (NREL, Fraunhofer ISE CalLab and TetraSun). In comparison to internal measurements at TetraSun and measurements at Fraunhofer ISE, a considerable deviation for the J_{sc} value was observed for the NREL measurements. Part of it, 0.3-0.6 mA/cm^2, can be attributed to the different probe bar design used at the different measurement locations. The remaining difference is well within the ± 3% measurement uncertainty.

Besides the general benefit of a higher than standard efficiency, TetraSun's technology is identified by a superior temperature coefficient of -0.32%/K (see Figure 2). This translates to more power generation in real-life outdoor conditions where the module temperature is not kept constant and can easily achieve ~45°C on free standing installations or up to 75°C on rooftops.

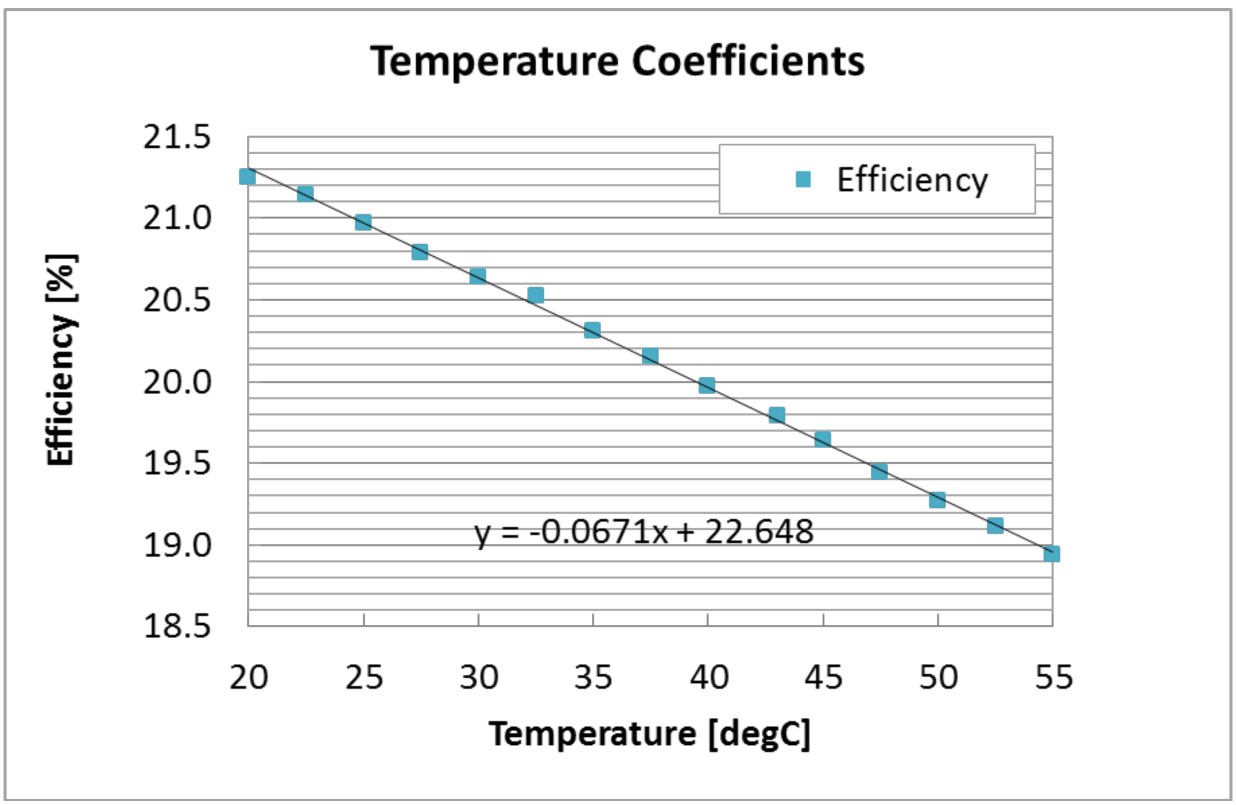

Figure 2: Temperature coefficient of bare cell between 20°C and 55°C. A low value of -0.32%/K results in improved energy yields in outdoor installations, where the module temperature is not constant but significantly increased.

Task 2 – Process Integration

This task consisted of the development of an integrated process flow for low-cost high-efficiency crystalline silicon solar cells. A fine line patterning process for the front metal grid, developed by TetraSun in parallel to this back side passivation incubator project, was successfully integrated into the process flow. This fine line front metal grid consists of plated Cu. The same applies for the back side; these two processes can be accomplished at the same time and result in a short process flow. The technical challenges to overcome were mainly the development of barrier layer that prevents the diffusion of Cu into the silicon substrate. In case this happened, this would result in a degradation of the solar cell and lead to a strong degradation of the V_{oc} values. Tasks 3 and 6 addressed this potential issue. However, such failure mechanism was not observed; this shows the validity of the chosen technical approach.

