



SUNPOWER CORPORATION

Grid-Competitive Residential and Commercial Fully Automated PV Systems Technology

U.S. Department of Energy
Technology Pathway Partnerships
DOE Award DE-FC136-07GO17043

Final Technical Report

August 2011

This material is based upon work supported by the Department of Energy under Award No. DE-FC36-07GO17043.

Executive Summary

Under DOE's Technology Pathway Partnership program, SunPower Corporation developed turn-key, high-efficiency residential and commercial systems that are cost effective.

Key program objectives include a reduction in LCOE values to 9-12 cents/kWh and 13-18 cents/kWh respectively for the commercial and residential markets. Target LCOE values for the commercial ground, commercial roof, and residential markets are 10, 11, and 13 cents/kWh.

For this effort, SunPower collaborated with a variety of suppliers and partners to complete the tasks below. Subcontractors included: Solaicx, SiGen, Ribbon Technology, Dow Corning, Xantrex, Tigo Energy, and Solar Bridge.

Task	Description	Phase
1	Ingot Growing Technology Development	I
2	Wafering Technology Development	I-II
3	In-line Manufacturing of Back Contact Cells	I-III
4	Low-cost, High-Performance Modules	I-III
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SunPower's TPP addressed nearly the complete PV value chain: from ingot growth through system deployment. Throughout the award period of performance, SunPower has made progress toward achieving these reduced costs through the development of 20%+ efficient modules, increased cell efficiency through the understanding of loss mechanisms and improved manufacturing technologies, novel module development, automated design tools and techniques, and reduced system development and installation time.

Program highlights include:

- Obtained world record with 24.2% efficient cell
- Initiated production of 23% efficient cells
- Released 20% efficient modules to production at lower cost than previous generation
- Developed first "unitary" rooftop product, T5 Commercial Rooftile, with 250 MWp+ in sales to date
- Launched next-generation tracker platforms using 128-cell modules, with 250 MWp+ in planned deployment
- Ramped module production at 75-MWp domestic modco in Milpitas, CA
- Introduced universal monitoring platform for residential and commercial segments

Based on an LCOE assessment using NREL's Solar Advisor Model, SunPower achieved the 2010 target range, as well as progress toward 2015 targets.

Market Segment	2010	2015
Commercial Ground	0.078	0.039
Commercial Roof	0.090	0.057
Residential	0.162	0.11

SunPower and TPP participants would like to thank the U.S. Department of Energy Solar Energy Technology Program for funding received under this program through Agreement No. DE-FC36-07GO17043.

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TPP Overview

Project Title: Grid-Competitive Residential and Commercial Fully Automated PV Systems Technology

Covering Period: September 1, 2007 – January 31, 2011

Date of Report: February 28, 2010

Award Number: DE-FC36-07GO17043

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Project Objective & Summary
To develop turn-key, high-efficiency residential and commercial systems that are cost effective in delivering electricity at grid parity. Key program objectives include a reduction in LCOE values to 9-12 cents/kWh and 13-18 cents/kWh respectively for the commercial and residential markets. Target LCOE values for the commercial ground, commercial roof, and residential markets are 10, 11, and 13 cents/kWh.

Throughout the award period of performance, SunPower has made progress toward achieving the LCOE cost targets through the development of 20%+ efficient modules, increased cell efficiency through the understanding of loss mechanisms and improved manufacturing technologies, novel module development, automated design tools and techniques, and reduced system development and installation time.

Budget

Budget Period	Start	Finish	DOE Funding	TPP Cost Share	Total
1	9/1/2007	10/31/2008	$10,454,981	$11,656,980	$22,020,961
2	11/1/2008	10/31/2009	$8,879,139	$10,394,475	$19,273,614
3	11/1/2009	2/28/2011	$4,728,895	$5,524,366	$10,253,261
Total			$24,063,015	$27,484,821	$51,547,836

**Final cost share may exceed negotiated amount based on final expenditures*

Task 1: Ingot Growing Technology Development

TPP Task Lead: Solaicx *Phase I*

Task Objective
Develop and commercialize continuous Cz silicon ingot growing technique

Highlights

- Fabricated 22% cells with material from continuous-growth Cz silicon ingot

Milestone Summary

	Milestone	Status as of Phase Completion
	Phase I	
√	Evaluate ingot produced from new grower cycle for low oxygen and high lifetime	Completed as planned

Technical Accomplishments

Phase I

In a conventional batch process, each crystal puller cycle of operation produces a single ingot. The crucible is destroyed and the cost of pot scraps are charged to the ingot grown. In a continuous process, however, multiple ingots can be grown. Thus compared to conventional batch ingot growth, costs are reduced by sharing consumable costs over multiple ingots, by reducing cycle times and improving silicon use efficiencies. Maintaining the melt height in the crucible at a constant provides stable growth conditions which allows maximized pull speed further reducing cycle time. Solaicx demonstrated the feasibility of continuous growth of silicon crystal ingots in a prototype crystal grower with the potential to increase throughput from ~1MWp per year to >4MWp. Critical success factors for the Solaicx program include meeting targets for low cost, oxygen concentration less than 16 ppma, and minority carrier lifetime more than 1 ms in n-type single crystal silicon. Low costs are driven by fabricating the maximum number of ingots in a single cycle of operation, by producing the maximum kilograms per hour of material and by most efficient use of the lowest cost polysilicon feedstock. Low oxygen and high lifetime derive from optimal crystal growing conditions.

Initial results for this growing technology demonstrated the potential of this growing technique to yield similar results to existing processes; see Table 1.

Table 1. Comparison of SunPower cells made with standard and Solaicx continuous-growth ingots

Wafer type	Median Voc (mV)	Median Jsc (mA/cm^2)	Median FF (%)	Median η (%)
Standard	683.5	40.78	79.65	22.2
Solaicx	681.2	42.07	79.71	21.9

Further development work on this portion of the program was discontinued for subsequent phases due to Solaicx focus on p-type silicon during this time period.

Task 2: Wafering Technology Development

TPP Task Participants: SunPower Corporation & SiGen *Phases I & II*

Task Objective

Highlights

- Migrated all production to 145-µm wafers

Milestone Summary

	Milestone	Status as of Phase Completion
	Phase I	
√	Demonstrate prototype wafer sample at 165 µm thickness before etching to usable thickness for cell and meeting manufacturing requirements for wafer quality.	Demonstrated manufacturing capabilities using 145 µm thickness wafers Migrated 40% of production to new wafer thickness
P	Optimize BeamSaw throughput by minimizing the implant dose required for a successful cleave process. Once the process has been optimized, implant and cleave at least one hundred wafers (100) and measure BeamSaw throughput and yield.	• Made > 100 samples of 50 um thick wafers • Not possible to make the thicker 120 um wafers until the new hardware is qualified • Production throughput and yield numbers were not established by the close of Phase I
	Phase II	
√	Demonstrate wafer sample at 165 µm thickness before etching made with prototype equipment but demonstrating parameters expected from production equipment.	Initiated production of 145 µm thickness wafers in full production at SunPower
	Phase III	
√	Demonstrate wafer sample at 145 µm thickness before etching made with combination of prototype and production equipment demonstrating parameters expected from production equipment and meeting manufacturing requirements for wafer quality.	Completed in Phase II with early adoption of 145-µm wafers in production

Technical Accomplishments

Phase I

This effort focused on the demonstration of using thin wafers (165 µm and 145 µm respectively) in the full scale manufacturing process. The work included modifications to the manufacturing process and equipment set to enable use of thin wafers. SunPower successfully processed wafers, cells and modules using 145 micron thickness. At the close of this phase, SunPower produced approximately 40% of total production volume with cells at this thickness and continued implementation for all production in the subsequent phase. Improvements in cell handling and soldering aided in allowing this task to be done at an accelerated pace.

In parallel with internal efforts, SunPower partnered with SiGen on the development of a novel wafering technology. Leveraging existing technology, SiGen worked to use layer-transfer technology to cleave wafers from bulk material. This “kerf free” process offered the potential for improved silicon utilization, while maintaining high efficiencies.

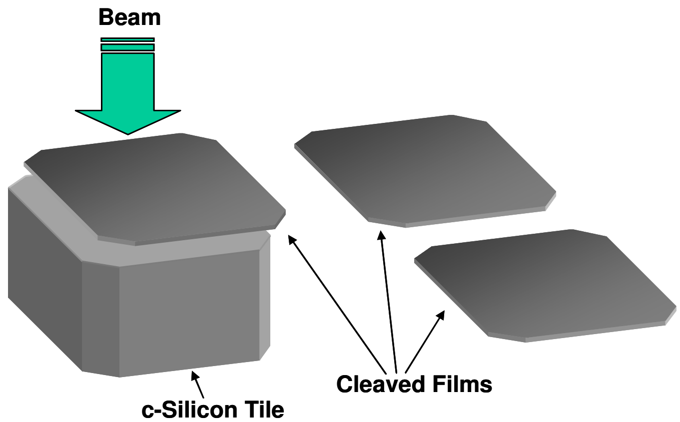


Figure 1: SiGen wafer cleaving process

During this phase, SiGen focused on hardware modifications to achieve the desired wafer thickness (≥120 µm) and process validation. SiGen successfully processed wafers at 125x125 mm form factor at 50-µm thickness. The image below shows a typical wafer edge using this process.

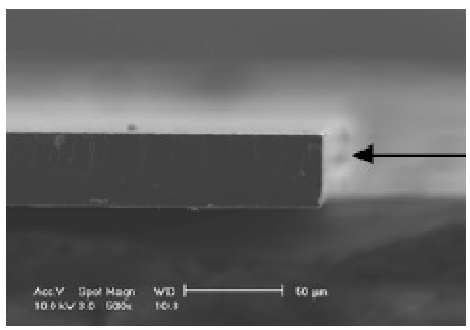


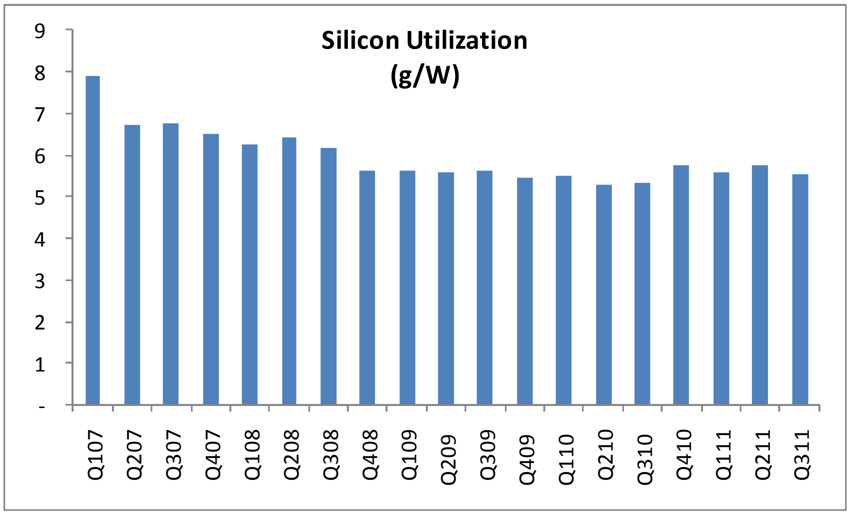
Figure 2: SiGen wafer edge profile

SiGen performed this work using silicon material with <1,1,1> crystal orientation. However, due to issues inherent in the cleaving process with respect to achieving other crystal orientations, SiGen was unable to achieve the desired results using <1,0,0> materials, as required by SunPower.

SunPower also engaged Ribbon Technology in a short demonstration. This effort focused on developing a method to ‘float’ molten silicon on to liquid tin or indium and manufacture ribbon silicon in a similar manner as that of window glass. The initial work from the subcontract was very encouraging, but considered to be years away commercialization.

Based on the recommendations of the Review Committee following Stage Gate 1, both partnerships were discontinued. SunPower then entered Phase II focused solely on production implementation of thinner wafers.

Phase II
Early in this phase, SunPower fully migrated production to 145 µm wafers. This work resulted in yielding approximately 7-8 additional wafers per kilogram of silicon. This process achieved use of 5.8 g/W of crystalline silicon, the highest usage factor in the industry at the time.



With full implementation of this technology in Phase II, SunPower closed out this task nearly 18 months ahead of the original schedule.

Task 3: Automated In-line manufacturing of High Performance Back-Contact Solar Cells

TPP Task Participants: SunPower Corporation *Phases I - III*

Task Objective
Develop manufacturing processes and tools for high volume and low cost production of high efficiency solar cells.

Highlights
- Achieved world-record cell efficiency at 24.2% for large-area silicon wafers
- Released 22%+ efficiency cell into production in late 2010

Milestone Summary

	Milestone	Status as of Phase Completion
	Phase I	
√	Independently prototype solar cell structures and processes which, when integrated, result in a demonstration of feasibility for low cost manufacturing	Completed as planned
√	Complete initial evaluation of high throughput, low cost tools compatible with cell design and lower cost manufacturing suitable for high volume production	Completed as planned: initiated tooling development
√	Identify cost and solar cell performance of manufacturing approaches, project manufacturing costs, and down-select technologies	Completed as planned: locked cell architecture
√	Demonstrate progress toward development of 22% cell using pilot process using a combination of optimized and developed methods.	Achieved 22% efficiencies
	Phase II	
√	Demonstrate progress toward development of 23% cell using production processes	Achieved 23%+ efficiencies with production-ready processes
√	Demonstrate progress toward development of greater than 20% next-generation prototype one-sun cell	Achieved 20-21% efficiencies using simplified manufacturing processes
	Phase III	
√	Initiate production of 23% cells, third party certification, and customer qualification	Initiated production with 22%+ cells following comprehensive process evaluation and fine-tuning in production environment. With continued process development, achieved 23% target.
√	Demonstrate progress toward development of 23.0% next-generation production process one-sun cell that is produced with autoline compatible steps	Successfully produced 23.9% cell in laboratory-scale production Process optimization to achieve 23%+ cells ongoing

Technical Accomplishments
Solar cell conversion efficiency leverages cost savings throughout the value chain. Today, SunPower has initiated limited production of 23%+ cells. In the laboratory, we have measured up to 23.9% efficiency with the same cell design and processing. SunPower plans to continue improvement on the technology transfer from the lab to the production line in order to continue to improve the production efficiency over time. SunPower also plans to convert additional capacity to the new 23%+ cell production.

SunPower has successfully implemented a variety of solutions for improving the cell efficiency and lowering manufacturing cost. These have included evaluation of the geometry effects (design rules), optimization of the collecting junction, the use of long lifetime silicon and the effects of surface passivation. SunPower has extensively modeled the solar cell performance and loss mechanisms, and these models have been used to guide advanced cell design and process modification.

SunPower has focused an extensive effort on linking stand-alone equipment together to achieve a continuous inline manufacturing line. SunPower has achieved substantial cost savings from 1) reduction in number of handling steps, 2) reduction in facility footprint, and 3) improved overall operational equipment effectiveness (OEE). This conversion has been accomplished by replacing the batch processes with continuous in-line processes.

Phase I

Work for the next-generation cell began with simulations and initial laboratory development. During the first phase, SunPower made significant process toward the development of a 23% efficient cell. In this early phase, the San Jose laboratory routinely made cells in the 21-22% efficiency range, as measured by NREL.

Table 2: Preliminary efficiency data for cells made in the San Jose laboratory on full area wafers

Wafer #	Area (cm^2)	Voc (mV)	Isc (A)	Jsc (mA/cm^2)	FF (%)	η (%)
080822-01	148.6 *nominal*	709.7	6.003	40.40	77.5	22.24
080822-02		709.5	5.929	39.90	78.0	22.10
080822-03		705.3	5.892	39.65	78.3	22.90
080822-04		706.2	5.926	39.88	78.7	22.17
080822-05		709.4	5.941	39.98	78.8	22.36
080822-06		707.1	5.912	39.78	78.6	22.13
080822-07		711.1	5.898	39.69	77.8	21.97

In order to achieve these efficiencies, SunPower (i) optimized cell design rules (lines and spaces) [moving from 21.02% to 21.88%]; (ii) modified the passivation chemistry [to 22.60%]; and (iii) adopted use of high lifetime silicon materials [23.79%]. This progression is demonstrated in Figure 3 below.

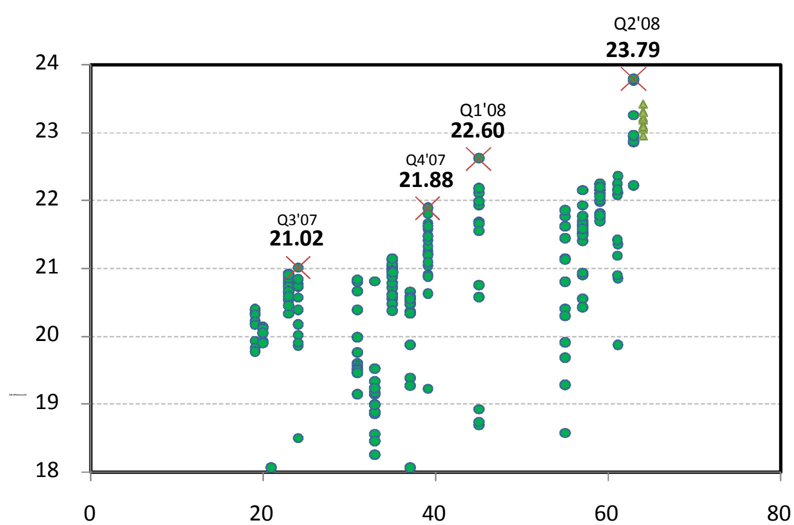


Figure 3: Graph demonstration migration of cell efficiency vs. prototype run

Phase II

After establishing the baseline cell design rules and process, SunPower then concentrated on improving manufacturability of the new cell. Simplification of the manufacturing process delivers substantial cost reduction through (i) reduction in number of handling steps; (ii) reduction in factory footprint; (iii) elimination of process materials; and (iv) improved operational equipment effectiveness (OEE).

Cells fabricated using the simplified process demonstrated promising results. Ongoing process development during the remainder of Phase II closed the efficiency gap to the 23% target for lab-scale production.

Table 3: Data for cells made with Phase II simplified manufacturing sequence in the San Jose laboratory on full area wafers

Wafer #	Area (cm^2)	Voc (mV)	Isc (A)	Jsc (mA/cm^2)	FF (%)	η (%)
PROD-1821	149.0	701.9	5.863	39.35	72.9	20.14
PROD-1824	148.7	706.4	5.829	39.19	74.2	20.54
PROD-1923	148.7	707.9	5.970	40.15	73.6	20.93
PROD-1924	148.7	703.8	5.832	39.23	76.7	21.18
PROD-1954	148.8	711.9	5.904	39.69	77.7	21.95

Additionally, SunPower continued to push the envelope on efficiency, as shown in Table 4 below.

Table 4: Data for high-efficiency cells made in the San Jose laboratory on full area wafers

Wafer #	Area (cm^2)	Voc (mV)	Isc (A)	Jsc (mA/cm^2)	FF (%)	η (%)
PROD-323	148.6	709.8	6.015	40.47	79.1	22.7
PROD-252	148.6	714.9	6.003	40.40	80.1	23.1
PROD-1401	154.9	722.4	6.235	40.26	78.4	22.8
PROD-1402	154.9	720.9	6.249	40.33	78.2	22.7
PROD-1403	155.0	717.9	6.238	40.24	78.7	22.7
PROD-1657	154.9	725.2	6.178	39.90	79.7	23.1

In parallel, SunPower laid the groundwork for transitioning from pilot- to production-scale manufacturing. During this period, SunPower installed the first prototype equipment in the Philippines as a pilot line for the new technology. Figure 4 shows the efficiencies achieved during the pilot ramp of the SPML line, using a combination of production and laboratory process steps.