Furthermore, the upscaling of the cell area was an important part of the integration work. Small cells of 4 cm^2 were rapidly ramped up via 25 cm^2 to the full area of 153.3 cm^2. This was accomplished without compromising the passivation quality as can be concluded from the high V_{oc} in excess of 69 5mV for full area cells.

Task 3 – Preliminary Reliability Testing & Task 6 – Module Fabrication and Reliability Testing

These tasks tested for the ability to assemble the cells into long-term reliable PV modules. The preliminary requirements of Task 3 were identified to be:

- Pull strength of soldered ribbons F≥ 1N/mm of ribbon width
- Ability to withstand soldering temperature of ~350°C without degradation
- 500 h of 85%/85°C damp/heat with less than 3% $_{rel}$ degradation

These criteria of Task 3 were met; see Figure 3 and Figure 4.

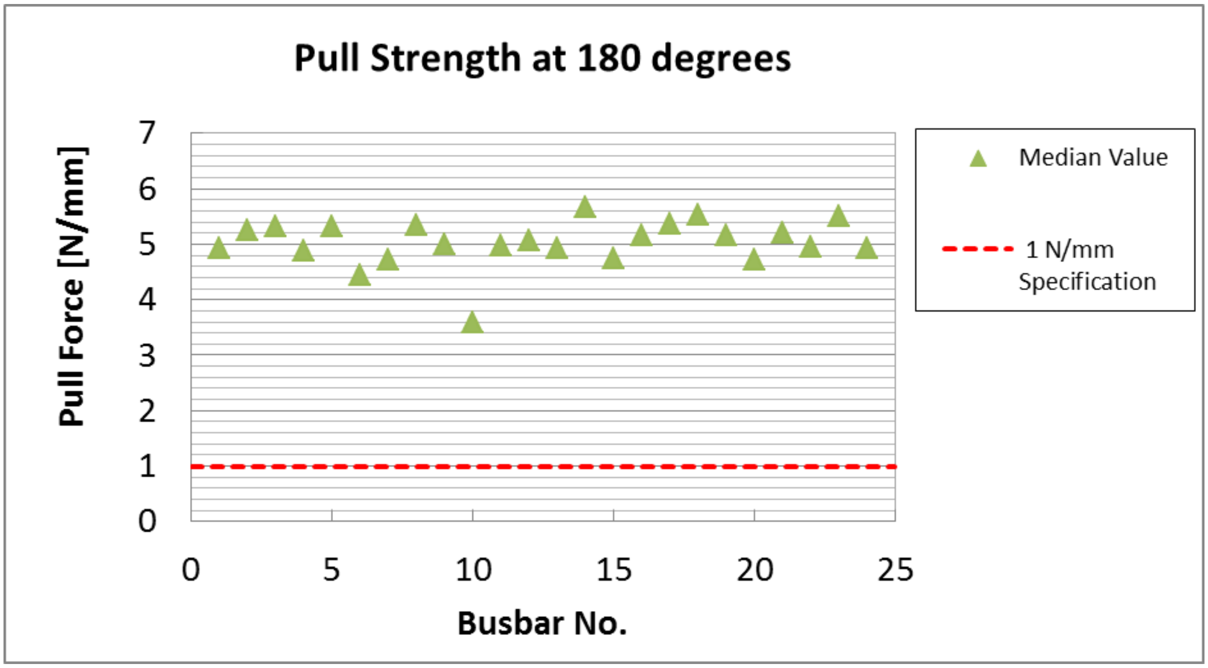

Figure 3: Pull test data 180 deg nominal angle. The criteria of 1N/mm median pull strength is well exceeded for all 24 ribbons under test.