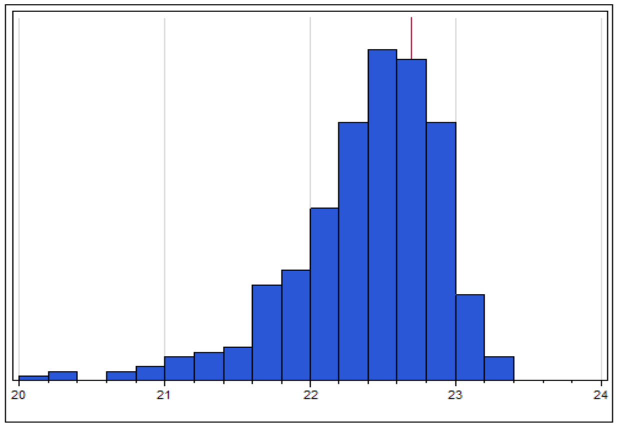


Figure 4: Cell efficiency distribution from early SPML runs

Phase III

In the final phase of the program, SunPower focused on finalizing the design specification and process recipes for the new generation cell technology and, subsequently, transferring the new process from the laboratory to the production line.

Early in 2010, the key technical focus was improving the performance of the simplified process from the previously reported 22% to the target of >23% through process optimization.

Table 5: Data for cells made with Phase III simplified manufacturing sequence in the San Jose laboratory on full area wafers

Sample #	Area (cm^2)	Voc (mV)	Isc (A)	Jsc (mA/cm^2)	FF (%)	η (%)
942	154.83 *nominal*	723.2	6.099	39.39	81.4	23.18
947		722.7	6.132	39.61	80.6	23.08
862		715.7	6.141	39.66	81.3	23.07

After demonstrating the 23% efficiency cells in the lab, the focus of our development efforts shifted to improving manufacturability through step or process elimination. The simplified sequence eliminated two steps from the original manufacturing process for this cell design.

In parallel with technology transfer efforts, SunPower continued to hone the laboratory-scale processes to further push efficiency. The efforts culminated in establishing a new world record for large-area silicon devices with the production of a 24.2% efficient cell (Table 6 and Figure 5).

Table 6: Characteristics of record Generation 3 production cell

Wafer type	Area (cm^2)	Voc (mV)	Isc (A)	Jsc (mA/cm^2)	FF (%)	η (%)
CZ (n-type)	155.1	721	6.275	40.46	82.9	24.2

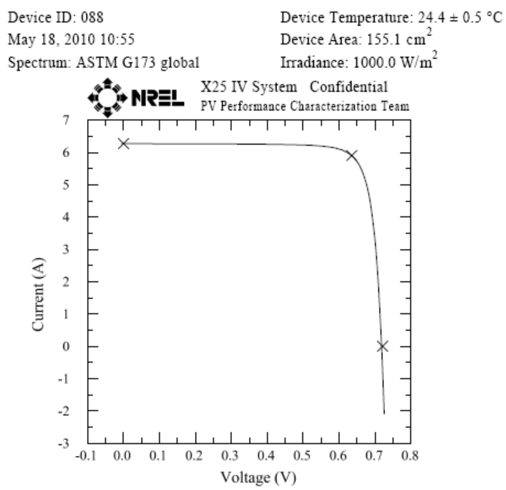


Figure 5: IV curve for record Gen 3 solar cell. Measured by NREL.

Beginning mid-2010, SunPower initiated the transfer of the new cell manufacturing processes from the laboratory to the production line in the Philippines. Initial lots demonstrated early success in the transfer, with many cells above 22% and few below 21%. Although these efficiencies were lower than the laboratory samples, these early results demonstrated manufacturing feasibility at the production scale. Additionally, the data showed strong process control based on similar efficiency distributions across multiple lots.

During technology transfer period, SunPower completed a comprehensive step-by-step process evaluation to identify and target critical parameters impacting efficiency. These efforts resulted in improvements for median efficiency of multiple lots (Figure 6).

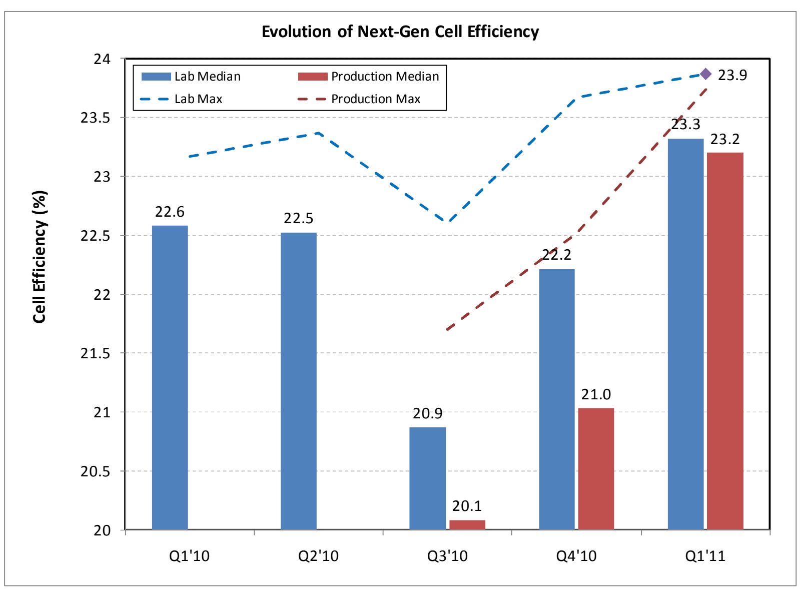


Figure 6: Maximum and median efficiencies for cells produced at laboratory and production scales

While the San Jose laboratory continued to produce cells with 23%+ efficiency, the median efficiencies on the production line migrated upward but remained below the target during pilot production. SunPower moved forward with bringing this technology into production at current efficiency levels and will continue to evaluate additional opportunities to improve the production efficiencies.

Following further process optimization, SunPower successfully achieved the 23%+ cell efficiencies on the production line.

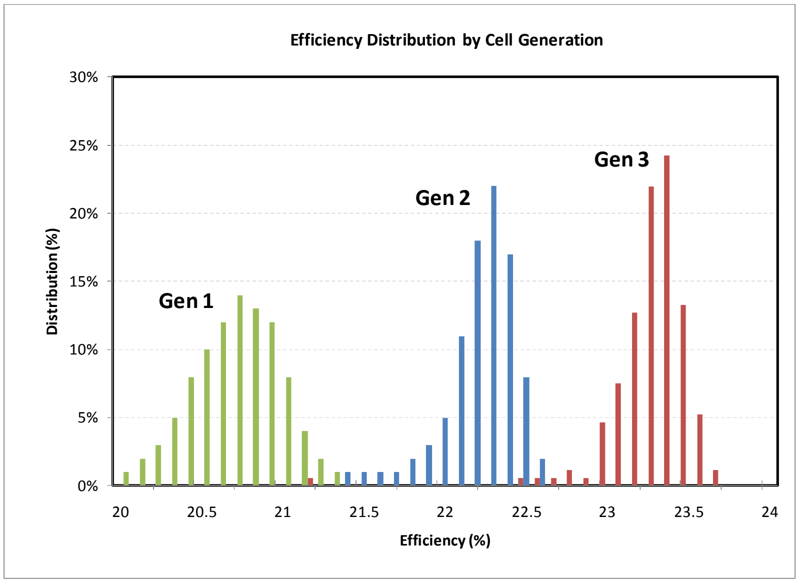


Figure 7: Production distribution for new 23%+ cell compared to previous generations of SunPower cells

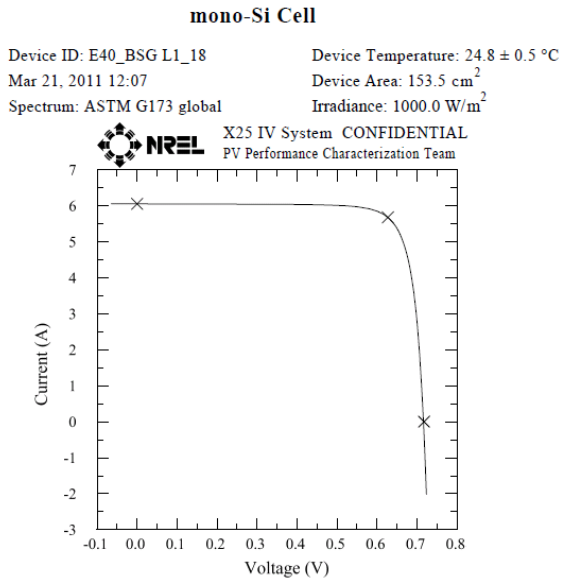


Figure 8: IV curve of 23% production cell

Task 4: Low Cost, High Performance Modules for Easy System Integration

TPP Task Participants: SunPower Corporation *Phases I – III*
Lower-tier: Dow Corning

Task Objective
Design modules compatible with downstream systems integration and installation processes. Design and develop manufacturing processes for cost-effective, high yield production of modules.

Highlights

- Released world-record efficiency module into production at 20.44% total-area efficiency
- Achieved 7% increase in module efficiency through improvements in module materials
- Demonstrated capability of bifacial modules for select applications based on field studies

Milestone Summary

	Milestone	Status as of Phase Completion
	Phase I	
√	Complete feasibility study of on-roof, polymer-front module	Feasibility study completed: lower performance than glass front modules, issues with soiling and scratches during installation.
√	Produce bifacial laminates with at least 3 constructions fielded for energy production experiments	Complete: modules fielded in Nevada for long-term evaluation
√	Develop prototype bifacial modules through reliability tests	Done, various issues encountered (delamination, discoloration etc), path forward to address the issues found.
√	Complete reliability tests of edge condition (exposed, plastic, metal)	No issues seen, designs selected are universal weather we use a frame/edge protection or leave exposed.
√	Complete module mounting comparison (back-bonding vs. frame)	Complete: selected frame mounting configuration
√	Demonstrate improved optical model to predict module losses to within 1% relative over range of optical properties of the front and back layers and cells	Completed model development and validation
√	Demonstrate electrical model with capability of reducing mismatch within modules and systems	Completed development of preliminary model
√	Produce reliability test results and cost comparison of conductive adhesives	Feasibility studies show reliability issues with this approach, resources redirected to improving soldering process.
√	Produce encapsulant enabling first-generation fire-rated laminate prototype	Feasibility studies show encapsulant enabled class A fire rated not possible (failed class A fire test).
	Phase II	
√	Demonstrate initial reliability and fire testing for full-size in-roof laminates	Completed fire testing and preliminary reliability evaluation
-	Demonstrate production of first-generation in-roof laminates	Postponed development targeted for residential segment due to market conditions
√	Develop and test second-generation, fire-rated laminate	Class A fire laminate was designed and tested. The laminate passed Class A fire test.
√	Down-select on-roof module approach and field test results of prototype on-roof module	Complete: simplified the design and material selection for on-roof approach.
√	Obtain UL certification of new module for roof-top commercial application	Obtained both UL and TUV certifications

	Milestone	Status as of Phase Completion
√	Demonstrate production module for commercial applications	Feasibility study completed: lower performance than glass front modules, minimal issues with soiling and scratches during installation.
	Phase III	
√	Demonstrate module designs compatible with downstream systems integration and installation processes.	Successfully launched new 96-cell and 128-cell module platforms into commercial and utility markets, respectively
√	Demonstrate design and development of manufacturing processes for cost-effective, high yield production of modules.	Designed, tested and implemented in production (limited release) improved soldering process that increased UPH by 8%.
√	Demonstrate development of second-generation modules for roof-top and ground-mount commercial applications.	Second generation 96-cell module was designed for optimized efficiency by changing the module design and materials and cell.
√	Demonstrate development of modeling tools and common technologies for module platforms.	Preliminary modeling tools for predicting module efficiency were developed.
√	Complete new generation component cost reduction, demonstrating cost reduction of 10% relative to baseline.	Alternative sources for selected module materials were identified and qualified.
√	Demonstrate development of adhesive and encapsulation materials and application systems.	Limited released modules with improved light trapping into cells, enabled by improved transmission through glass and encapsulant, enabling first 20% efficiency module commercially available. Volume production expected in 2011.
√	Produce encapsulant designed for improved module efficiency	

Technical Accomplishments
While cell efficiency is the primary driver in overall system performance, the packaging of cells into modules is the basis for all downstream system design. Through the TPP, SunPower leveraged its vertical integration to co-develop module and system products for target markets. Through this work, SunPower developed next-generation residential and commercial module platforms, with emphasis on advances in the latter reflecting market conditions.

Performance Modeling *Phase I*

Early work focused on the improvement of optical modeling of modules in order to identify loss components. SunPower modeled the various interfaces and materials based on measured absorption, reflections, and transmission data. This modeling tool delivered results within 1% of measured values and served as a means of screening materials under consideration. Additionally, the tool improved the team's understanding of losses and developing mitigation strategies in order to improve efficiency.

Manufacturing Technology *Phase I*
The work in this task leveraged SunPower's PV Manufacturing R&D subcontract entitled "Automated Manufacturing of High Efficiency Modules" which was terminated when this agreement began. During this phase, SunPower implemented modifications to production equipment and processes to enable handling of thinner wafers (Task 2). Initial production runs utilizing thin silicon wafers confirmed the manufacturing feasibility with yields exceeding the initial target of 98.5% for both 145- and 165-μm cells.

Fire-rated Laminates

Phase I
Targeting residential and commercial rooftop markets, SunPower pursued development of a first-generation fire-rated laminate, with the goal of producing a product capable of achieving Class A fire

rating under UL1703 test conditions. Preliminary testing with materials form Dow Corning showed promising results with the use of Silicone encapsulants. The team built prototype laminates using the following construction: glass/silicone/cells/silicone/glass. These prototypes underwent preliminary environmental testing, including humidity-freeze, thermal cycling, and damp-heat testing. The humidity freeze test data showed a minimal drop in module efficiency.

	Delta relative to control			
Sample	Voc (V)	Jsc (mA/cm^2)	FF (%)	Δ μ (%)
1	-1.33	-0.69	-0.24	-2.25
2	-0.52	-0.99	0.12	-1.38
3	-1.23	-1.82	-0.63	-3.65
4	-1.62	-0.99	-0.82	-1.45
5	-1.01	1.07	0.12	0.17

The early results of the environmental testing guided Dow in developing the next set of encapsulant samples for evaluation in Phase II.

Phase II
Following the environmental testing performed in Phase I, SunPower continued development work on several constructions geared toward achieving the Class A fire rating. Panels were manufactured using Silicone, EVA, and glass as the back side cover sheet. Both the EVA and the Silicone backside constructs failed the Class A first testing. However, the glass/glass construction survived and passed the testing. The glass / glass panel presented considerable manufacturing and cost barriers. Based on the results of this work, SunPower suspended further development of fire-rated laminate.

(i)

(ii)

Figure 9: Results of “Spread of Flame” test for Class A fire-rating, showing (i) failure of Silicone construction and (ii) pass of glass/glass construction.

<u>Bifacial Modules</u>

Phase I
For select applications, bifacial module constructions offer the potential for increased energy production. During this phase of the program, SunPower produced prototype modules with 16.8% front- and 10% backside efficiency. In field testing, backside irradiance varied between 10-20% of front-side irradiance. Initial results showed promising gains relative to the standard module construction, prompting follow-on work in subsequent phases of this program.

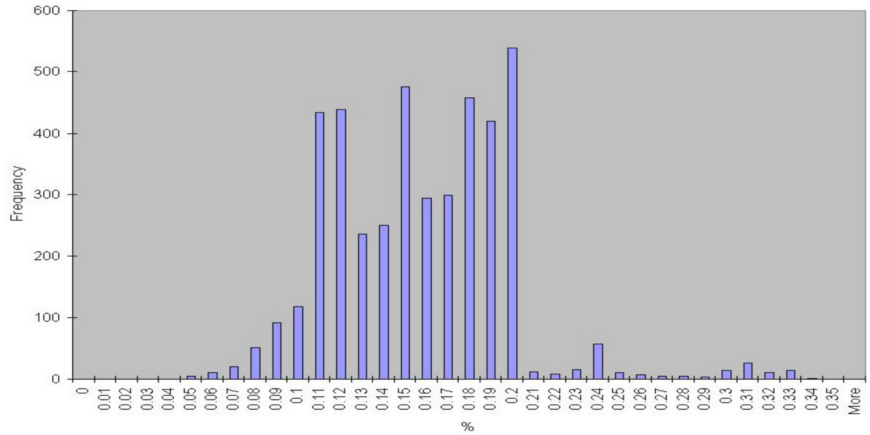


Figure 10: Histogram showing % of backside irradiance relative to frontside

Phase II

Building on the early validation work from the previous phase, SunPower began prototyping bifacial module constructions geared for large commercial and utility systems. The team focused on the identification of optimal material stacks and quantifying the power contribution from the backside of the module to the overall module power output with field testing. Modeling and measuring the backside contribution presented considerable challenges, requiring the creation of a new model to predict energy production. Further refinement of the model and field testing was required in order to move this technology forward in the final phase of the program.

Phase III

<u>Material selection</u>*:* SunPower designed an experiment to establish encapsulant browning rate profiles for a variety of constructions at different temperatures. A detailed characterization and model of the browning effect was completed and validated by experimental data, which used a variety of backsheet and encapsulants for comparison. We used these results to estimate the extent of browning and effect on reliability and performance over the module life.

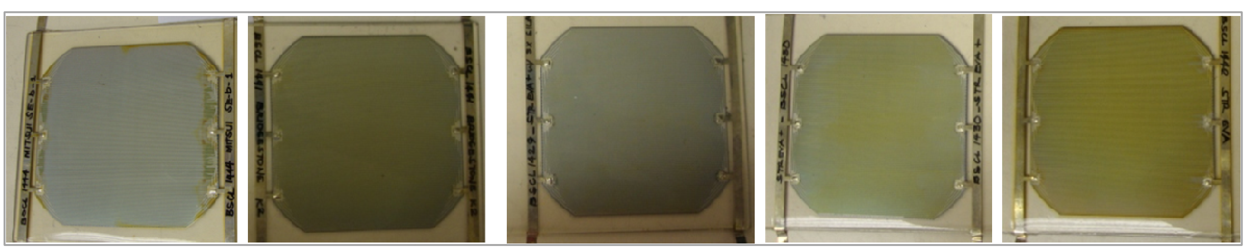


Figure 11: Examples of accelerated browning on a variety of bifacial backsheet and encapsulant candidates

SunPower then downselected the bifacial laminate materials to address concerns of browning observed in laboratory samples (Figure 11). Based on these results, the team concluded that minor backside browning was comparable to that observed with existing materials and will have no significant impact on long term reliability or performance of the modules. Future work on bifacial modules will focus more on mechanical design in context of specific end system application assuming this material combination.

<u>Field performance</u>: Bifacial modules offer a potential energy gain at many sites. However, relative gain compared to standard construction has both site and seasonal dependence. In the final phase of the program, SunPower fielded two bifacial module configurations at a commercial tracker site. At the site, SunPower installed continuous, string-level monitoring of bifacial modules in two different mounting configurations. These strings are monitored side-by-side with a string of mono-facial control modules. All modules were built from the same lot and bin of cells to reduce random cell variations as much as possible.

Figure 12: Bifacial modules interspersed with standard product commercial installation. Control (row 2) and bifacial modules (rows 3 and 4) field at commercial T0 site for continuous string monitoring

Data from the initial field results showed relatively low gains due to the low ratio of back to front irradiance. For this site, SunPower anticipates more promising results because snowy ground cover will increase the back/front irradiance factor and increase bifacial performance.

Table 7: Expected vs. actual energy gain for 72-cell and 96-cell bifacial modules

Form factor	Expected Energy Gain (VF 0.75)	Measured	
		Back/Front Irradiance	Energy Gain
96-cell bifacial	0.7%	10%	0.9%
72-cell bifacial	0.7%	10%	1.3%

In parallel to this evaluation, SunPower expanded monitoring of backside irradiance to five additional commercial sites throughout California to better characterize the potential benefit of fielding bifacial at a variety of locations. The systems were selected to cover a variety of ground cover conditions and GCRs – both of which are expected to significantly affect backside irradiance. This monitoring will stay in place long term to observe how seasonal variation affects performance.

Commercialization: During the course of this program, SunPower's evaluation demonstrated the potential benefits of bifacial technology. Further commercialization of this technology will continue to be assessed based on market conditions.

While the performance of the system was validated, there were several additional considerations gating the decision to commercialize this technology:

- Universal Applicability: The performance was very sensitive to the reflectivity of the ground. This limited the total accessible market for this technology.
- Cost: The bifacial modules had a higher cost/watt when compared to the standard modules, and this cost had to be offset by higher system performance. Our analysis showed that this was possible, however, only on a systems very well suited to bi-facial module performance.

For these reasons, SunPower discontinued is work on bi-facial module platform.

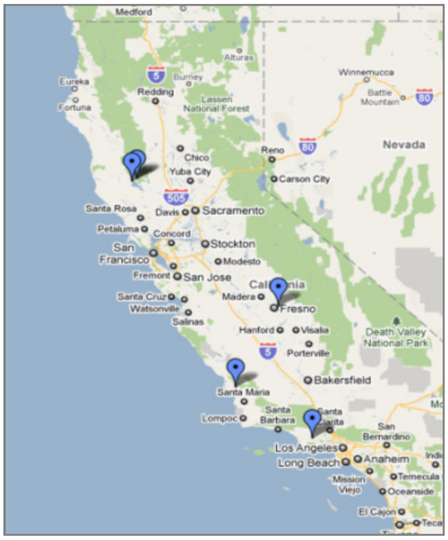


Figure 13. Locations of backside irradiance monitoring sites.

Figure 14. Installation of backside irradiance sensors on existing tracker system

Next-Generation Modules

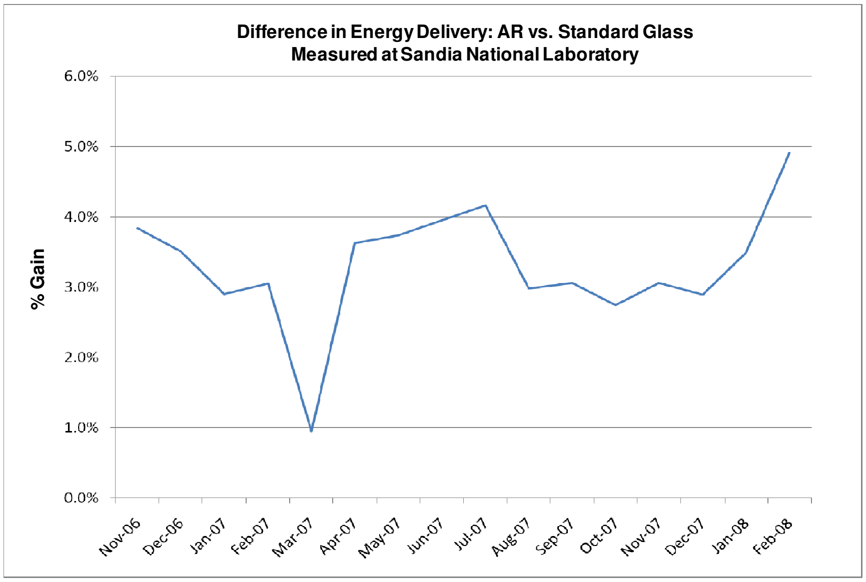
Larger diameter cells

Phase I
During the first phase of this program, SunPower introduced a new module series using larger-diameter cells. The migration from 150-mm and 165-mm cells increased the packing density in the module, thereby increasing module efficiency. In combination with other design changes, use of these cells enabled production of modules with efficiency >20%, a new world record at the time of measurement.

Phase III
In the final phase of the program, SunPower migrated to 160-mm cell diameter based on a refreshed cost-benefit analysis given changes in polysilicon feedstock pricing. With the other gains in the cell and module efficiency, SunPower is still able to manufacture modules with 20%+ efficiency.

AR Glass

Phase I
In an effort to further boost module efficiency, SunPower continued ongoing work associated with utilizing glass with anti-reflective coating as a new standard for module construction. Beginning in late 2006, SunPower partnered with Sandia National Laboratory to evaluate early prototype modules side-by-side with standard panels. SNL reported a 2.8% average increase in energy production over a 16-month period.



During this phase, SunPower completed material validation with encouraging early results through a 10,000-unit field test. The results showed a 0.6% gain in panel efficiency, with a resulting increase in power of 2.5-3.0%. While the efficiency gains held the potential for lower LCOE, further commercialization of this technology required follow-on development to address known issues with coating defects and non-uniformity, as well as reliability assessments of material degradation overtime.

Phase II

While AR glass offered the potential for significant efficiency gains, the manufacturing and handling issues encountered required additional development work prior to large-volume adoption of this technology. SunPower coordinated with suppliers to improve the durability of the coating in order to reduce risk of damage associated with shipping, processing, and installation.

During this investigation, SunPower identified and initiated qualification of an alternative ARC glass with durability similar to uncoated glass, yet still able to deliver increased power. Figure 15 provides a summary of accelerated test results from this phase. Based on these results, SunPower chose to move forward with large-scale production using AR glass across its multiple module platforms.

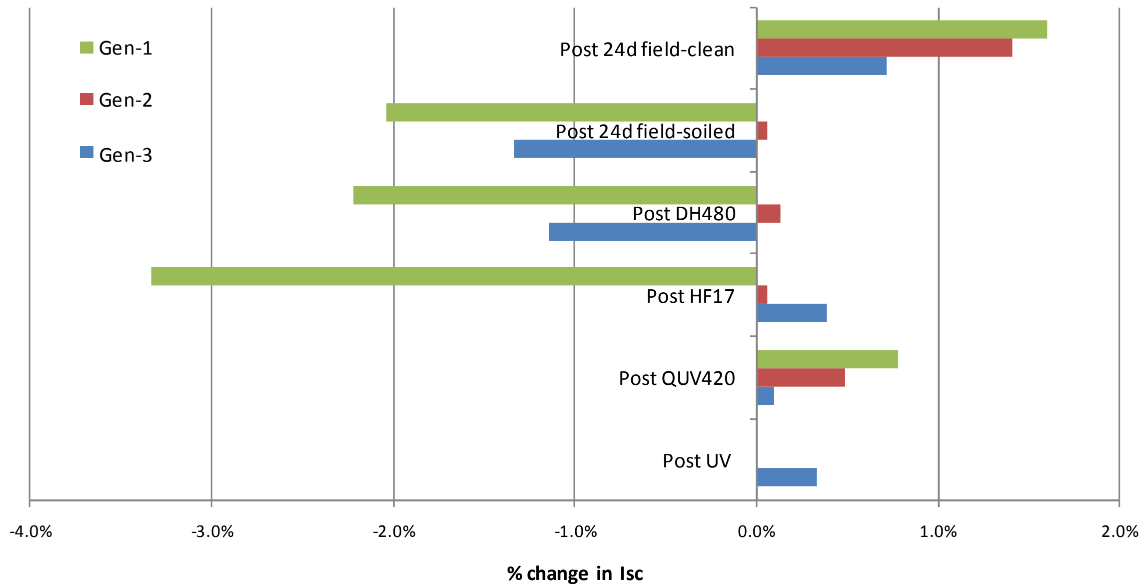


Figure 15: Results of accelerated testing for alternate AR coating

Phase III
Performance Gain: In early 2010, SunPower began to ramp production with AR glass, including bringing on an alternate coating. The flash test data associated with the first 800 module production run confirmed the expected 2.5% performance gain relative to standard modules.

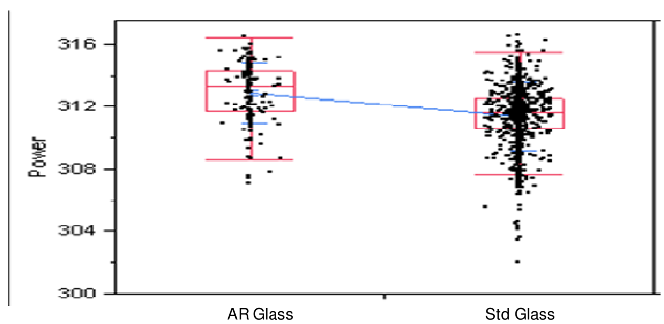


Figure 16: Power comparison by glass type

Manufacturing: Given the performance gains achievable with AR glass, SunPower pursued expanding use across multiple product lines. However, product availability and early runs with AR glass showed

During the production ramp, SunPower Operations experimented with pro-active cleaning procedures in order to mitigate damage to the AR coating. While manufacturing at pilot volumes, the team noted encapsulant residue on the AR glass during the lamination process (Figure 17). By increasing the frequency of laminator cleaning, this issue was greatly reduced with limited impact on line time.

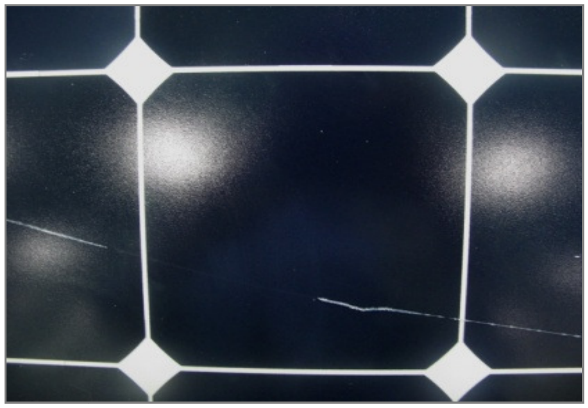
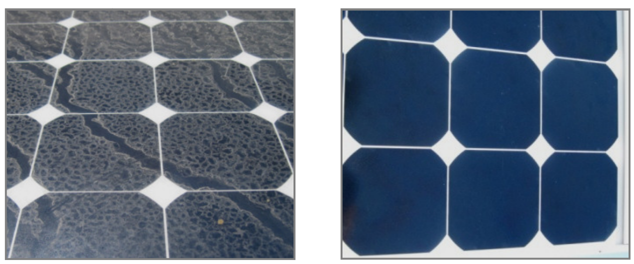


Figure 17: Photo showing streak of encapsulant residue on AR glass following lamination

Field performance: Throughout the development process, SunPower continued to monitor early installation sites for energy and physical performance. SunPower inspected modules with AR glass coating with 8 months of exposure in an area with severe dust, near a concrete plant. Significant soiling occurred on the modules installed in a horizontal orientation. Post washing with dish soap and water, no scratching or residual soiling was seen. No power loss was measured following cleaning. Figure 18 shows a comparison pre- and post-washing.



(i) (ii)

Figure 18: Comparison of (i) soiled AR glass module with 8-months exposure and (ii) post-washing showing no damage to coating

In-Laminate Diodes

To validate use of in-laminate diodes, SunPower worked to model and validate the temperature profile of the diode and surrounding area when the diode is functioning. When areas of the module are shaded and the bypass diode kicks in, the team anticipated the diode to reach higher than normal operating conditions for the PV module (85℃), which could prematurely lead to accelerated aging of the encapsulant and other materials in the PV module near the diode location. Both simulations and experimentation showed that the diode could reach up to 30℃ hotter than the rest of the module.

During mid-2010, SunPower made three 72-cell modules using the in-laminate diodes and new heat sink design. Field tests of these modules included selectively shading cells to trigger the diodes and confirm operation. Initial field results matched the expected temperature range based on the design targets. Ongoing results continued to show the diodes operating below 85℃, as designed.

Although field results were promising throughout the contract period, the team found potential reliability risks with the original component design. While thermal cycling the prototypes, the team identified a potential delamination failure for this particular diode. Based on these results, SunPower re-entered design discussions with the current vendor and began to explore other alternatives. Continued evaluation will continue beyond the agreement period.

Improved Transmission Encapsulant
During the final phase of the program, SunPower coordinated efforts with a key supplier to develop a new encapsulant with improved light-capture properties.

A side-by-side beta test system has been designed to validate the energy gain from the encapsulant with improved transmission in the field. The average module power and gain is shown in Table 8.

Table 8: Comparison average power of baseline and improved encapsulant

Encapsulant	Avg Power (Wp)	Relative Gain (%)
Baseline	322	-
Improved transmission	328	1.7%

We manufactured and installed the first 1800 units of modules for beta site deployment in Q4 2010. Following installation, our team will begin performance monitoring for a 12-month period, beyond the SAI contract and reporting period.

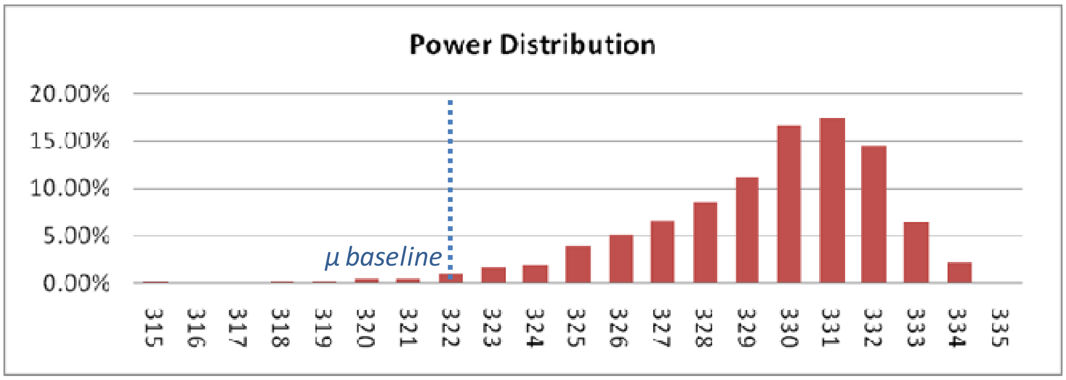


Figure 19: Power distribution for >1800 modules made with improved-transmission encapsulant

New Product Introduction: 96-cell and 128-cell Platforms

Phase II
SunPower obtained UL certifications for the 96-cell and 128-cell module series using reduced-cost constructions and larger cells introduced in Phase I. During this phase, SunPower launched the 96-cell commercial module, as well as the unitary T5 commercial rooftop product (Task 5).

Phase III
128-cell Module Launch: During the final phase of the program, SunPower successfully ramped production of the 128-cell commercial module. SunPower developed this module platform in parallel with the development of the next-generation T20 tracker (Task 5) and fielded the first major installation at a 20-MWp utility-scale array in Colorado.

This deployment enabled SunPower to validate the new shipping construct for the large-format modules, monitoring shipping yields and ease of handling in field. With this shipping design, SunPower achieved 200 kWp/truck shipping density with the larger modules.

Figure 20: SunPower's 128-cell modules shown (i) palleted on job site and (ii) during installation on T20 v2.3 tracker

Task 5: Unitary Product Design

TPP Task Participants: SunPower Corporation *Phases I – III*

Task Objective
Develop a family of products for the residential, commercial, and utility markets whose designs are conducive to automated production/integration in a factory environment.

Highlights

- Developed and released T5 Commercial Rooftop product into production
  - Sold 250-MWp deal with Southern California Edison
- Developed and released T20 v2.3 Commercial Tracker product into production
  - Installed 20-MWp array in 2010 for Xcel Energy in Colorado
  - Initiated installation of 24-MWp array during late 2010 in Ontario
- Fielded alpha design of next-generation horizontal tracker at local test site

Milestone Summary

	Milestone	**Status as of Phase Completion**
	Phase I	
√	Release pilot of next-generation rooftop system for constrained rooftops	Launched SunPower's T5 Commercial Rooftop product for pilot production
50%	Develop prototype of next-generation residential retrofit product	Identified key attributes of the next generation design based on extensive market analysis and developed preliminary designs *Removed from program scope due to ongoing downturn in housing market*
25%	Develop prototype of next-generation BIPV rooftop product. Develop prototype of next-generation retrofit product	Developed and evaluated preliminary designs. Initiated preparation of patent applications.
√	Develop prototype next-generation tracker technology	Installed prototypes of next-generation T20 trackers at internal test site
	Phase II	
√	Release production version of next generation commercial rooftop system for constrained rooftop	Ramped launch of T5 Commercial Rooftop Product with limited release in March 2009 and full release in October 2009
√	Develop prototype of next-generation commercial rooftop system for unconstrained rooftops	Built prototypes based on preliminary designs
√	Release production version of next-generation tracker technology (multiple versions)	Released next-gen T20 trackers for pilot production in May 2009
	Phase III	
√	Demonstrate development of a family of products for the commercial market with designs conducive to automated production/integration in a factory environment	Released T5 commercial roof tile and T20 tracker platforms during Phase II
√	Complete prototype of next generation unitary ground tracker	Installed alpha prototype of two rows with planned production vendor
√	Demonstrate pilot manufacturability and initiate field testing of unitary tracker through alpha release.	
√	Review captured and forecasted cost reduction activities for all previously released products	See SG3 SAM analysis

Technical Accomplishments
At the system level, SunPower undertook a product development program focused on the integration of the laminate with the mounting system for both rooftop and ground applications. This integration radically reduced installation time, eliminated redundant materials and labor, and improved system aesthetics.

<u>Residential</u>

Phase I
Work on the residential rooftop systems focused on market analysis and technical design of unitary module concepts for the retrofit market. The design work included the development of a minimally penetrating unitary module that reduces installation costs and time. Extensive market and customer needs analysis as well as detailed cost modeling was performed to inform module form factor and other design details.

Based on this work, the team identified that a fire-rated module would be critical to new designs for BIPV products, which are primarily intended for new home construction rather than retrofit. Work on fire rated laminates was on-going in Task 4 of this program during this phase. Due to the economic conditions in the US housing market, the business case for BIPV is limited, thus further shifting the focus to retrofit system design.

Phase II
Due to the worsening economy, work on residential-specific system development was delayed and later removed from the scope of the program in favor of further work on commercial products.

<u>Commercial Rooftop</u>

T5 Solar Roof Tile

Phase I
During the first phase of this program, SunPower designed and prototyped our first unitary product for commercial rooftops, the T5 Solar Roof Tile. Key design features include:

- Unitary Design: interlocking frame pieces that incorporate mounting, interconnection, and ballasting features to provide low cost, fast installation, simplified logistics, and improved wind performance of rooftop-mounted systems
- Efficient shipping – nesting allows for increased shipping density
- Flat roof mounting system integrated with PV laminate
- Use of durable, outdoor-rated plastic (GE Noryl) allows mounting features, wiring guides, and interconnection points to be molded into the module frame
- Molded plastic frame provides low cost and minimizes the number of parts, providing reduced overhead and logistics costs
- Plastic mounting design provides roof-friendly interface and fast, easy assembly of the array with minimum labor cost
- Low tilt (5° tilt) and 85% ground cover ratio (GCR) provide optimized combination of system power and energy capture, providing low LCOE
- Low base weight (2.4 lb / ft^2) minimizes load on roof structure and allows for maximum array size
- Simple wiring schemes
- Improved drainage at southern edge of module minimizes soiling
- Stand alone equipment with automated RTV dispensing and framing, with manual material loading and unloading
- Robot adhesive dispensing provides efficient and repeatable quality

Phase II
SunPower launched the T5 rooftop product into full production. During this phase, the T5 rooftop system became fully qualified and certified for manufacturing in the Richmond, CA location. SunPower obtained certification for this product to UL-1703 standards.

From the start of production, T5 assembly has been semi-automated and designed to run on a high through-put manufacturing line. By SG2, manufacturing was underway with over 1.3 MW of product manufactured and installed.

Figure 21 Production mold for T5 frame components at supplier facility in California

The T5 assembly line is located at SunPower's manufacturing facility in Richmond, CA. The design is modular, thus enabling the system manufacturing to move to market areas as required. During this phase, work was initiated to double the manufacturing capacity at the Richmond manufacturing location to fulfill North American demand.

(i) (ii)

Figure 22 (i) Laminate entering T5 assembly line at SunPower's Richmond manufacturing facility and (ii) Stackable T5 PV units ready for staged for shipping

Figure 23 Portion of 1-MW T5 installation in Santa Clara, California

Phase III

During the final phase of this program, SunPower developed ancillary components in order to expand the potential applications for the T5 rooftop product. The T5 product design accommodates a large range of wind zones. However, certain areas require anchoring at points along the perimeter of the array. During this phase, SunPower completed the design and qualification for an anchoring solution with improved thermal expansion performance. The wind calculator was updated to allow for installations in these zones and distributed to our project design teams.

While the T5 product design was optimized for flat membrane-based roofs, we initiated an investigative effort to evaluate the potential to deploy T5 on metal roofs as well. Based on the required development investment and assessment of market penetration, our team found that a significant development effort would be required to adapt T5 for a compatibility with only a subset of metal roofs currently installed. An adapted T5 product would not be compatible with non-sinusoidal metal roof types, which represents roughly 50% of metal roof market, which would limit SunPower's addressable market for all metal roofs.