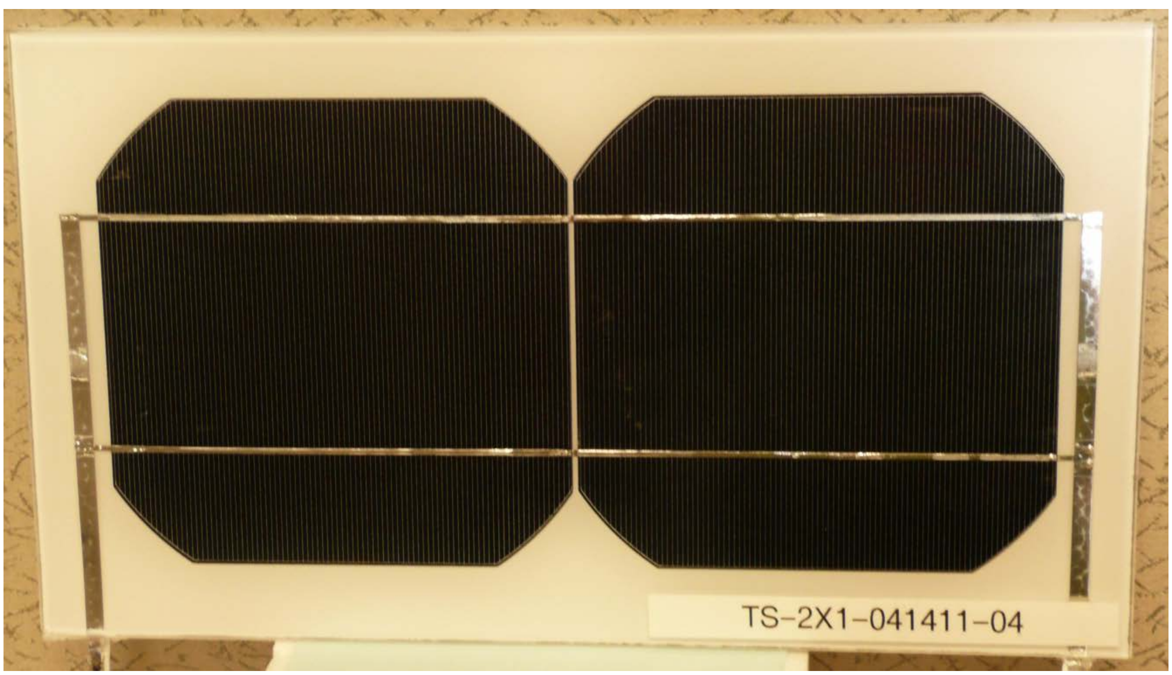

Figure 4: Picture of a 2-cell minimodule used for damp heat testing. The interconnect ribbons were soldered onto the plated metal grid. The module was prepared in a standard fashion featuring a glass front side and a standard white backsheet. The change of module power output was smaller than 3% compared to the controls (no exposure).

For Task 6, more modules consisting of strings of two or four cells were assembled and subjected to accelerated reliability testing according to IEC 61215:

- 1000 hours of 85%/85°C damp/heat
- 200 cycles of thermal stress -40°C /+85°C
- 15 kWhrs/m^2 of UV exposure

Again, a series of small test modules was built for accelerated reliability testing according to IEC 61215. For D15, eight minimodules were assembled consisting of two cells each. The modules were subjected to 1000 hours of damp/heat at 85°C/85%. The IV data as measured by NREL is shown in Table 1. The controls were not subjected to the stress test. The differences in the measurement of the controls after/before stress test resulted in a correction factor of 0.997 for each measurement. All changes are very small and there is no indication of any degradation.

Table 1: Results of modules after damp heat testing of 1000 h of 85°C/85% humidity. The pass criterion is ≤5% relative degradation. The median efficiency change is -0.11%.

Module number	Power before stress test [W]	Power after stress test [W]	Power after stress test adjusted to controls [W]	Change in power compared to controls
M1203-0001-1	6.157	6.151	6.131	-0.4%
M1203-0001-2	6.137	6.128	6.108	-0.5%
M1203-0001-3	6.263	6.279	6.258	-0.1%
M1203-0001-4	6.266	6.284	6.263	0.0%
M1203-0001-5	6.223	6.232	6.211	-0.2%
M1203-8 control	6.203	6.211	6.190	-0.2%
M1203-6 control	6.193	6.219	6.198	+0.1%
M1203-7 control	6.267	6.295	6.274	+0.1%

For deliverable D16, eight minimodules were assembled consisting of four cells each. The modules were subjected to 200 cycles of temperature changes between -40°C and +85°C. The IV data as measured by NREL is shown in Table 2.

The controls were not subjected to the stress test. The differences in the measurement of the controls after/before stress test resulted in a correction factor of 0.996 for each measurement. All changes are very small and there is no indication of any degradation.

Table 2: Results of modules after 200 thermal cycles between -40°C and +85°C. The pass criterion is ≤5% relative degradation.

Module number	Power before stress test [W]	Power after stress test [W]	Power after stress test adjusted to controls [W]	Change in power compared to controls
M1204-0017	13.67	13.651	13.598	-0.5%
M1204-0018 control	13.48	13.441	13.389	-0.7%
M1204-0019	13.51	13.545	13.492	-0.1%
M1204-0020 control	13.52	13.424	13.372	-1.1%
M1204-0021	13.57	13.645	13.592	0.2%
M1204-0022 control	13.68	13.657	13.604	-0.6%
M1204-0023	13.78	13.719	13.666	-0.8%
M1204-0024	13.71	13.669	13.616	-0.7%

In order to verify the UV stability of the cells, an accelerated UV test was performed by exposing the modules to 15 kWh/m^2 using UVA-340 bulbs. The IV data as measured by NREL is shown in Table 3. The controls were not subjected to the stress test.

Table 3: Results of modules after exposure to 15 kWh/m^2 of UV irradiation. The pass criterion is ≤5% relative degradation. There is no sign of degradation.

Module number	Power before stress test [W]	Power after stress test [W]	Power after stress test adjusted to controls [W]	Change in power compared to controls
1143-1	6.663	6.719	6.712	+0.7%
1143-2 control	6.616	6.661	6.654	+0.6%
1143-3	6.598	6.678	6.671	+1.1%
1143-4 controls	6.669	6.642	6.635	-0.5%
1143-5	6.743	6.799	6.792	+0.7%
1143-6 controls	6.562	6.564	6.557	-0.1%
1143-7	6.679	6.752	6.745	+1.0%
1143-8	6.568	6.612	6.605	+0.6%

The differences in the measurement of the controls after/before stress test resulted in a correction factor of 0.998 for each measurement. All changes are very small and there is no indication of any degradation.

In preparation for the full-size module assembly, a small module of four cells was built; see Table 4. The cells were taken from the pilot production run described in Task 5. The IV test results taken at taken at NREL are given in Table 4. The area was taped off by black tape leading to an aperture area of 624.2 cm^2. The average power output per cell is >2.8 W; this satisfies the requirements of deliverable D14 (≥2.46 W/cell) and is a very good value for module efficiency and cell to module conversion ratio (compare with Table 7).

Table 4: IV measurements of four cell minimodule with continuous light source simulator (LACSS) and outdoors. Asterix (*) denotes a spectral correction of outdoor measurement.

LACSS			Outdoor		
	Module	Cell		Module	Cell
Pmp:	11.27 W	2.818 W	Pmp:	11.21 W	2.803 W
Voc:	2.671 V	0.668 V	Voc:	2.694 V	0.674 V
Vmp:	2.174 V	0.544 V	Vmp:	2.195 V	0.549 V
Isc:	5.670 A	5.670 A	Isc:	5.542* A	5.542 A
Imp:	5.185 A	5.185 A	Imp:	5.007 A	5.007 A
FF:	74.4 %		FF:	75.0 %	
η:	18.1 %		η:	18.0 %	

The full-size module consisted of 72 cells, all strung in series. The front glass is AR coated. For this module, instead of a white backsheet, the rear is covered by glass. This satisfied the requirements of deliverable D19.

Table 5: IV measurement of full-size module as taken by NREL in an outdoor measurement. The module was measured in two conditions: with a black backsheet placed on the back, which suppresses albedo illumination, and "as is," which allows for bifacial operation of the module. The latter condition results in clearly increased power generation due to the rear side illumination.

Outdoor with black backsheet			Outdoor without backsheet		
	Module	Cell		Module	Cell
P_{mp}:	203.0 W	2.819 W	P_{mp}:	232.3 W	3.226 W
V_{oc}:	47.84 V	0.664 V	V_{oc}:	48.75 V	0.677 V
I_{sc}:	5.588 A	5.588 A	I_{sc}:	6.248 A	6.248 A
FF:	75.1%		FF:	76.3 %	
η:	15.8 %		η:	18.3 %	
T:	31.6 °C		T:	27.5 °C	

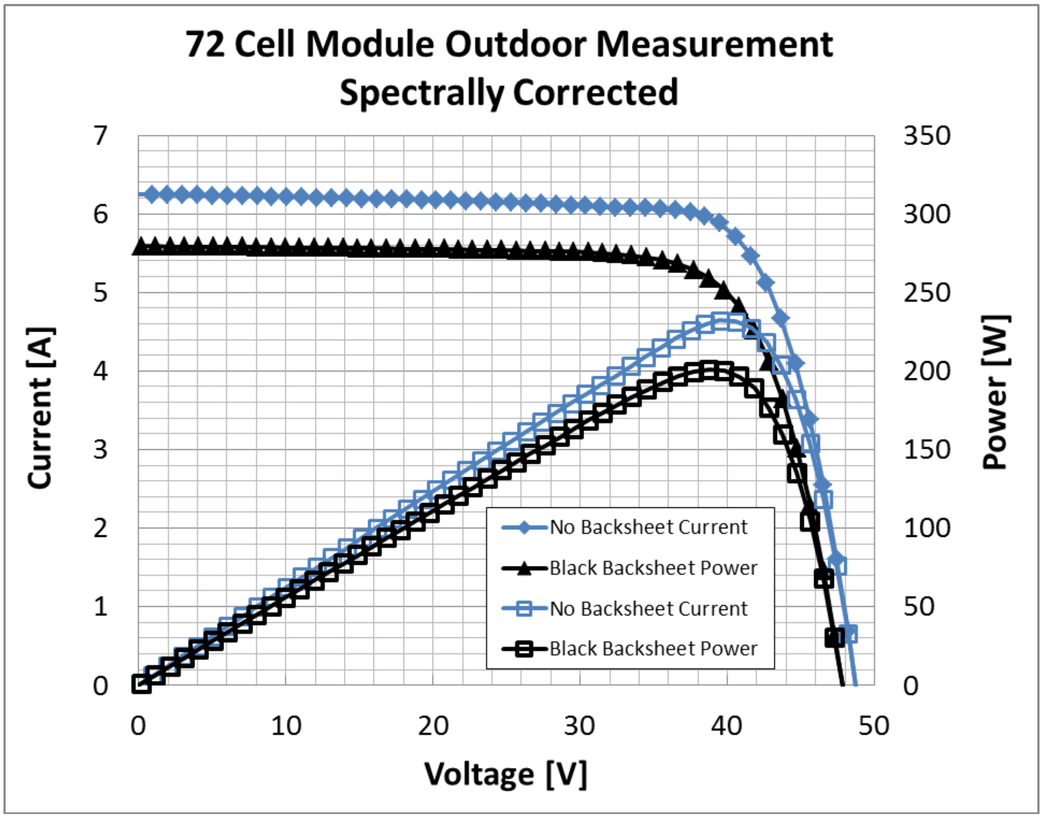

Figure 5: IV measurement of full-size module as taken by NREL in an outdoor measurement. The module was measured in two conditions: with a black backsheet placed on the back, which suppresses albedo illumination, and "as is," which allows for bifacial operation of the module. The latter condition results in clearly increased power generation by 14% relative due to the rear side illumination.