Figure 25: Production version of anchor solution for metal roof applications

The product management department has decided to pursue a different solution for metal roofs—one that will accommodate all metal roof types.

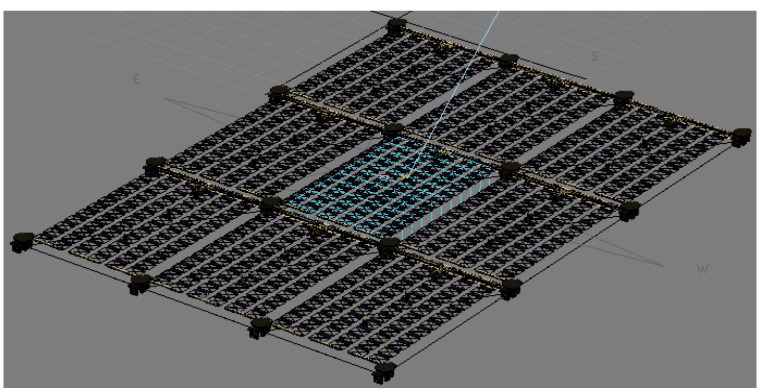
Early shipments of T5 showed unacceptably high levels of module breakage (1.5%) due to packaging deficiencies and inadequate training. After the first megawatt of T5 was shipped, a new pallet and packaging were designed and implemented, and for the following 5+ megawatts, yield increased to 99%. The difficulty and expense of certifying the repaired module coupled with the vast improvement in T5 yield enabled our team to shelve this portion of the development effort for the T5 product.

In parallel with these design efforts, SunPower continued to install the T5 system at large commercial sites. SunPower also signed an agreement to supply Southern California Edison with 200 MW of T5 over the next 5 years. This agreement marked very early success for the release of this new product. As of SG3, these installations are underway.

Unconstrained Commercial Roof Product

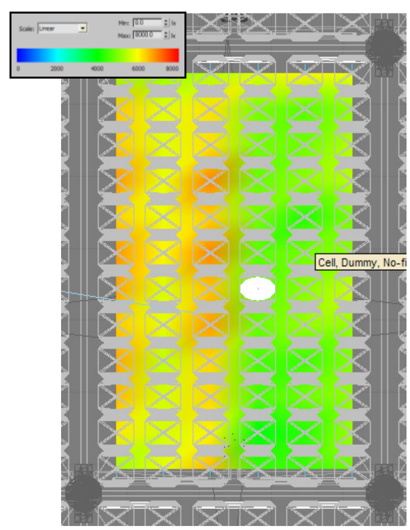
Phase II
Large rooftop area combined with low consumption profiles result in non-area constrained sectors of the market. Product requirements and features differ significantly from the constrained market. SunPower looked at the costs and performance of a wide variety of product concepts to address this sector of the market. The most promising design was used to create initial proof-of-concept designs.

SunPower created an optical model of the unconstrained commercial roof product to determine the feasibility of this approach for predicting the performance of the product. This exercise demonstrated that the optical model was useful for qualitative assessment of edge effects and cell spacing, but it was not suitable for quantitative performance calculations.



(i)

Figure 26 (i) Image of optical model of 3x3 array; (ii) Typical output of model for single module



(ii)

In order to assess the performance, an array of nine prototypes was installed at SunPower's test site. SunPower continued to monitor the output of this system to assess the energy captured on an annual basis. However, further development on this product platform was not pursued.

Figure 27: Unconstrained Commercial Roof Product prototypes installed at test site

<u>Commercial Ground</u>

T20 Solar Tracker

Phase I
Prior to the start of the SAI program, SunPower introduced a 20-degree tilted tracker using many of the advantages of the existing horizontal tracking platform. Given the relatively high cost of modules during this period, the increased land requirement was offset by the energy gain. Under the SAI program, SunPower set out to cost reduce the T20 tracker platform, while expanding the addressable market.

Figure 28: 14-MWp T20 v1 tracker system deployed at Nellis Air Force Base

Building on the lessons learned from the Nellis AFB deployment, SunPower developed a next-generation to withstand higher loads and to ease assembly. Through improved material utilization and reduced field labor, SunPower was able to achieve substantial cost reduction.

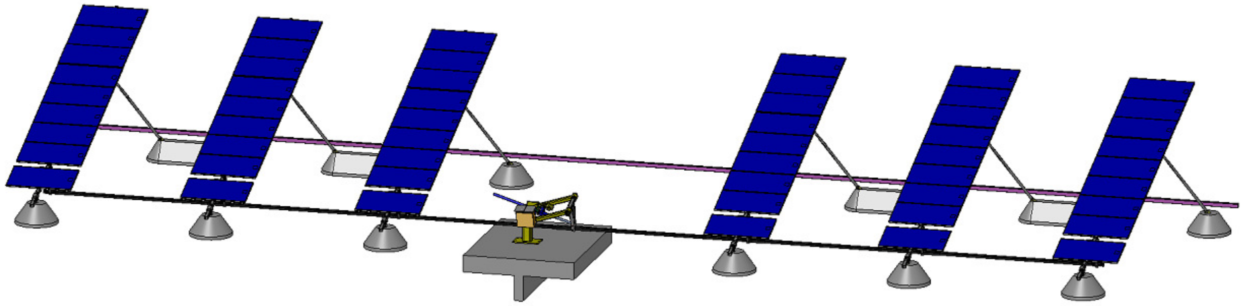


Figure 29: Model of T20 v2 tracker showing new drive unit location and module mounting design

Cost reduction drove the redesign effort for this incremental release. By relocating the drive unit to the center of the row, the drive system could serve a larger number of trackers per row by more efficiently loading the drive unit. This fairly simple redesign effort yielded cost savings by amortizing the cost of the drive unit (motor and foundation) across more trackers.

This same approach was applied to the tracker foundation design. With this new release, new foundation designs were released in order to enable adjacent trackers to share the north foundations, resulting in additional cost savings.

In addition to material savings, the T20 v2 design achieved cost reduction through improved assembly rates and decreasing more costly field labor requirements. With this design, simple bolted clips were used to attach the PV modules. Additionally, bolted joints replace welded joints for ease of field assembly.

Given capacity constraints, SunPower designed this tracker to support product from multiple PV module manufacturers with minimal part variations. For example, the T20 v2 design used a common base assembly with module mounting kits to enable single- and double-panel configurations, depending on module form factor.

To further reduce manufacturing, logistics, and installation costs, the T20 v2 platform supported both in-field and factory assembly methods. Depending on available labor, infrastructure, and transportation considerations, SunPower could easily mobilize for either assembly option to achieve an optimal cost on a site-specific basis.

(i) (ii)

Figure 30: T20 v2 trackers with 72-cell modules installed in 14-MWp system. Views of tracker array (i) at elevation and (ii) from aerial during construction

The first production build of 14-MWp was completed in Olivenza, Spain. During the installation, the design improvements enabled a highly accelerated installation while maintaining quality standards.

Phase II

Building on the experience with the Phase I deployment, SunPower developed and released a further optimized version of tilted tracker through the T20 v2.3 effort. Electrical variants were developed to meet US electrical codes and support both 600- and 1000-V systems for both commercial- and utility-scale deployment.

In coordination with the module development team (Task 4), the tracker designers focused this development effort to support the SunPower 96-cell and 128-cell modules. Moving to the larger form factors provided additional cost reduction by reducing electrical components, increasing PV area on each tracker, optimizing shipping density, and streamlining installation. Additionally, by limiting the module options to SunPower models, new design elements were adopted to achieve further cost reduction through integration of module and system design, as well as theft-deterrent rivet attachment. During this phase, SunPower built and installed prototype units for “form, fit, and function” validation, as well as full-scale cycle testing.

To further standardize the T20 platform, the design team expanded the product definition to include the DC collection system: wiring routing, combiner box selection and mounting, and cable tray to trench transition. By locking these electrical design parameters, project-specific design efforts were significantly reduced, enabling increased throughput for the system design team and reduced design time for a given construction permit package. Additionally, by eliminating variability with respect to the electrical system, installation best practices and improvements were more easily shared among the various sites and installation crews during the final phase of the program.

Integrating product design with the shipping construct, the design team partnered with the logistics team in order to achieve high-density shipping for this product platform. This updated shipping construct enabled cost reduction through reduced shipping and handling to the tracker torque tubes and drive struts. Due to its demonstrable success during deployment, this design premise has carried forward into each next-generation tracker design effort.

Phase III

Early in the Phase III, SunPower installed two demonstration-scale T20 v2.3 arrays at our Richmond and San Jose facilities. These small-scale pilot installations validated field procedures and feasibility of new features on the T20 v2.3 product, as well as verified design compatibility with both helical piles and ballasted foundation options.

Following this field validation and manufacturing process qualification, SunPower deployed the T20 v2.3 product at a 24-MWp installation in Alamosa, Colorado. This project provided an excellent venue for improvement and validation of shipping procedures, including packing and unpacking methods. This project also represented the first large-scale field deployment of the 128-cell commercial modules developed under Task 4 of this program.

Figure 31: T20 v2.3 & 128-cell module installation underway at 24-MWp array in Alamosa, CO

In 2H2010, SunPower entered general release for the T20 v2.3 product, following installation and commissioning of 10 MW installed in Alamosa, Colorado. This product launch marked SunPower's second integrated system product, providing the first platform for installation of SunPower's 128-cell module. New design features enabled significant improves in overall installation time, most notably PV mounting to the tracker. The construction crew was able to optimize tracker installation, resulting in a 2-week schedule recovery and achieve the first major construction milestone for the project on time.

Figure 32: T20 v2.3 trackers following commissioning

T0 v2 Solar Tracker

Phase III
During the final phase of the program, SunPower expanded tracker-related development activities to include the horizontal tracker platform, T0. Since proposal submission for the TPP, module prices significantly dropped, thus reducing the benefit provided by the tilted tracker design. As such, SunPower leveraged the design improvements made on the T20 platform to develop a next-generation horizontal tracker, T0 v2.

This development project was part of a standardization project to provide a "Power Plant in a Box" concept for utility scale projects, where standard AC and DC building blocks are to design 20+ MW utility projects, SunPower's Oasis Utility product. This concept set to streamline the design and permit procedure, as well as provide significant cost benefits from both from a newly optimized product design platform incorporating more labor-efficient installations procedures. The aim of developing a highly standardized product was to improve the overall system reliability and efficiency by minimizing the level of customization and locking the component level interaction.

This effort covered from concept development through early field validation. The main goals of this effort were (i) overall installed cost reduction, (ii) improvement in reliability, and (iii) ease of installation. After evaluating a number of different designs concepts, SunPower evaluated options through several rounds of early prototyping and testing. Results from this work confirmed the cost-reduction potential through improved material utilization without impacting structural performance.

Optimization of material use and installation labor was pivotal in the design approach for the new T0 v2.0 with an overall goal of minimizing the overall system cost. Moving the labor portion of the product cost from the field to the factory was a key priority in order to minimize the budget impacts of location-dependent labor rates. An additional benefit from this design strategy was improved product reliability and quality by assembling the product in a more controlled production environment.

A new wind tunnel study was completed to provide more insight into the wind load characteristics for both individual trackers and macro level tracker blocks. It is assumed that further optimization of the mechanical components will be possible with the completion of this work.

Under the program, SunPower completed concept downselection and released an alpha design for manufacturing and field validation, as well as follow-on qualification testing.

(i) (ii)

Figure 33: Views during alpha installation of T0 v2 tracker. (i) New torque tube design featuring factory-welding PV mounting saddles and bolted connections between segments. (ii) Alpha system with PV modules installed, demonstrating alignment achieved with new design.

The alpha version of T0 V2.0 tracker was installed at a local site, marking successful completion of the final milestone under this task. Installation of main mechanical components was completed in less than two days. The new tracker design reduced field welding substantially. Use of riveted and bolted connections with built-in alignment features enabled efficient installation. The pre-welded PV mounting brackets on the torque tubes makes perfect alignment of PV modules an easy task.

Task 6: Cells to Systems Factory

TPP Task Participants: SunPower Corporation *Phases I – III*

Task Objective
Design, develop, and implement processes and equipment for the unitary product factory.

Highlights

- Deployed 25-MWp manufacturing line for T5 Commercial Rooftop Product in Richmond, CA
- Deployed 75-MWp manufacturing line for laminates and modules in Milpitas, CA

Milestone Summary

	Milestone	Status as of Phase Completion
	Phase I	
√	Complete design of the automated laminate line	Completed design for SunPower-owned and operated line
√	Develop prototype high-volume manufacturing approach of next-generation commercial rooftop system for constrained roofs	Completed pilot production of T5 commercial rooftop product
25%	Complete manufacturing plan for next-generation BIPV and next-generation retrofit products	De-emphasized associated work due to slow down in residential market
50%	Implement systems-level manufacturing processes and equipment at US manufacturing facility for commercial-ground products	• Identified processes and equipment • Deployment pending factory-assembly demand (vs. field-assembly)
	Phase II	
50%	Continue design, development, and implementation of processes and equipment for the unitary product factory	• Completed equipment design • Ordered initial equipment, e.g. auto-layup • Site selection in progress
	Demonstrate automated laminate line based on module technology developed	
√	Release updated manufacturing equipment and processes for commercial-ground products	Completed with pilot release of next-gen T20 tracker product
√	Continue implementation of semi-automated manufacturing line to convert laminates to unitary system products for commercial markets	Ordered equipment for second T5 manufacturing line
√	Develop plan to integrate systems manufacturing with laminate manufacturing	Established plan to integrate next-gen T20 line in facility with laminate/module lines
	Phase III	
BE	Demonstrate design, development, and implementation of processes and equipment for the unitary product factory.	Integration of laminate and system framing lines under evaluation at close of agreement
√	Complete the design of the next-generation automated laminate line.	Completed design in Phase II
√	Complete process and equipment specifications to allow rapid scaling into regional markets.	Established modco design based on regional deployment concept in 75-MWp increments
√	Demonstrate production ramp of automated laminate line based on module technology developed	Ramped production at 75-MWp facility in Q111 using latest module generation technology and automated manufacturing
√	For framed modules, demonstrate prototype high-volume manufacturing approach for new generation component cost reduction	
√	Demonstrate implementation of semi-automated manufacturing line to convert laminates to unitary system products for commercial markets.	

Technical Accomplishments

Cells-to Laminates

Phase I

As part of its emerging manufacturing strategy, SunPower initiated an effort to design and implement regional module and system manufacturing capabilities. The lower cost, higher efficiency cells from the SunPower factory in the Philippines served as a critical input to this manufacturing model. The regional module manufacturing hubs were conceived to reduced transportation, deployment, and module fabrication costs, thus enabling U.S. manufacture of modules and unitary products.

At the start of the program, SunPower focused initial efforts on scoping the production line and validating economic and market assumptions. A conceptual overview was developed, and contact with several equipment suppliers began. In collaboration with potential suppliers, the manufacturing technologies group initiated critical definition of the line.

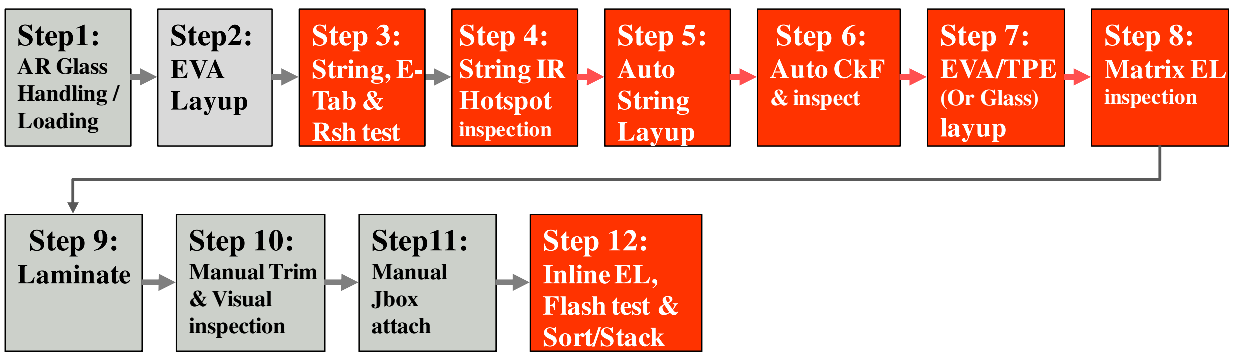


Figure 34: Process flow for automated module manufacturing line during concept phase

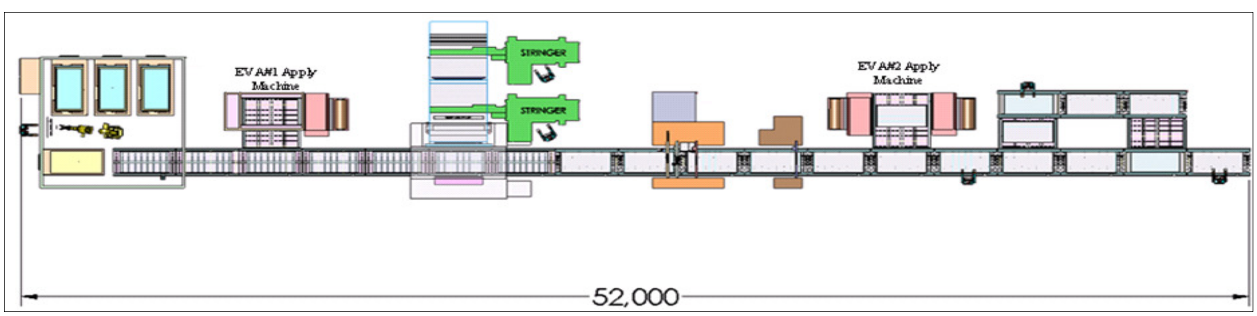


Figure 35: Layout of front-end processes (Steps 1-8) during concept phase

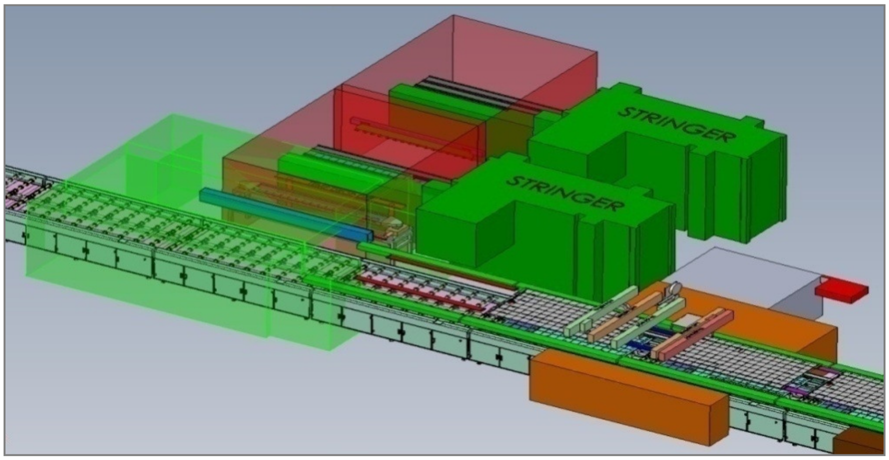


Figure 36: Early model of manufacturing line at stringers

At the close of this phase, the location of the first line was not yet determined. An evaluation of several sites was underway.

In addition to blocking out the line layout, SunPower initiated development of new equipment with a number of suppliers. Since all the equipment is custom for the SunPower cells, a very close relationship between the vendor and the SunPower manufacturing group was critical. During this phase, SunPower was actively evaluating the proposed automated stringer system (Figure 36), as well as a robotic system for the adhesive dispensing application that is commonly used in the automotive and electrical industries for framing.

Phase II
Building on the initial work in Phase I of the program, SunPower completed production line design, while evolving a comprehensive US manufacturing strategy. The strategy aimed to design, procure, install and operate to world-class manufacturing practices, a 75 MW “Cells to Laminate” factory in the US. The plan included installation and ramp of two ~35 MW phases. The lines were developed to be capable of manufacturing, packaging and shipping SPWR 96- and 128-cell laminates and modules. As of Phase II, the exact location was not yet determined. However, locations in California, Florida, Texas, or Arizona were under evaluation and negotiation.