Task 6 is concluded by the manufacturing of three modules by a beta customer of TetraSun during the months of February, March and April of 2012. The modules consist of 72 cells each; they have 3 bypass diodes and used EVA and a white backsheet as encapsulant. The glass is antireflection coated. The IV test results performed by TetraSun's customer are shown in Table 6. The output power was significantly improved from the first to the third module by improvements in all parameters.

Table 6: IV measurements of 72 cell modules as measured by TetraSun's customer. The cells were fabricated in TetraSun's pilot line and shipped to the customer for standard module fabrication.

	Module 1	Module 2	Module 3
Production Date	Feb-12	Mar-12	Apr-12
P_{max} [W]	200.4	206.1	212.2
V_{oc} [V]	48.36	48.73	48.93
I_{sc} [A]	5.61	5.70	5.73
FF [%]	73.9	74.2	75.6

Installation Site

In order to prove TetraSun's technology in the field, an outdoor installation was set up consisting of the three modules described in the previous section. This is an established installation site that allows monitoring of the vital parameters of the installation: Power, solar irradiation and temperature. The modules face south and are mounted at an angle of 10 degrees. A picture of the installation is shown in Figure 6.

Figure 6: Picture of outdoor installation with three TetraSun modules in Yokohama, Japan.

The installation is under continuous monitoring since midday of May 7, 2012. As an example, the data collected on May 8, 2012, is shown in Figure 7 and Figure 8.

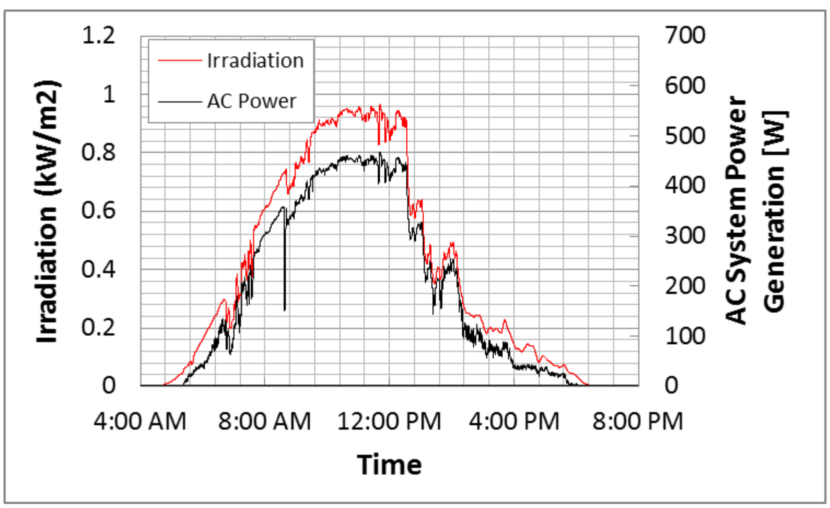

Figure 7: Test results of outdoor installation for May 8, 2012. The measurements are taken continuously 24/7; shown here is the interesting interval between dawn and dusk.

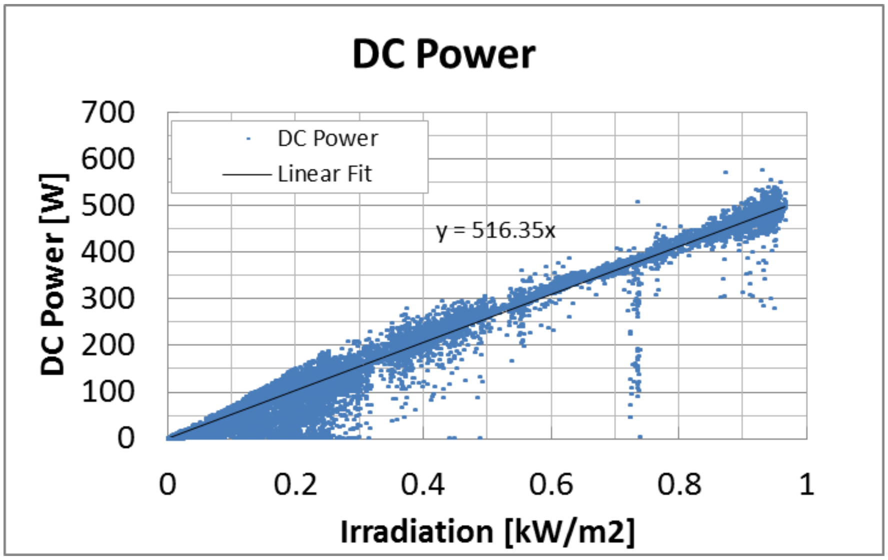

Figure 8: DC generated power over solar irradiation. The string generated 516 watts per kW of irradiation under the weather conditions in Yokohama on May 8, 2012.

In order to monitor performance over time, it is important to look at the ratio of DC power and the solar irradiation. This data is displayed in Figure 8 for May 8, 2012. The installation generated 516 watts per kW of solar irradiation (→ 516 W_p).

Computing the same ratio for every day yields the graph shown in Figure 9.

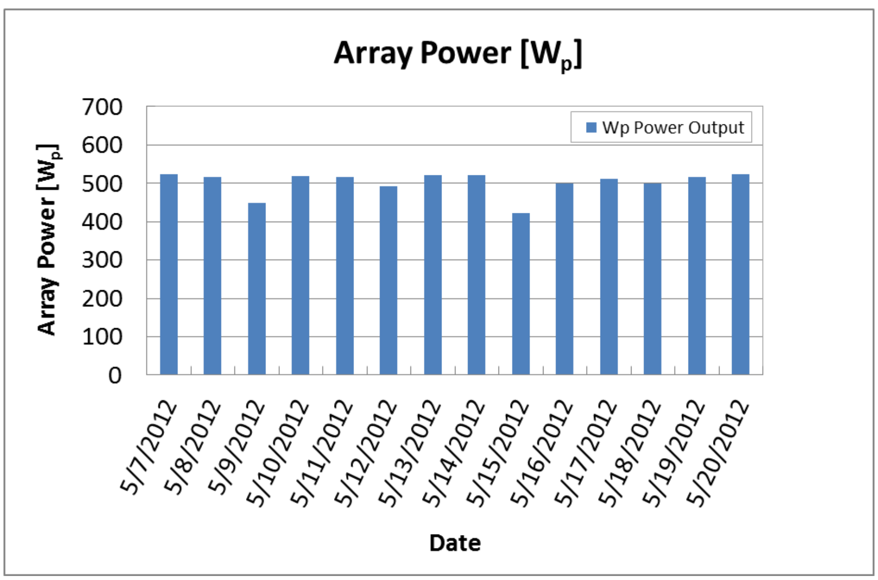

Figure 9: Stability of the test installation during the first two weeks of monitoring. The power is stable. Variations are a reflection of the changing weather conditions.

Task 5 – Pilot Production

After developing the basic process flow, TetraSun has started pilot production of the TetraCell in its Milpitas facility at 4.4 wafers per hour (wph); see Figure 10. Therefore the staffing level was increased to five technicians.

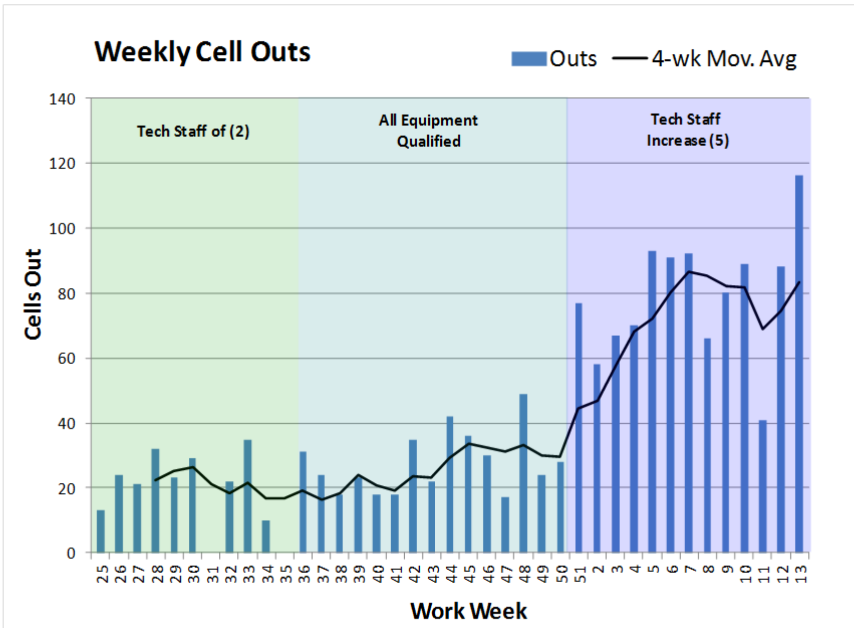

Figure 10: Throughput of TetraSun's pilot line. The lots delivered as D12 were run in week 3 and 4 of 2012, during the ramp of pilot production. It is expected to average at about 100 wafer starts per week for engineering and sample production.

Twenty cells from an early pilot run were measured against NREL calibration cell P8775 and submitted as deliverable D12. The results of the measurements are shown in Table 7. The measurements were verified by the NREL calibration laboratory. This ramp up of sample production made it possible to support the reliability program, full size module production and the outdoor installation. Also, the line supports engineering activities to continuously improve the cell efficiency, test new materials and qualify wafer supply. This had led to significant advancements and improved the baseline process at the time of completion of this project to 20%; see Figure 11.