During this phase, SunPower placed orders for long-leadtime equipment, including second-generation auto-stringers and lower-cost laminators. SunPower also validated elimination of certain process steps, thus decreasing the required footprint for the line. In coordination with a key vendor, Sinton Consulting, SunPower qualified use of a new vertical flash tester for the new facility.

Phase III
During the final phase of the program, SunPower initiated production ramp at the 75-MWp module manufacturing facility. SunPower and Flextronics announced a strategic partnership to manufacture modules in Milpitas, California through a contract manufacturing relationship. In the first year of operation, the partnership created approximately 100 new jobs. This location will allow SunPower to quickly and cost-effectively supply SunPower panels to solar installations at homes, commercial and public facilities, and power plants throughout the Western U.S.

Because of ongoing negotiations at the close of 2009, the start of the plant was delayed during this phase by approximately seven months, necessitating a no-cost extension to the SAI program.

Early in 2010, fabrication for all equipment was completed. SunPower tracked small delays associated with the laminators and auto-layup systems. Suppliers were able to resolve the issues in order to hit the revised implementation schedule.

Following announcement of the Milpitas facility, SunPower initiated orders for the second set of manufacturing equipment.

Figure 37: Photos of stringer integrated into auto-up system during process qualification at vendor

In parallel with qualification testing at equipment vendors, SunPower and Flextronics initiated facility upgrades and preparation at the new building. During this period, the plant layout was finalized, and backend equipment began to be received at the facility.

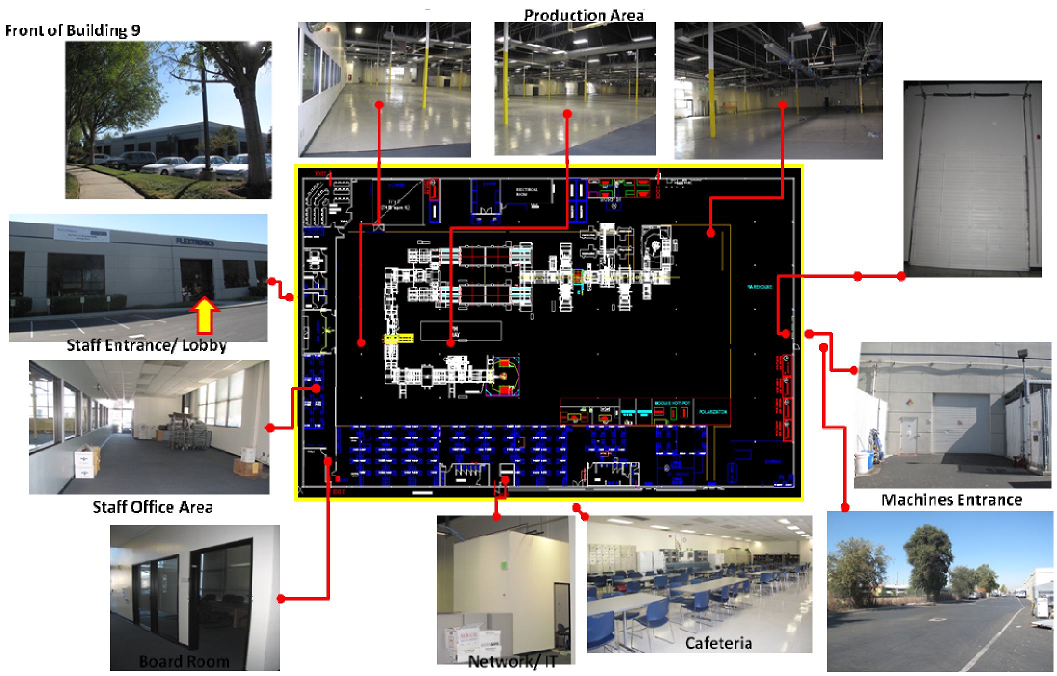


Figure 38: Snapshot of facility preparations and line layout during mid-2010

By the end of 2010, SunPower and Flextronics installed all of the equipment and initiated pilot production. Within weeks, Flextronics switched to full production rates with expected yields.

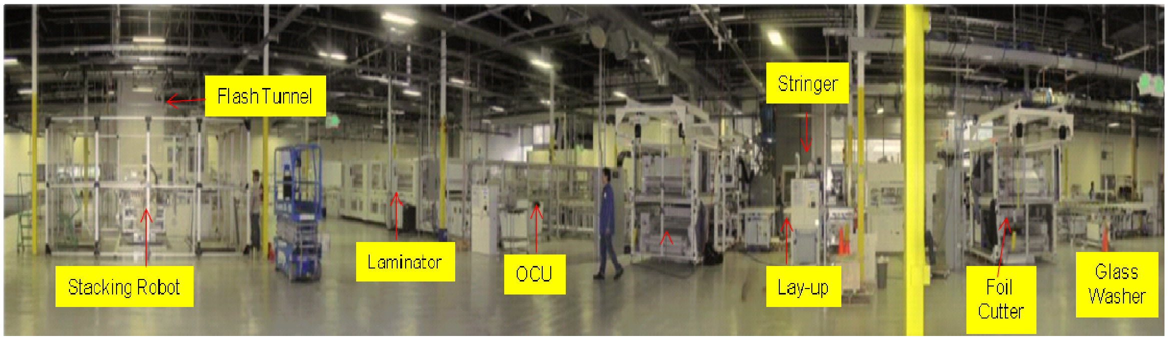


Figure 39: Panoramic photo of completed automated module manufacturing line

Laminates-to-Systems

Phase I

In parallel with the development of the module manufacturing line, the systems design team was collaborating with a manufacturing design firm to develop an automated framing station for the T5 unitary product (Task 5). This framing station was designed to either operate as a modular component of the module line under development or as a stand-alone system.

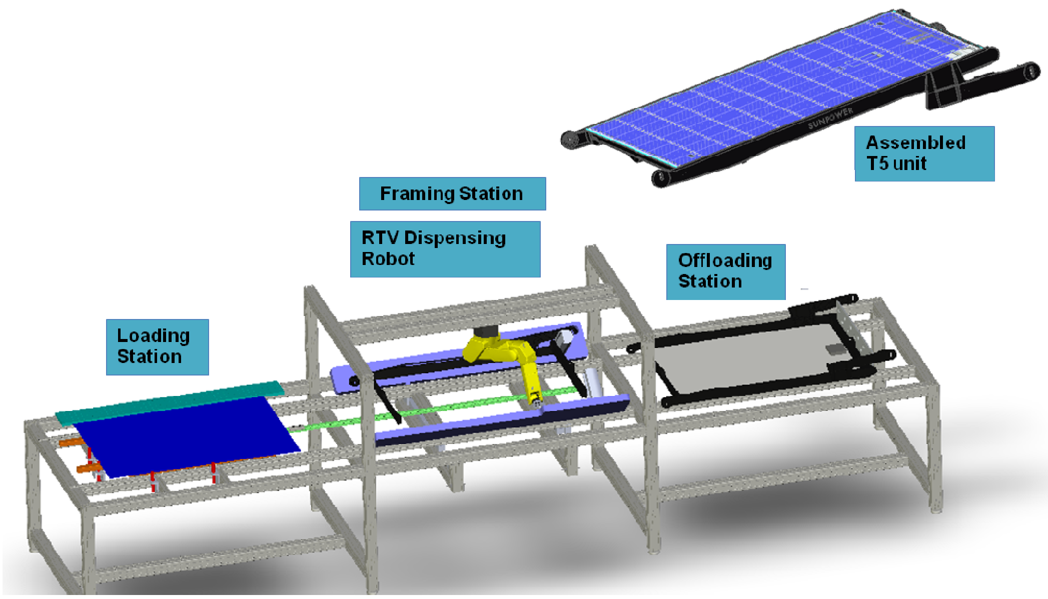


Figure 40: Early model of T5 framing station

Phase II

SunPower initiated manufacturing of the T5 roof product at its facility in Richmond, California. Following product and manufacturing qualification, assembly equipment was first validated at an equipment partner and then installed at SunPower's facility. As of the completion of Phase II, over 1 MWp of product had been produced and shipped. Following completion of the SAI-related milestones, SunPower has since expanded to four production lines, each with subsequent gains in production capacity.

Figure 41: Photo of T5 assembly line with team displaying early production unit in Richmond, CA

Task 7: Engineer to Order Software

TPP Task Participants: SunPower Corporation *Phases I – III*

Task Objective
Develop automated system design and deployment technology.

Highlights

- Implemented automated design tool (PVFast) to cover all SunPower commercial rooftop product offerings
- Implemented automated design tool (PVHome) for SunPower residential applications
- Developed module-level energy simulation tool for rooftop applications

Milestone Summary

	Milestone	Status as of Phase Completion
	Phase I	
√	Demonstrate ETO capability to automatically generate a complete system design, BOM, and cost information based on design rules	Presented capabilities during live demonstration at DOE Stage Gate I review
-	Demonstrate comprehensive model of T&D network, baseline and optimized	New Power Technologies unable to meet milestones. Cancelled associated future work.
	Phase II	
√	Continue development of a fully automated systems design function that accounts for site-specific geometries and topographies	Completed as planned
√	Demonstrate automatic generation of complete drawing set necessary for client review, permitting, subcontracting, and related sales documents	
-	Automate layout of T-20 Ground Mounted Systems	De-emphasized based on benefits associated with development of module-level energy simulation tool
	Phase III	
√	Demonstrate development of automated system design and deployment technology. Demonstrate capability to engineer system components based on local wind and seismic conditions and building code rules.	Completed software-related development work with releases of PVFast v1.3, PVSim v1.1, and PVHome v1.0 patch
√	Demonstrate semi-automated layout of electrical components, wiring and conduit.	
√	Demonstrate automatic generation of all system costs including materials, labor, shipping and other supply chain costs.	

Technical Accomplishments

<u>PVFast</u>

Typical commercial solar projects take between 10-20 weeks to design, analyze, simulate and contract. Each project typically represents a unique system designed to customer specifications. Through a comprehensive set of design automation improvements, the design time has been? reduced to about one hour for preliminary designs. The Engineer-to-Order (ETO) System is an emerging sub-specialty in design automation for the rapid design of configurable systems through rules-based design. SunPower successfully developed and implemented an ETO system, known as PVFast, which takes system design inputs to develop a set of drawings, bills-of-materials, optimized designs and costing information and accounts for site specific geometries and topographies.

Phase I

SunPower initiated the development of an “Engineer to Order” design software overlay for AutoCAD with the goal of creating a fully automated systems design function that accounts for site-specific geometries and topographies.

During this phase, the ETO prototype for rooftop applications was released to a limited group of *beta* testers (March 2008). Based on early experience with it, the software development team refined the roll-out plan to other testers and users. Beta users provided the following preliminary feedback on the initial release:

- Users found the system useful, easy to use and were excited to use it
- Users reported a 10-15x productivity gain over current manual process
- One customer reported that he is impressed with the system and will use it for all design work
- The system is highly stable, e.g. doesn’t crash or generate critical errors

Based on this early success, the PVFast software demonstrated its potential to simplify and accelerate the design and deployment of PV systems.

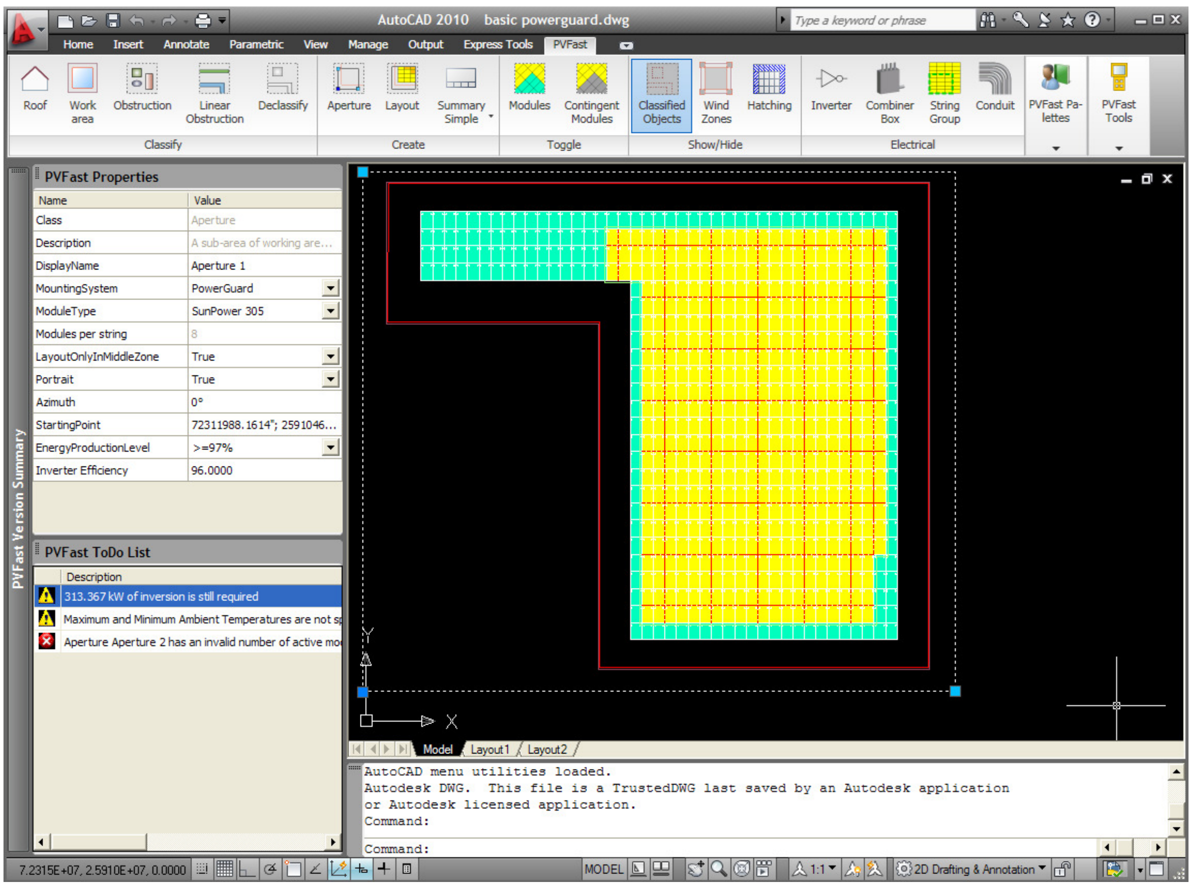


Figure 42: Phase I PVFast development using SunPower’s PowerGuard rooftop assembly

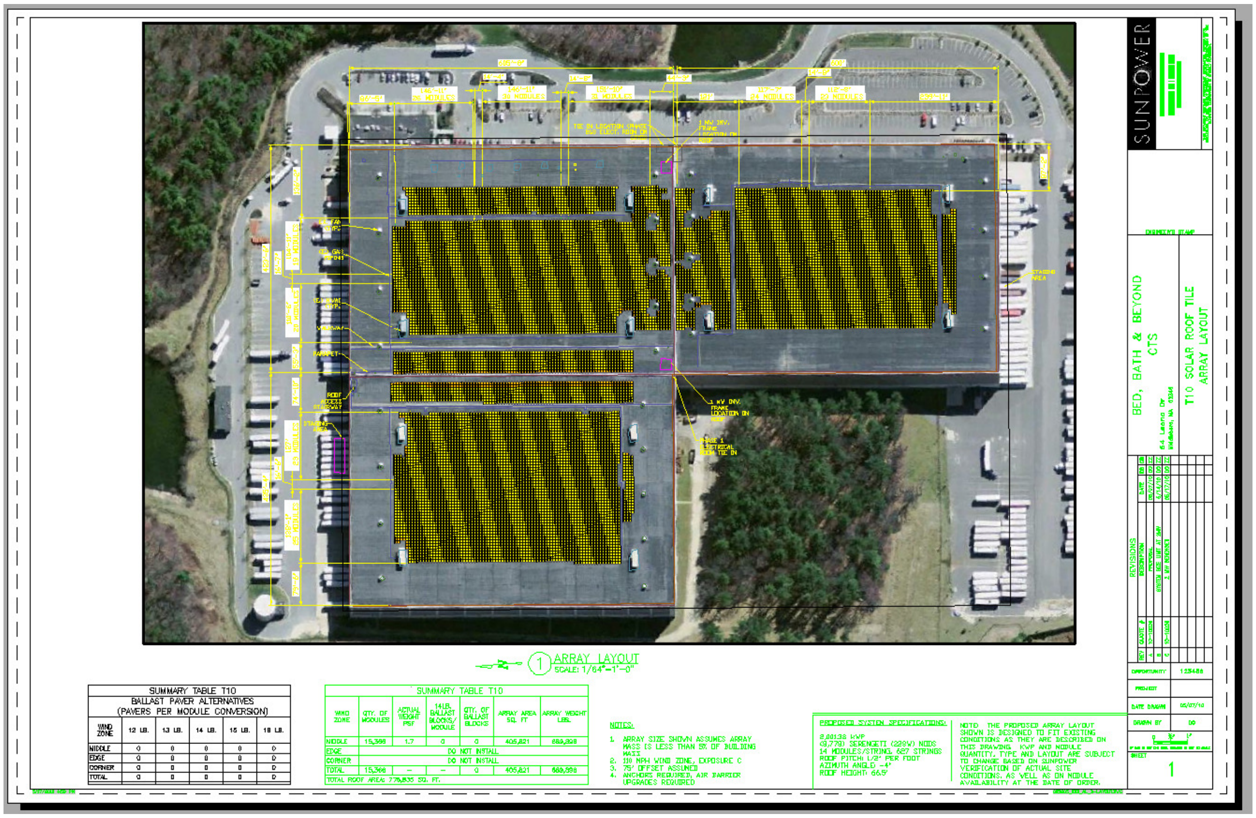
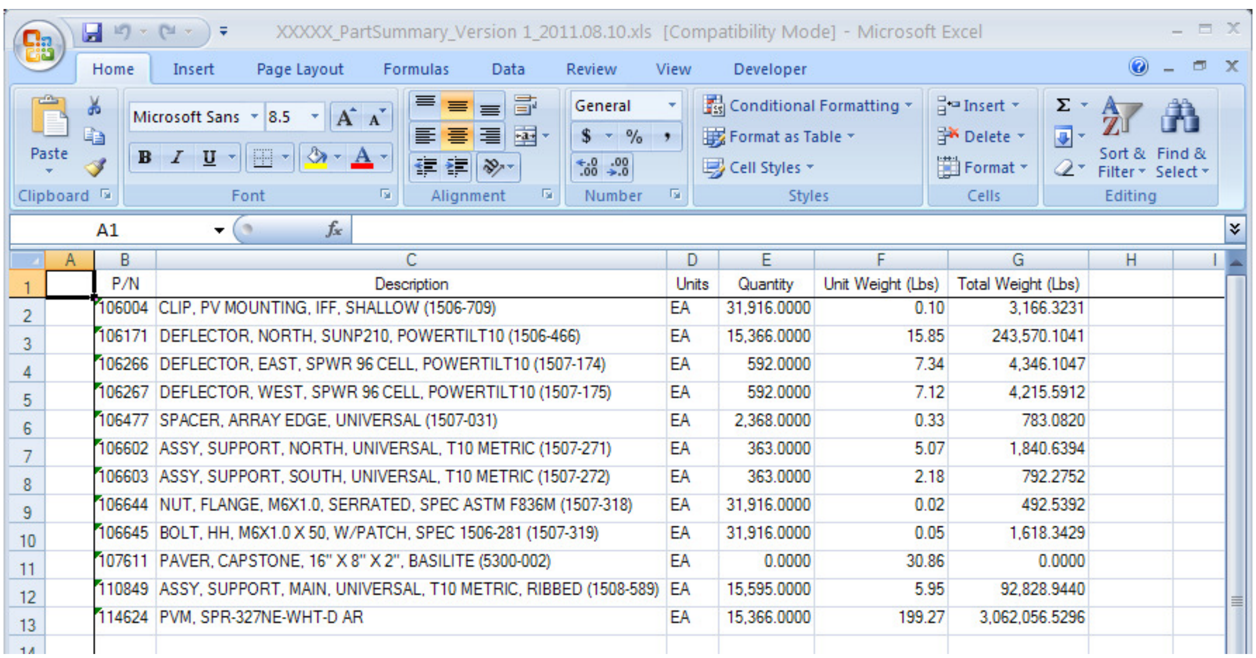


Figure 43: PVFast layout on the SunPower drawing template



P/N	Description	Units	Quantity	Unit Weight (Lbs)	Total Weight (Lbs)
106004	CLIP, PV MOUNTING, IFF, SHALLOW (1506-709)	EA	31,916.0000	0.10	3,166.3231
106171	DEFLECTOR, NORTH, SUNP210, POWERTILT10 (1506-466)	EA	15,366.0000	15.85	243,570.1041
106266	DEFLECTOR, EAST, SPWR 96 CELL, POWERTILT10 (1507-174)	EA	592.0000	7.34	4,346.1047
106267	DEFLECTOR, WEST, SPWR 96 CELL, POWERTILT10 (1507-175)	EA	592.0000	7.12	4,215.5912
106477	SPACER, ARRAY EDGE, UNIVERSAL (1507-031)	EA	2,368.0000	0.33	783.0820
106602	ASSY, SUPPORT, NORTH, UNIVERSAL, T10 METRIC (1507-271)	EA	363.0000	5.07	1,840.6394
106603	ASSY, SUPPORT, SOUTH, UNIVERSAL, T10 METRIC (1507-272)	EA	363.0000	2.18	792.2752
106644	NUT, FLANGE, M6X1.0, SERRATED, SPEC ASTM F836M (1507-318)	EA	31,916.0000	0.02	492.5392
106645	BOLT, HH, M6X1.0 X 50, W/PATCH, SPEC 1506-281 (1507-319)	EA	31,916.0000	0.05	1,618.3429
107611	PAVER, CAPSTONE, 16" X 8" X 2", BASILITE (5300-002)	EA	0.0000	30.86	0.0000
110849	ASSY, SUPPORT, MAIN, UNIVERSAL, T10 METRIC, RIBBED (1508-589)	EA	15,595.0000	5.95	92,828.9440
114624	PVM, SPR-327NE-WHT-D AR	EA	15,366.0000	199.27	3,062,056.5296

Figure 44: Example BOM generated automatically from a PVFast system design

Phase II

Building on the early success of the PVFast beta trials, the SunPower development team expanded the capabilities of the program with the July 2009 release of v1.2 to cover all SunPower rooftop products. Additionally, the software included a new feature to enable designers to assess module-level energy output during the design process. This feature demonstrated early integration with the modeling engine behind PVSim, the energy prediction software also under development in Tasks 7 and 9 of this program. Through this integration, the designers accessed energy prediction simulation results and shading analysis, enabling real-time optimization of system design.

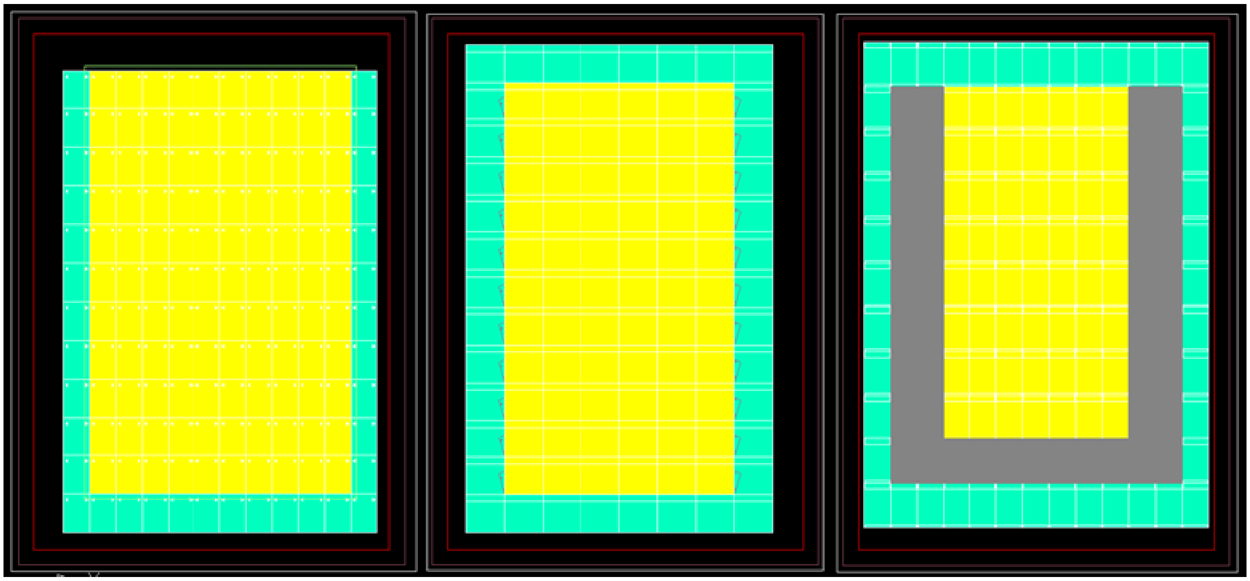


Figure 45: SunPower's three rooftop products: (i) PowerGuard, (ii) T10 and (iii) T5, demonstrating different layout requirements based on product attributes.

This phase also enabled designers to import rooftop information from GPS devices used during site audits. Once imported, the roof features could be characterized (e.g. skylight, vent) and characteristics assigned (height).

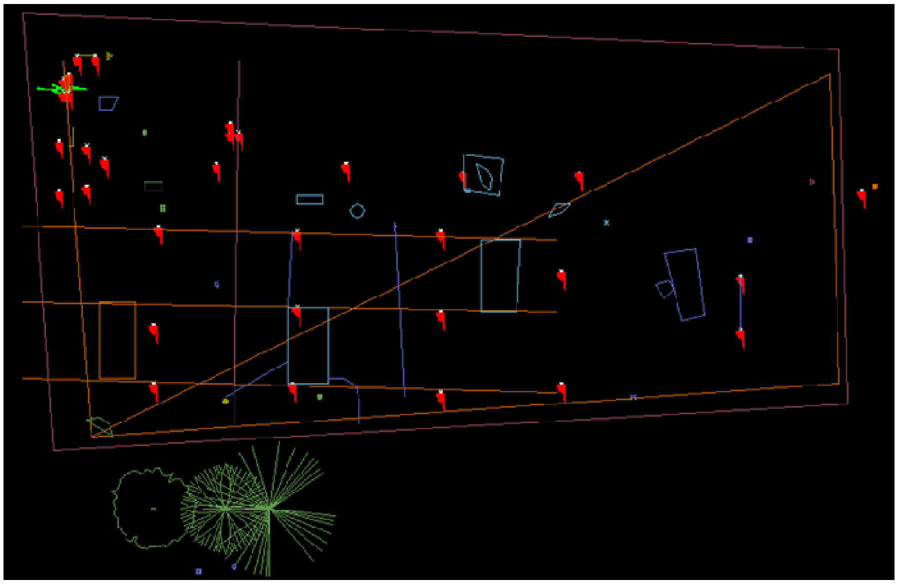


Figure 46: Resulting AutoCAD rendering of the imported GPS data

Phase III

During the final phase of the program, further refinement of the PVFast software was implemented in order to improve the shading simulation, as well as enhance wind load calculations and energy performance assessments. The incremental release was made in July 2010.

Figure 47: Sample T5 layout on a rooftop with shading obstructions and relative module energy production ranked using the PVFast color code

EnergyProduction Level Setting	Modules Displayed and Included in Layout	Module Color: Module ON	Module Color: Module OFF
>=99%	Modules producing energy at 99% of maximum and above.		
>=97%	Modules producing energy at 97% of maximum and above.		
>=95%	Modules producing energy at 95% of maximum and above.		
>=90%	Modules producing energy at 90% of maximum and above.		
Not applicable.	Modules producing energy at below 90% of maximum.		
Not applicable.	Illegal Modules, any energy production level.		
Not applicable.	Contingent Modules, any energy production level.		

Figure 48: PVFast module color code to assist designers in making decisions about module placement around shading and “illegal” obstructions

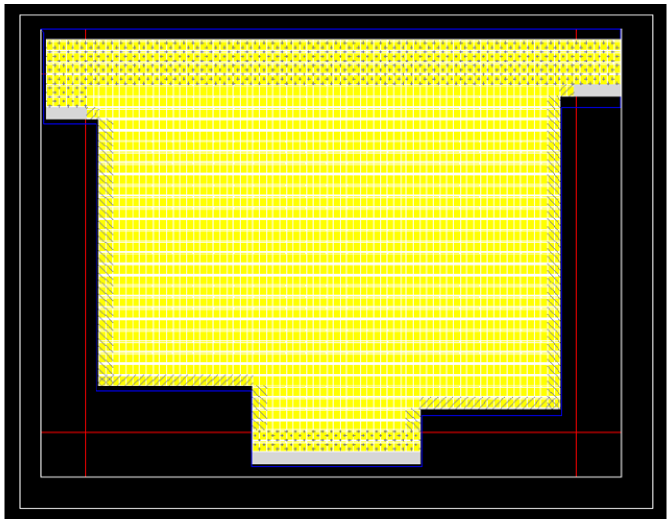


Figure 49: Module hatching identifies areas of the array which require ballasting to meet wind load guidelines

<u>PVSim</u>

Phase II
In April 2009, SunPower's existing PV system energy simulation tool, PVGrid, was upgraded from a Windows based tool to a web-based application that is fully compatible with SunPower's design, estimation & simulation software suite. The upgrade, called PVSim, included an overhauled user interface, database-controlled input variables, increased functionality for documenting simulations, and more flexible outputs from the simulation. PVSim is architected around a central SQL database, which contains all weather data, component data (modules, mounting systems, inverters, etc.), and is accessible by all SunPower employees with the need to install either software or database tools. The integration with the SunPower design & estimation software suite also allowed PVFast to take advantage of the improved simulation engine migrated from PVGrid to PVSim.

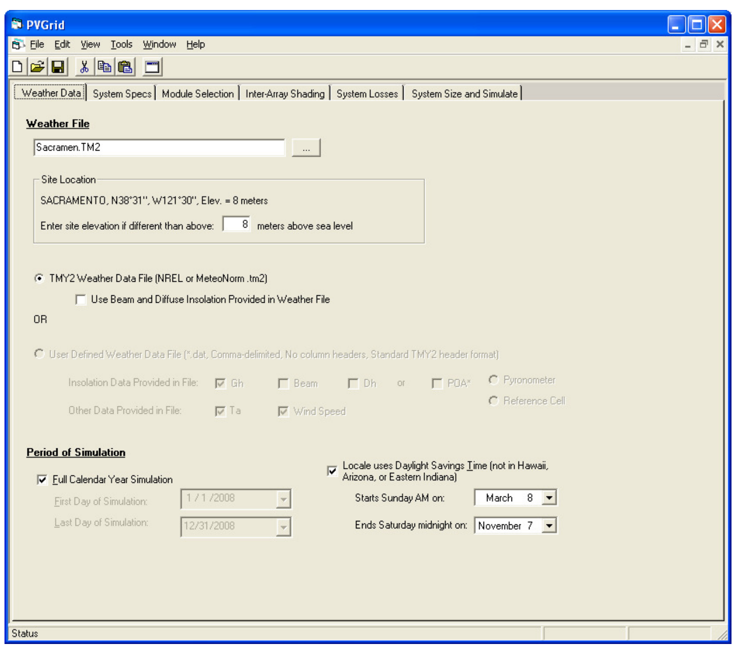


Figure 50: SunPower's previous PV system energy simulation tool, PVGrid, developed on the Windows desktop platform

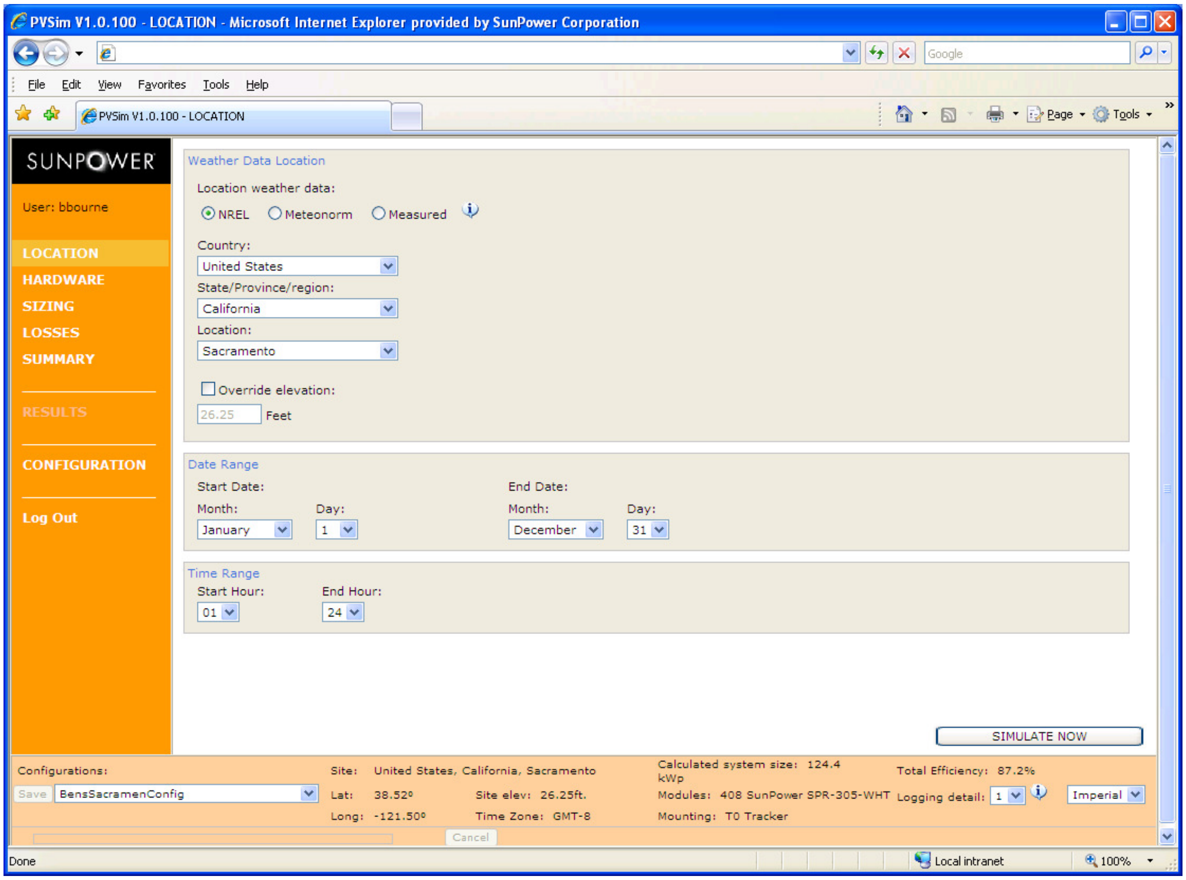


Figure 51: Version 1.0 of SunPower's current PV system energy simulation tool, PVSim, developed on a web-based platform

Phase III

During the final phase of the program, the software development team integrated the existing SunPower performance simulation model with a more sophisticated user interface and interactions with the PVFast software.

Features added to the tool include the ability to set sub-hour time steps, enabling more detailed simulations and energy production predictions and, ultimately, leading to more accurate cost forecasts. An accurate energy prediction facilitates appropriate selection of system size and configuration for a specific application, reducing the potential for over-designed systems and the associated excess expenditures.

The following demonstrates the updated functionality implemented in July 2010 release of PVSim 1.1:

- Advanced simulation configuration management
    - Search engine
    - Import configurations from PVFast designs
- Improved inverter sizing page for more accurate inverter modeling and AC clipping loss calculation
- UI controls to run production simulations at the stored native interval in the SunPower commercial monitoring database, and corresponding outputs
- Detailed itemized annual loss table in outputs
- Full energy flow table from global horizontal irradiance to final AC energy production

The enhanced configuration management system implemented in Phase III allows a refined search engine for filtering through the growing database of user configurations. It also allows a PVSim user to import a PVFast configuration that is generated directly from design drawing:

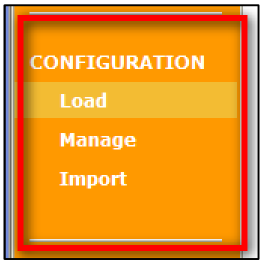


Figure 52: User menu for the PVSim/PVFast advanced configuration management system

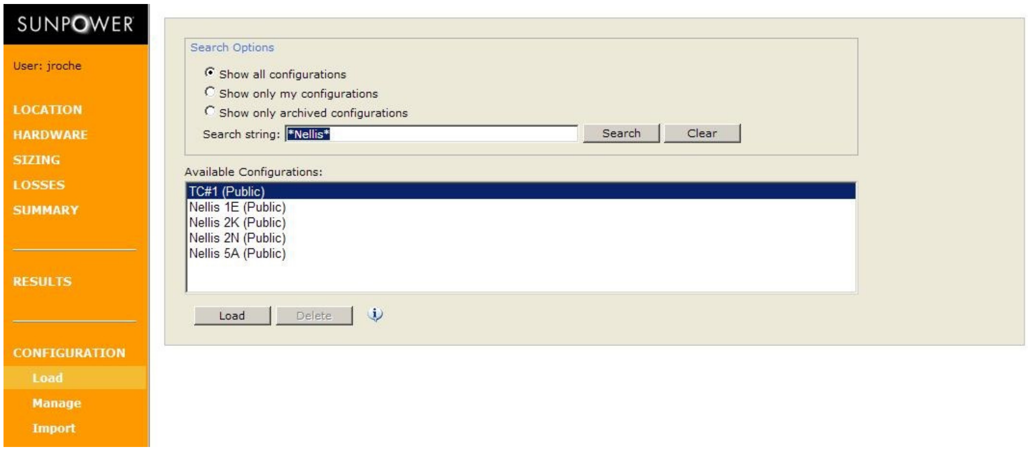


Figure 53: Search engine for the PVSim/PVFast advanced configuration management system

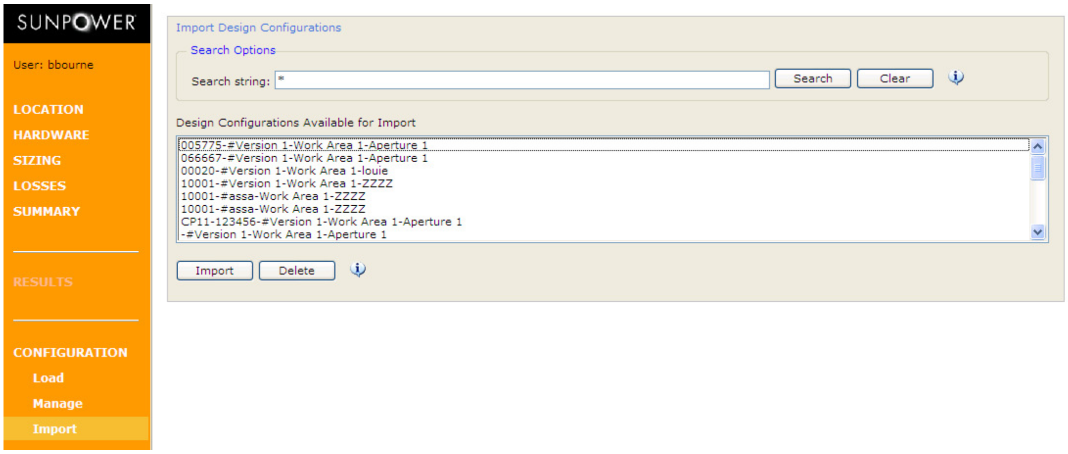


Figure 54: PVSim utility used to import PVFast designs for energy simulations in PVSim

Sizing PV systems involve many constraints such as module string length, inverter capacity, and customer sizing requirements. The PVSim v1.1 revision to the sizing page streamlined the sizing process for users, and gives them access to the broad range of inverters available for projects. This revision also improved the accuracy of the inverter efficiency model and of the inverter AC clipping calculation.