Table 7: IV measurements of cells from early production run for D12. Equivalent cells from the same batch were used to build the minimodule of D14.

Cell ID	Area [cm2]	Voc [V]	Isc [A]	FF [%]	Pmax [W]	Efficiency [%]
820	148.6	0.671	5.425	77.4	2.820	19.0
823	148.6	0.672	5.426	77.2	2.817	19.0
825	148.6	0.674	5.416	76.9	2.805	18.9
826	148.6	0.673	5.428	77.6	2.834	19.1
827	148.6	0.674	5.401	77.9	2.835	19.1
837	148.6	0.674	5.403	78.0	2.840	19.1
838	148.6	0.674	5.401	77.4	2.819	19.0
839	148.6	0.673	5.410	77.5	2.820	19.0
844	148.6	0.677	5.401	78.2	2.857	19.2
845	148.6	0.676	5.439	78.3	2.881	19.4
846	148.6	0.677	5.451	78.7	2.904	19.6
848	148.6	0.676	5.444	77.5	2.852	19.2
851	148.6	0.677	5.385	78.5	2.861	19.3
852	148.6	0.673	5.386	77.1	2.797	18.8
853	148.6	0.676	5.394	78.2	2.851	19.2
854	148.6	0.675	5.442	78.1	2.868	19.3
958	148.6	0.679	5.399	78.1	2.862	19.3
961	148.6	0.679	5.438	78.1	2.881	19.4
963	148.6	0.679	5.452	78.2	2.896	19.5
968	148.6	0.680	5.460	78.0	2.895	19.5
969	148.6	0.680	5.446	77.3	2.862	19.3
Average	148.6	0.676	5.421	77.8	2.850	19.2

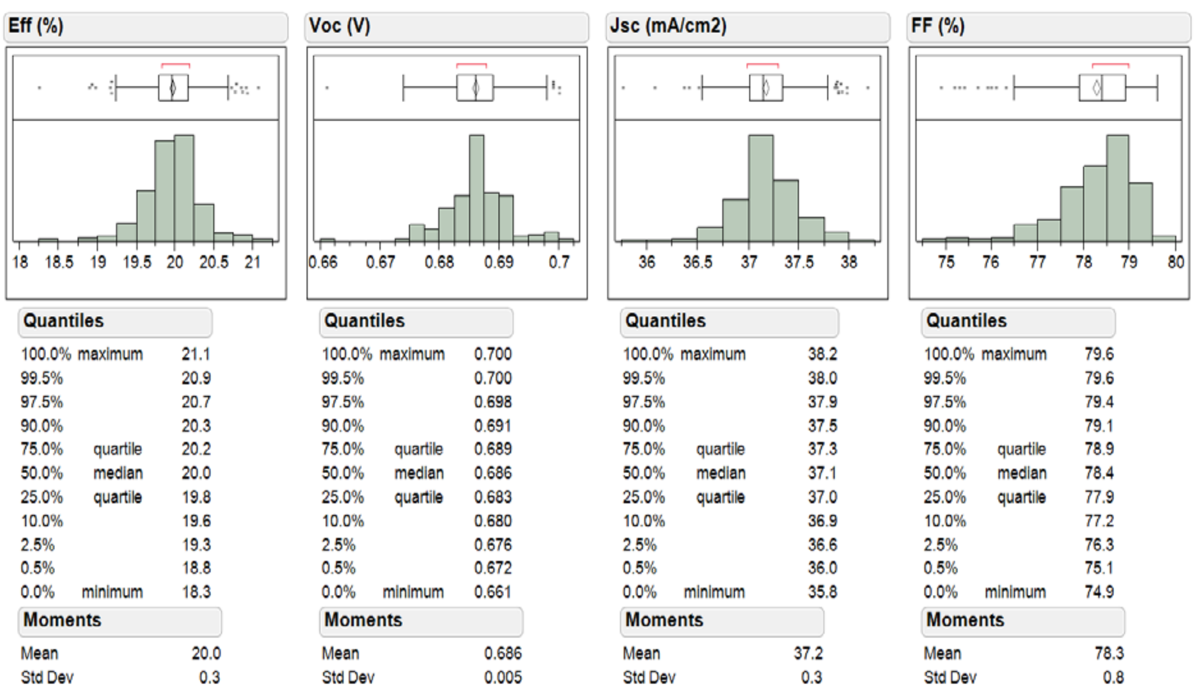

Figure 11: IV parameter distribution of baseline runs from March to April 2012. The efficiency distribution is centered at 20%.

Task 7 – Cell and Process Cost Analysis

TetraSun frequently validates the economic viability of its technical approach via a detailed Cost of Ownership (CoO) model. The following Figure 12 shows the modeled cell CoO broken down by category. Materials (includes chemistries, metals, gases…etc.) followed by depreciation contribute the most to the cell processing cost. It should be pointed out that the modeled CoO is a near identical porting of the process TetraSun currently runs in pilot production to high volume. To date, limited resources have been allocated to optimizing the process flow, individual processes or the high volume tool set to reduce the projected cell processing cost. Many opportunities do however exist for reducing the CoO, and as such the currently modeled CoO (~$0.19/W$_p$) represents a conservative estimate for the projected cell processing cost.

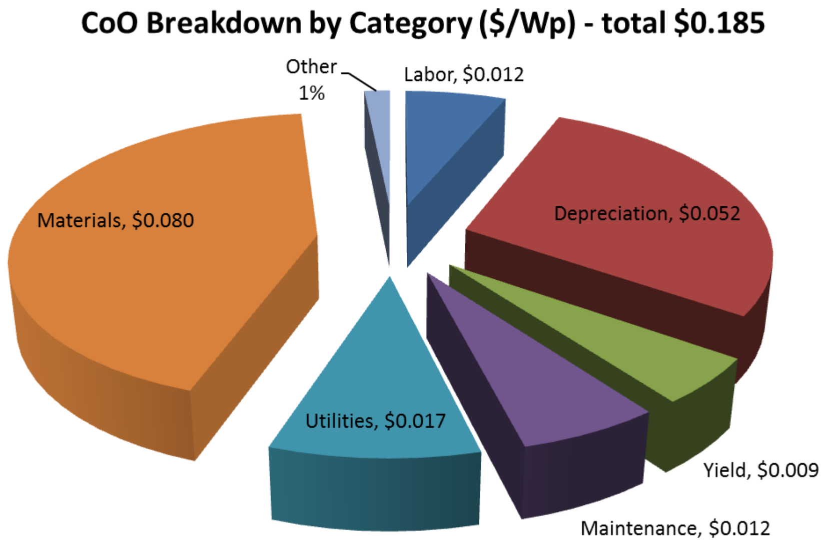

Figure 12: CoO model of first-generation TetraCells in high-volume production. The calculations include depreciation, yield losses, materials, etc.

Areas for specific targeted cost reductions include: reduced process cycle times, replacement of expensive chemistries with lower cost alternatives, negotiated equipment Capex reductions (list/standard pricing is currently used), and many more. It is estimated that cost reductions for materials (-$0.04/W$_p$) and depreciation (-$0.015/W$_p$) could be achieved in the near term. The resulting cell processing cost would be reduced from $0.19/W$_p$ to ~$0.15/W$_p$.

Table 8 below shows preliminary estimates for installed system cost for different areal installation costs ranging from $75/m^2 to $450/m^2. Such a range of installation costs approximately spans the current market from best-of-class utility scale installations (@~$150/m^2) to best-of-class residential installations (@~$450/m^2).

As can be seen a reduction in installed system cost between \$0.39/W_p and \$1.01/W_p (~22%) is achieved, in comparison to standard cell technology. Further, with moderate reductions in system and module costs of \$1.00/W_p total installed system cost, as per the SunShot Initiative, is readily achieved; see Table 8.

This reduction in installed system cost does not take into account further reductions in the LCOE which may derive from the use of TetraSun cell technology. For example, lower temperature coefficient (in comparison to screen-printed cells; see Figure 2) can result in increased energy yield of up to 10%.

Table 8: Value of efficiency and low cost. The calculations used show that with TetraSun's technology the SunShot Goal of \$1.00/W_p can be achieved.

Areal Installation Cost (\$/m^2) [2]	SunShot	\$75	\$150	\$225	\$300	\$375	\$450
Standard Module cost (\$/W_p)	\$0.78	\$1.08	\$1.08	\$1.08	\$1.08	\$1.08	\$1.08
TetraSun Module cost (\$/W_p)	\$0.50	\$0.82	\$0.82	\$0.82	\$0.82	\$0.82	\$0.82
Standard Module Installation Cost (\$/W_p) @ 15% [1]	\$0.50	\$0.50	\$1.00	\$1.50	\$2.00	\$2.50	\$3.00
TetraSun Module Installation Cost (\$/W_p) @ 20% [4]	\$0.38	\$0.38	\$0.75	\$1.13	\$1.50	\$1.88	\$2.25
Inverter Cost (\$/W_p) [3]	\$0.12	\$0.27	\$0.27	\$0.27	\$0.27	\$0.27	\$0.27
Standard Installed System Cost (\$/W_p)	\$1.40	\$1.85	\$2.35	\$2.85	\$3.35	\$3.85	\$4.35
TetraSun Installed System Cost (\$/W_p)	**\$1.00**	\$1.47	\$1.84	\$2.22	\$2.59	\$2.97	\$3.34
Dollar saving versus Standard	-\$0.41	-\$0.39	-\$0.51	-\$0.64	-\$0.76	-\$0.89	-\$1.01
Cost saving versus Standard	29%	21%	22%	22%	23%	23%	23%

1) Total area module efficiency for industry standard 15% crystalline silicon module
2) Derived from \$/Wp installation cost at 15% module efficiency
3) Taken from Photon International Sept 11. Fixed cost per Wp does not change with module efficiency
4) Total area module efficiency for TetraSun 20% crystalline silicon module