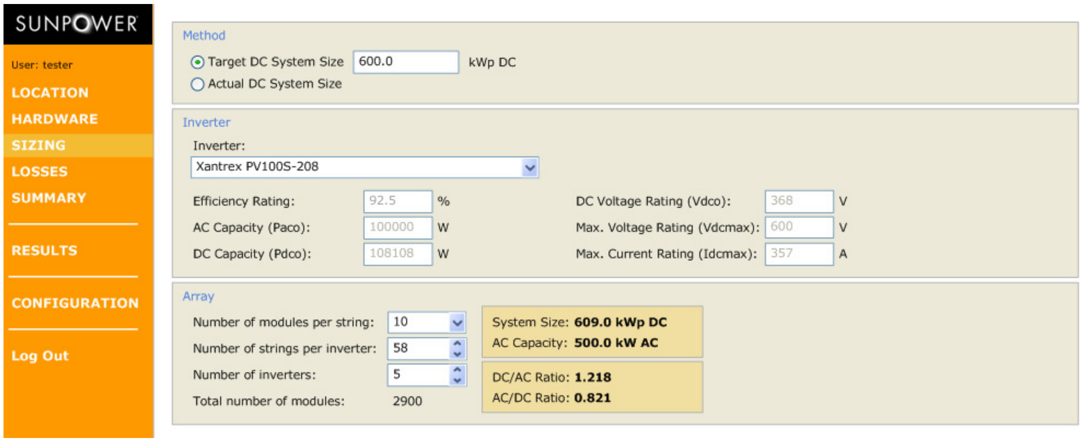


Figure 55: PVSim inverter sizing page update for improving accuracy of the inverter model and AC clipping losses

The time step control provides the ability to select a time step of either one hour or the native interval for a performance simulation, depending on the native interval stored in SunPower's commercial DAS.

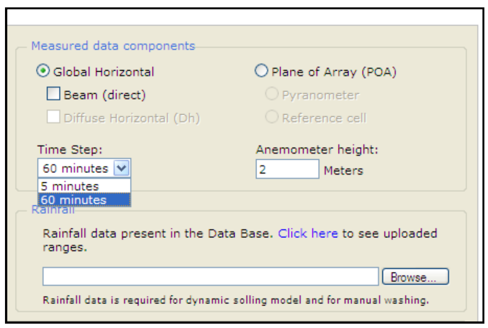


Figure 56: Improved simulation interval control

PVSim 1.1 generates an output file with interval-by-interval reports of all intermediate and output parameters (Table 9).

Table 9 Interval-by-interval output sample from PVSim 1.1

End-of-Interval Timestamp and Clock Time at Middle of Interval								Solar Position at Middle of Interval		Irradiance		Avg AC Power (at Meter)
Time Stamp	Year	Month	Day	Hour	Minute	Second	Clock Time (hh:mm:ss)	Solar Altitude (Degrees)	Solar Azimuth (Degrees)	Gh (W/m²)	POA (W/m²)	Avg AC Power (kWh)
01/29/2006 13:25:00	2006	1	29	14	25	60	13:22:30	21.5	14.3	386.9	401.1	96.2
01/29/2006 13:30:00	2006	1	29	14	30	60	13:27:30	21.3	15.6	382.4	408.1	98.2
01/29/2006 13:35:00	2006	1	29	14	35	60	13:32:30	21.0	16.8	378.2	416.9	100.0
01/29/2006 13:40:00	2006	1	29	14	40	60	13:37:30	20.8	18.1	372.9	424.8	102.2
01/29/2006 13:45:00	2006	1	29	14	45	60	13:42:30	20.5	19.3	367.0	432.2	104.2
01/29/2006 13:50:00	2006	1	29	14	50	60	13:47:30	20.3	20.5	362.1	441.3	106.2
01/29/2006 13:55:00	2006	1	29	14	55	60	13:52:30	20.0	21.8	356.0	449.5	108.0
01/29/2006 14:00:00	2006	1	29	14	60	60	13:57:30	19.6	23.0	348.3	454.9	108.9
01/29/2006 14:05:00	2006	1	29	15	05	60	14:02:30	19.3	24.2	340.6	458.9	109.7
01/29/2006 14:10:00	2006	1	29	15	10	60	14:07:30	19.0	25.4	333.7	464.5	110.6

Many customers, independent engineers and technical advisors require that we provide comparative results with their own PV system simulations. This process is simplified if the explicit losses calculated during the simulation are known. Calculated losses and adjustments relative to STC are summarized in the following output example of a PVSim 1.1 simulation. PVSim also outputs the effective energy flow from global horizontal or plane-of-array irradiance. See Table 10 and Table 11.

Itemized Annual Energy Losses	%
Shading Loss	0.00
Soiling Loss	-6.42
Angle-of-Incidence Loss	-4.07
Air Mass Adjustment	0.09
Operating Temperature Adjustment	-5.86
Efficiency vs. Irradiance Adjustment	-1.56
Thermal Voltage Adjustment	-0.02
Module Flash Adjustment	0.87
Module Mismatch Loss	-2.00
DC Wiring Loss	-1.00
Inverter Efficiency Adjustment	-6.50
Inverter AC-Capacity Clipping Loss	0.00
Transformer Efficiency Loss (Day)	0.00
Transformer Efficiency Loss (Night)	0.00
AC Wiring Loss	-0.20
Site Shading Loss	0.00
Auxiliary Load Loss	0.00
Annual Availability	98.00

Table 10: Itemized Loss Calculations

Irradiance and Energy Simulation Flow	Loss (%)	Value
Global Horizontal Insolation (Gh)		**1791808 Wh/m²**
Tracked Surface gain (Transposition Factor)	1.110	
Tracked Insolation (Ipoa)		**1988907 Wh/m²**
Shading Loss	0.00	
Soiling Loss	-6.42	
Angle-of-Incidence Loss	-4.07	
Insolation on Cell Surface (Icells)		**1785594 Wh/m²**
Effective Solar energy on cell surface (Icells * Single Module Area)		**2390910 Wh**
Effective Solar energy on cell surface @STC conditions		**442318 Wh**
Air Mass Adjustment	0.09	
Operating Temperature Adjustment	-5.86	
Efficiency vs. Irradiance Adjustment	-1.56	
Thermal Voltage Adjustment	-0.02	
Module Flash Adjustment	0.87	
Effective electrical energy from each module		**413758 Wh**
Effective electrical energy from all modules in system		**5792614 Wh**
Module Mismatch Loss	-2.00	
DC Wiring Loss	-1.00	
Effective electrical energy on DC side of inverter		**5619994 Wh**
Inverter Efficiency Adjustment	-6.50	
Inverter AC Capacity Clipping Loss	0.00	
Effective electrical energy on AC side of inverter		**4590457 Wh**
Daytime Transformer Efficiency Loss	0.00	
Nightime Transformer Efficiency Loss	0.00	
AC Wiring Loss	-0.20	
Site Shading Loss	0.00	
Auxiliary Load Loss	0.00	
AC Energy at the meter/interconnect		**4445443 Wh**
Annual Availability	98.00	
AC Energy with Estimated Annual Availability Loss		**4356534 Wh**

Table 11: Energy flow calculation

By providing a detail of itemized losses, SunPower customers now have the ability to directly compare our performance estimates against those of competitors using other simulation engines. This has proven to be a powerful tool in educating customers on factors impacting energy production and evaluate systems with widely varying components, as well as engaging with independent engineers during project development and financing.

<u>PVCost</u>

Phase II

In parallel with the design and simulation software development, the team launched an alpha release of a comprehensive and parametric based cost engine. The initial release enabled cost estimation for the T10 roof product based on a parametric, rule-based project costing system. While the initial release showed promise, continued development of this portion of the software suite was discontinued based on the required relative benefits with the other efforts.

<u>PVHome</u>

Phase III

Using PVFast as a framework, the software team developed and released the first version of automated design software for residential applications. Until the implementation of automated drawing set generation, the process per plan set could take up to two days. With this automation, processes are completed in as little as 15 minutes, and the potential for many manual errors is removed. The electrical single line drawing automation also results in substantial time and associated cost savings. The addition of automated inverter selection removes the need to involve electrical engineers in this stage of the design process, thus reducing design costs as well.

User Guides and “Read Me” documentation was created for all releases, and delivered as electronic documents to reduce cost of printing and distribution.

Drawing Set Generation includes everything necessary for permitting, including cover sheet, specifications, and electrical single line diagram. Different sizes are produced to suit different jurisdictions.

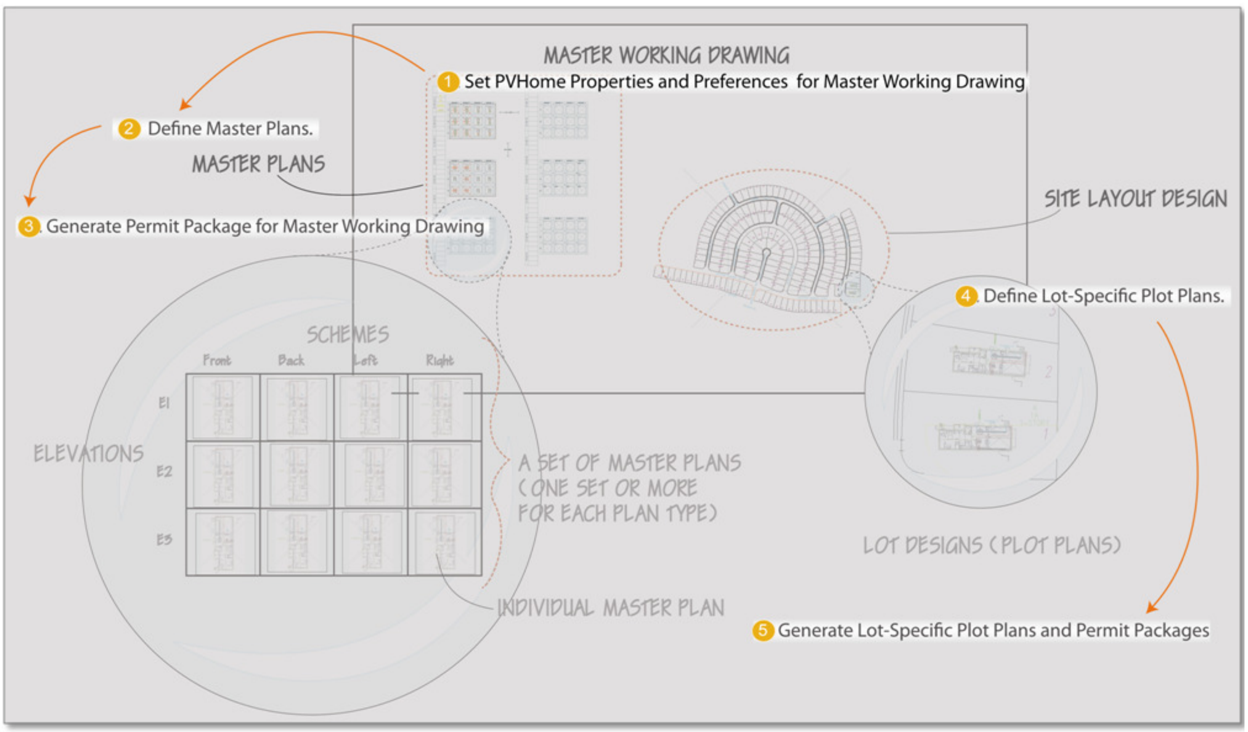
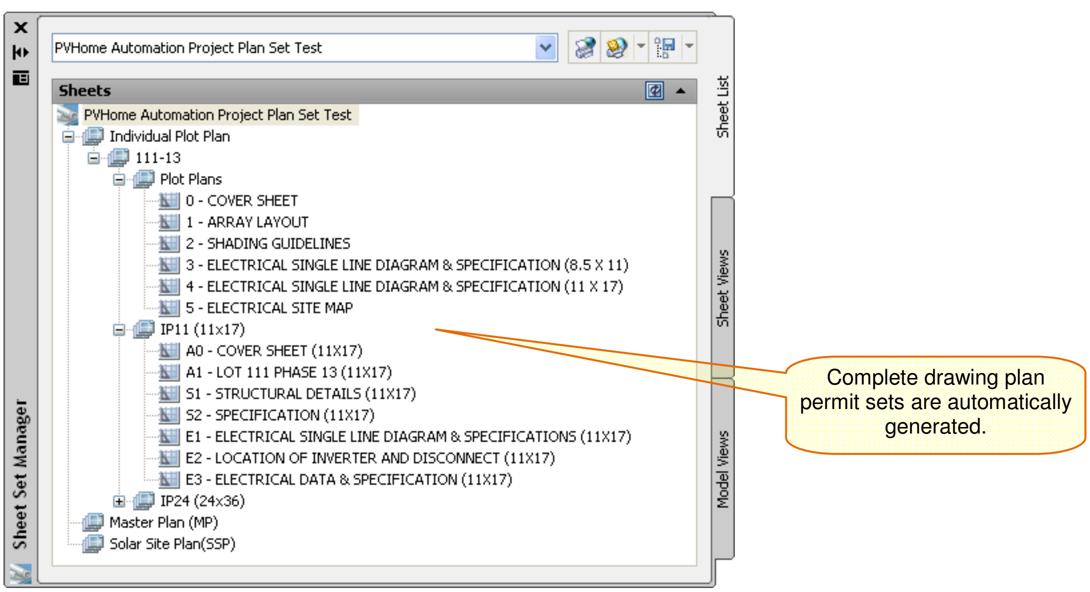


Figure 57: PVHome process flow for production home communities



Task 8: Portable Workshop for Residential PV Installers and Commercial VAR Channel Distributors

TPP Task Participants: SunPower Corporation *Phases I – II*

Task Objective

Develop and implement processes that increase efficiency in the downstream product delivery channel. Develop a fully equipped systems kit that is delivered as a unit to the site of the installation.

Highlights

- Developed and demonstrated all-in-one delivery mechanism through "mobile workshop" for residential dealers
- Launched to all SunPower Dealers is available for lease or sale
- 40% of residential dealer volume is shipped direct to job site and is expected to be main delivery method

Milestone Summary

	Milestone	Status as of Phase Completion
	Phase I	
√	Complete design of on-site, portable materials delivery kit and workshop	Completed as planned
60%	Deploy one (1) alpha prototype portable workshops with fully equipped systems kits for residential or commercial distributors	Deployment delayed due to lag in prototype of customized trailer
	Phase II	
50%	Deploy two (2) prototype portable workshops with fully equipped systems kits for residential and commercial distributors	Deployed one prototype to alpha customer Delayed deployment of second prototype in order to redesign specialized-module hand-cart
√	Demonstrate 80% reduction in installer's warehousing space required based on installer survey	
	Phase III	
√	Demonstrate development and implementation of processes that increase efficiency in the downstream product delivery channel.	Achieved through Phase II demonstrations
√	Demonstrate development of a fully equipped systems kit that is delivered as a unit to the site of the installation.	
√	Implement design software system for translating system configuration to packing list and component specs for kit.	
√	Demonstrate elimination of component packaging through deployment of mobile workshop.	

Technical Accomplishments

Phase I

SunPower initiated concept development and design of a portable workshop for residential PV Installers and Value Added Resellers (VAR) distributors. Building on SunPower's kitted delivery strategy, the design team created concepts for a mobile workshop complete with all tools and functionality to install a complete system at a given residence. During this effort, SunPower leveraged historical field data and dealer surveys to identify logistics, handling, and storage issues in order to create an optimized, low-cost delivery method.

During this phase, SunPower designed a custom cargo box to package modules and associated BOS in modular units to aid in logistics and reduce order processing time. Initial trailer concepts were also developed, including a small array to charge various cordless tools, workbenches with crimping tools to enable quick fabrication of DC homeruns, and bins for required hardware.

Phase II
Using the concepts developed in the first phase, SunPower initiated prototyping the new cargo concepts. This work resulted in the development of a “six pack” shipping construct for 72-cell modules. This packaging made moving modules easier both in the warehouse and on site. Additionally, these pallets were designed using reusable, recyclable plastics, significantly reducing waste associated with wood pallets.

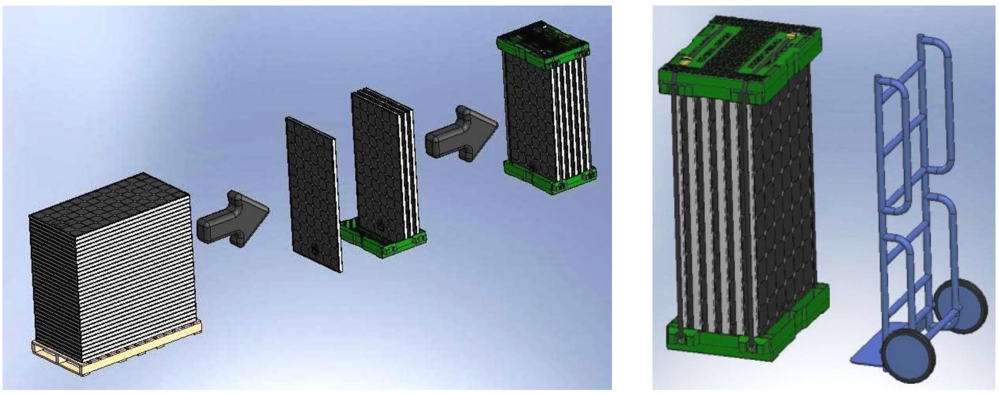


Figure 58: Schematic showing warehousing kitting of 6-module packs for dealer distribution

Based on dealer feedback and concept evaluation, SunPower moved forward with customizing a trailer. This option:

- Enabled at-will mobility by the dealer partner
- Added more maneuverability for convenient placement
- Extended delivery range well beyond a 100 mile radius
- Incorporated value-added tools to assist the dealer in performing installations with more speed and efficiency
- Safeguarded against damages to customer driveways

The resulting trailer served as a portable workshop with built-in workbenches outfitted with required tools and stocked with SunPower-specific hardware kits. Additional equipment, including hoists, further facilitated the installation process.

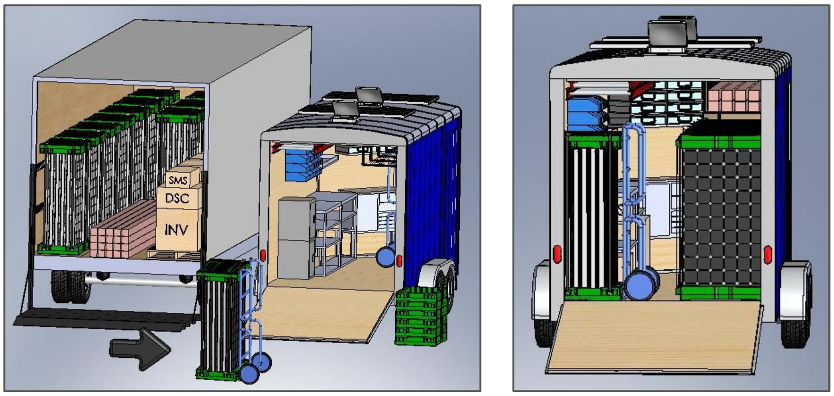


Figure 59: Schematic demonstrating restocking option for onsite trailers and space utilization for a given deployment

To validate the concept, SunPower coordinated with select dealers to deploy fully-equipped trailers on a test basis. The dealers provided resounding positive feedback based on reduced warehouse overhead, as well as improved delivery and installation time with the new equipment. Based on this success, SunPower launched this program into the dealer network.

Figure 60: SunPower and dealer co-branded mobile workshop (i) exterior; (ii) interior; and (iii) hand-truck with module kit

Task 9: Performance Monitoring and Modeling

TPP Task Participants: SunPower Corporation *Phases I – III*

Task Objective

Improve the accuracy of computer-simulated PV system energy production by calibrating models to network of installed and monitored systems' actual performance. Develop a web-based, customer accessible, system monitor service.

Highlights

- **Demonstrated improved accuracy of computer-simulated predictions of PV system energy production**
- **Established prominent place in the PV industry system modeling community**
- **Demonstrated automated performance monitoring software and hardware with real-time field performance and reliability reporting capabilities**
- **Significantly reduced O&M costs and monitoring installation costs by providing automation tools**

Milestone Summary

	Milestone	**Status as of Phase Completion**
	Phase I	
80%	Implement software and hardware enhancements to reduce unit cost by 10%	Fielded 10 simulator demonstration systems to enable beta testing at employee homes
√	Validate simulation model projections to actual solar energy production	
	Phase II	
80%	Demonstrate capability to collect real-time performance and reliability data	Migrated from 1-hour to 15-minute data for subset of sites
75%	Validate Balance of Systems (BOS) and environmental loss factors through field performance	Completed validation of most loss factors Follow-on work required to complete analysis for shading and inverter losses
	Phase III	
√	Demonstrate automated performance monitoring software and hardware with real-time field performance and reliability reporting capabilities.	Demonstrated through SCADA deployment on large-scale commercial projects. New platform will build in the capability to, via configuration, collect higher frequency data with lower latency for commercial systems than currently supported.
√	Demonstrate improved accuracy of computer-simulated projections of PV system energy production.	Monitoring user feedback on beta release of new PVSim version, including new time-interval capabilities and implementation of the PVUSA AC rating
√	Validate all improvements incorporated in performance model.	Completed benchmarking for PVSim v1.1
√	Demonstrate development of advanced Performance Monitoring Network hardware and software.	Monitored initial alpha units for new monitoring platform
√	Implement administrative user interface to reduce the ongoing service costs of supporting home solar installations by 15%.	SMS 1.2 residential dealer and end customer UI launched in US, giving each more detailed insight into PV system performance and status

Technical Accomplishments

Product Modeling

Phase I
At the start of the program, SunPower had developed and maintained a custom PV simulation tool called PVGrid for producing estimates of PV system energy production (yield). The PVGrid suite is schematically indicated below.

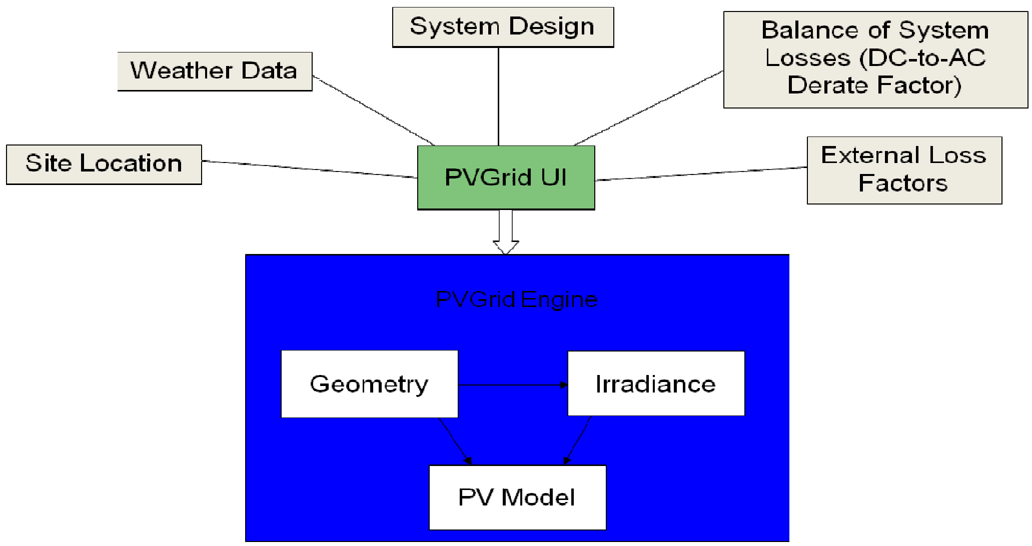


Figure 61: Schematic of PVGrid architecture

Yield simulations are one of the primary tools by which SunPower and its investors assess the value of our PV systems, therefore the accuracy of the simulations produced is of critical importance. Although there are sophisticated "off-the-shelf" PV simulation tools available, SunPower chose to invest in developing its own custom tool to provide maximum flexibility to meet the changing modeling needs of the company. In particular, in-house development enables quickly adaptation of the model to accurately reflect new mounting products and allows for use of data from our installed capacity base for model validation.

In 2007, SunPower's Performance team began a focused effort to systematically validate the entire PVGrid model, beginning with the most fundamental physical models. The goal of SunPower's validation work is to ensure that PVGrid incorporates the best available modeling science to produce the most accurate possible yield estimates. These validation efforts led to several changes to the PVGrid model and its resulting yield estimates. Careful and comprehensive comparisons of measured system yields to yield estimates produced using our updated PVGrid model show that the updated model is predicting real system output more accurately than its predecessor. Since these changes have significant impact on the perceived value of SunPower's products and systems, the changes to PV Grid and warrant careful explanation to the wide audience of affected PVGrid users.

Like most PV simulations tools, the PVGrid model produces yield projections by passing system-specific location and design information through a user interface to a computational engine. User-defined inputs to PVGrid include site latitude, longitude, and elevation; hourly weather (irradiance, temperature, wind speed); system design information such as mounting structure, tilt and azimuth, type and number of modules to be used; DC to AC loss assumptions such as module mismatch, cabling, transformer, and inverter losses; and external or environmental losses such as soiling and availability.

It is the responsibility of SunPower's Performance Group to ensure that PVGrid gives the most accurate yield estimates possible (i.e., that it produces yield estimates that match measured energy production from fielded systems as closely as possible). Our goal is to provide the most accurate possible estimate using the most current information as it becomes available. The group incorporates this information through a process of updates to and validation of the fundamental models and standard input assumptions in PVGrid.

At the start of the agreement, SunPower was actively using PVGrid v10.0, which incorporated validated geometry and solar position models for both fixed-tilt and tracking systems.

In April 2008, the Performance team released PVGrid v11.0. This PVGrid release included the Richard Perez models for calculating beam irradiance[1] and diffuse irradiance on a tilted plane[2] (plane-of-the-array, or POA). This model implementation was accompanied by a complete model and system-level validation. PVGrid v11.0 also provided expanded weather file and data aggregation capability, and a refined module performance database.

Changes to PVGrid that were incorporated in the v11.0 release were rigorously validated using irradiance data collected at the Sandia National Laboratories and at SunPower's own installations. The Sandia National Laboratories data was of critical importance to our beam irradiance model validation because it provided high-accuracy beam irradiance data from an Eppley Normal Incidence Pyrheliometer.

The table below details the benchmarking results for the subset of systems used to validate PVGrid v11.0. A benchmarking result in excess of 100% indicates that the actual system energy production exceeded the PVGrid projection; a result less than 100% indicates that actual system energy production was less than PVGrid projected. As detailed in the table, PVGrid v11, which represented our most accurate and reliable estimates of system performance at the close of Phase II, predicted actual system performance on average to within 1%. The adoption of the Perez irradiance models reduced mean bias error by approximately 5.5%, and shifted the tendency of PVGrid from significant underprediction to minor over-prediction (+0.25%). However, the root mean square error (RMSE) was still relatively high (3%).

In December 2008, PVGrid v11.1 was released with updated beam and diffuse angle-of-incidence modifier functions. This revision to the existing models was based on analytical evaluation of the anisotropic sky dome with respect to the tilted plane and the glass-laminate optical transmission properties.

[1] Perez R., Ineichen P., Maxwell E., Seals R. and Zelenka A. (1992). Dynamic global to direct irradiance conversion models. *ASHRAE Transactions* Vol. 98, Part 1, 3578, pp 354-369.

Ineichen P. and R. Perez (2002): A new airmass independent formulation for the Linke turbidity coefficient. Solar Energy 73, 151-157

Perez R., Ineichen P.,Moore K., Kmiecik M., Chain C., George R., Vignola F. (2002). A new operational model for satellite derived irradiances: description and validation. *Solar Energy 73*, N° 5, pp 307-317.

Ineichen P., (2007). Comparison and validation of three global-to-beam irradiance models against ground measurements (Center of Energy, University of Geneva). *Accepted for publication in Solar Energy, July 2007*.

[2] Perez R, Seals R, Ineichen P, Menicucci D. (1987). A new simplified version of the Perez diffuse irradiance model for tilted surfaces. *Solar Energy*, 39(3):221–31.

System type	*Location*	*Actual kWh/ PVGrid v10 kWh*	*Acutal kWh/ PVGrid v11 kWh*
T0	Bavaria, Germany	108%	98%
T0	Bavaria, Germany	108%	100%
T0	Bavaria, Germany	111%	99%
T0	Skillman, NJ	108%	99%
T0	Las Vegas, NV	113%	99%
T20	Las Vegas, NV	N/A	100%
PowerGuard	Las Vegas, NV	109%	102%
PowerGuard	Los Angeles, CA	104%	97%
PowerGuard	Parsippany, NJ	103%	95%
T10	Napa, CA	110%	102%
	All Systems: Average Error	**109%**	**99%**

Phase II
SunPower's Performance team undertook a focused effort to systematically validate the entire PVSim (formerly called PVGrid) model, beginning with the most fundamental physical models. The goal of SunPower's validation work was to ensure that PVSim incorporates the best available modeling science to produce the most accurate possible yield estimates. Consequently, in April 2009, PVGrid was upgraded from a Windows based tool to a web-based application that is fully compatible with SunPower's design, estimation & simulation software suite. The upgrades included an overhauled user interface, database-controlled input variables, increased functionality for documenting simulations, and more flexible outputs from the program. PVSim also incorporates several important model updates, including implementation of the Sandia Array Performance Model and Sandia Inverter Performance model for module and inverter performance modeling. The improved inverter model allows users to directly simulate the effects of inverter efficiency as a function of array voltage and power, inverter clipping, etc.. Other upgrades to PVSim includes the incorporation of dynamic angle-of-incidence losses for the diffuse component of irradiance, a refined temperature model for systems with low stand-offs from roofs or other surfaces, a refined shading model, and a completely generalized geometry model. These recent model changes resulted in changes to PVSim model yield estimates, and these were validated against measured system data using the same process by which PVGrid v11 was validated. Careful and comprehensive comparisons of measured system energy outputs indicate that the updated PVSim model is predicting real system output more accurately than its predecessor. Since these changes have significant impact on the perceived value of SunPower's products and systems, the changes to PVSim warrant careful explanation to the wide audience of affected PVGrid users. They will lower LCOE by improving simulation accuracy and the HAL integration will lead to improvement in the system design process by enabling real-time optimization of system layout and bill of materials.

A key result of the PVSim upgrade was to effectively remove the bias to over-predict performance. Details of the improvements listed above include:

- Irradiance model updates
  - Added numerical integration across entire available sky dome to correct isotropic diffuse, horizon diffuse and reflected diffuse components of POA irradiance for angle of incidence losses. This reduces total POA irradiance, particularly on low-tilt systems and systems located in highly diffuse climates.

- Temperature model
  - PVGrid uses an empirically-determined “standoff temperature delta” to account for increased operating temperatures of systems with low clearance between modules and mounting surface. Examples of this include SunPower’s PowerGuard panels, T10 and T5 fixed-tilt systems.
  - Standoff temperature delta is now scaled by effective irradiance (decreases cell temperature at lower irradiance for low-standoff systems)
  - The model update was developed using measured module temperatures from three operating PowerGuard systems.
- Shading model
  - Bypass diode activation is now modeled (less-conservative shading estimate). Previously, PVGrid made the conservative assumption that if a module was shaded anywhere, it could no longer contribute energy to the system. The new model allows cell-strings within modules to drop out of energy production while maintaining energy production from unshaded cell-strings in the same module.
- Geometry models
  - Two sign changes were made in source code to allow PVGrid to be used in southern hemisphere
  - Several UI changes were required to enable this change as well
  - Geometry model inputs are all database-driven in PVSim; the geometry model was modified to allow simulation of ANY mounting configuration based on a unique set of inputs from the system geometry database.
- Databases
  - A new location for the Linke turbidity database was established. This resolves a connectivity issue for new SunPower employees and existing SunPower employees on new-issue computers.
  - Updates to the PVGrid module database were made to account for recent flash test data. This keeps SunPower’s yield estimates current with module manufacturers’ product performance.
  - Mounting systems, weather data, system configurations, and other important data are all managed via a central database in PVSim

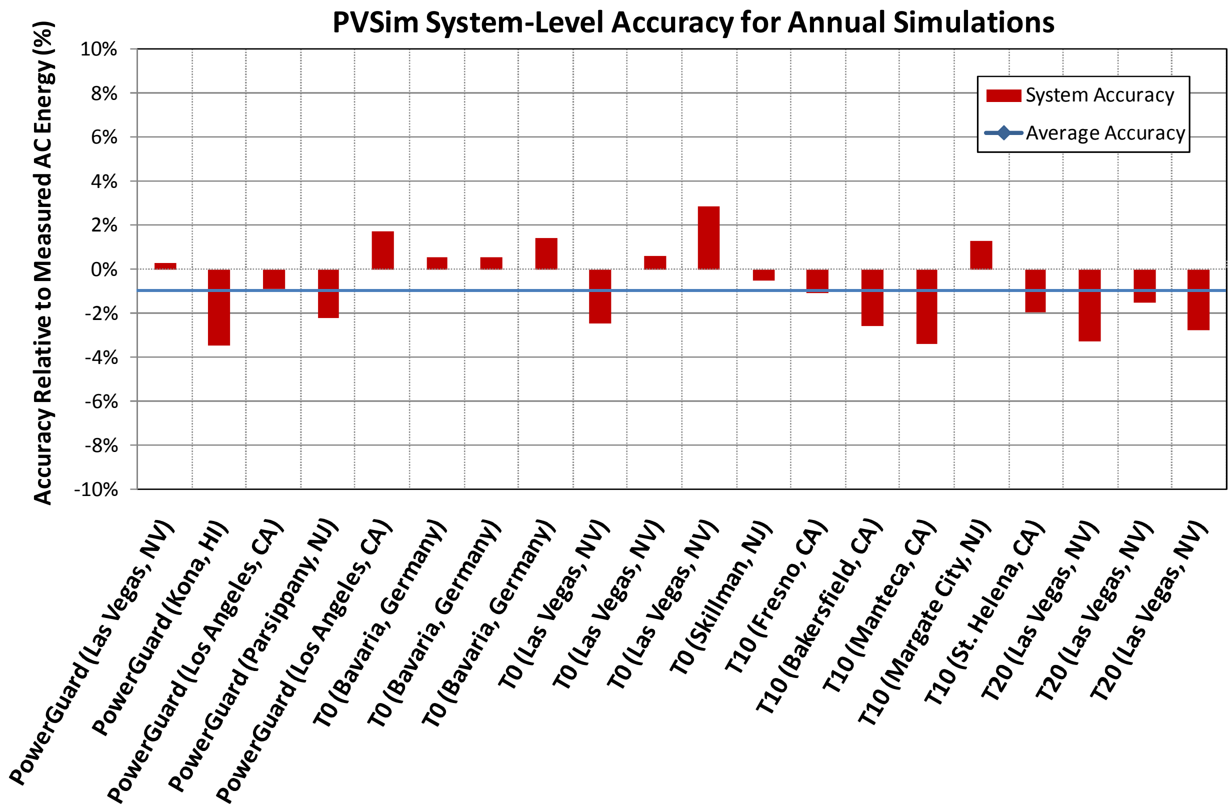


Figure 62: Validation results from PVSim v1.0. PVSim is more accurate than either PVGrid version 11.0 or 11.1—following the implementation of the Sandia Performance Model—and slightly underpredicts system performance.

In addition to work on our internal model, SunPower participated in an industry-wide effort to develop recommendations for inclusion in an ASTM system power rating standard. Standards for both energy and power are needed and SunPower has focused on power rating because it is most useful in acceptance testing. The challenge in the industry is to be able to fairly assess system performance for the purpose of project hand-off at any time of year in a short time period. The approach used was to build on the PVUSA regression rating method. The goals were to:

- Maintain simple, transparent test and analysis methods
- Reduce model uncertainty and seasonal variation in results
- Increase seasonal applicability
- Ensure applicability to wide range of technologies, locations

A group of industry experts was assembled to contribute to this effort, including representatives from utilities (San Francisco Public Utilities Commission and Florida Power and Light/NextEra Energy Resources), national laboratories (Sandia and NREL), independent engineers (BEW Engineering) and industry (SunPower and First Solar). The group published a paper at the June 2009 IEEE PVSC in Philadelphia, PA. This paper concluded that although refined regression methods may have some benefit, methods of data collection and subsequent data selection are more important to the result. The group recommended use of a calibrated reference cell for irradiance measurements and selection of data from days with clear, stable sky conditions only. The group also estimated the uncertainty associated with the test at 3.5 – 7.5% depending on the instrumentation selected for data collection. There is currently an ASTM work item (WK 22009) in process that was reviewed at the November 2009 ASTM E44.01 meeting in Atlanta.

Phase III
During the final phase of the program, SunPower worked to further refine the performance simulation engine, notably moving to sub-hourly intervals for modeling. The plots below demonstrate the benefit of simulating system production using sub-hourly intervals, particularly during periods of variable irradiance. The power industry has voiced concerns about the rapid change in PV system and distributed output during these transient periods, and interest in predicting this transient response through modeling approaches. Hourly simulations capture long-term predicted energy production, but do not adequately capture either output peaks or transient ramps between the production peaks and dips. This sub-hourly interval implementation in PVSim will allow us to (1) validate the PVSim model at the native data-collection interval and (2) predict short-term production at any interval ≥ 1 second using solar resource and weather data provided by a weather forecasting service.

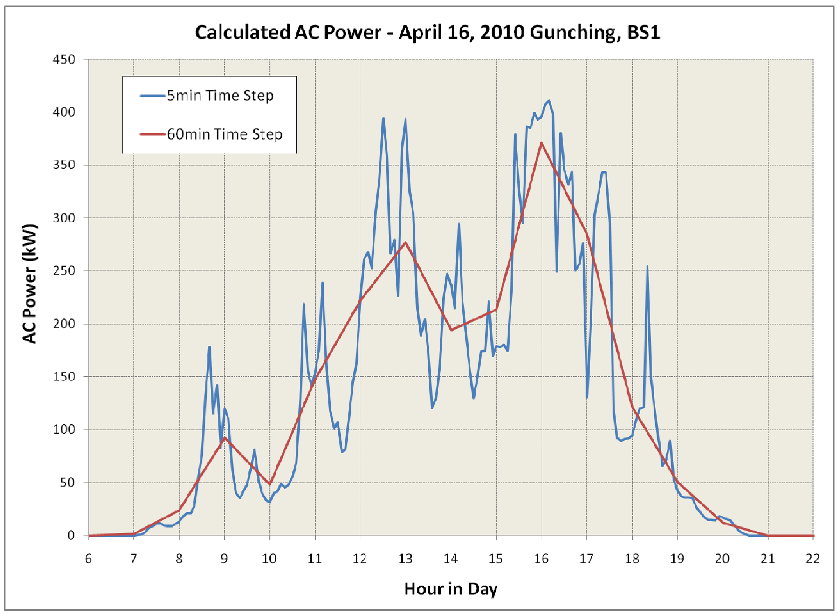


Figure 63: Demonstration of the benefit of modeling system performance at sub-hourly intervals

In addition, we have completed benchmarking of PVSim v1.1 for both 1-hour and native-interval representations of the measured MET station and measured AC energy from each system. The native interval stored in our commercial database is typically 15 minutes, with the exception of the Bavaria Solar I systems which have a native stored interval of 5 minutes. Figures 9.1 and 9.2 summarize the 1-hour-interval accuracy of PVSim v1.1 and the historical accuracy of PVGrid and PVSim, respectively, based on the production of 17 installed systems across a range of climate zones and the suite of standard SunPower mounting systems (PowerGuard, T10, T0 Tracker and T20 Tracker). A benchmarking result less than 0% indicates that the PVSim yield estimate was lower than actual system energy production ("underprediction"), while a result greater than 0% indicates that the PVSim yield estimate was greater than actual system energy production ("overprediction"). PVSim 1.1, which represents our most accurate and reliable state of system performance modeling at this time, predicts actual system performance on average to within 1.25%. While the mean accuracy of PVSim has decreased from -0.9% to -1.25%—resulting primarily from the transition from a constant-efficiency inverter model to a dynamic DC-power-dependent inverter model for our benchmarking systems—the standard deviation has decreased from 1.9% to 1.7%. It should be noted that a reduction in standard deviation may be considered more important than a reduction in MBE, as the variance about the mean dictates the statistical risk of predicting a single yield estimate for a project.

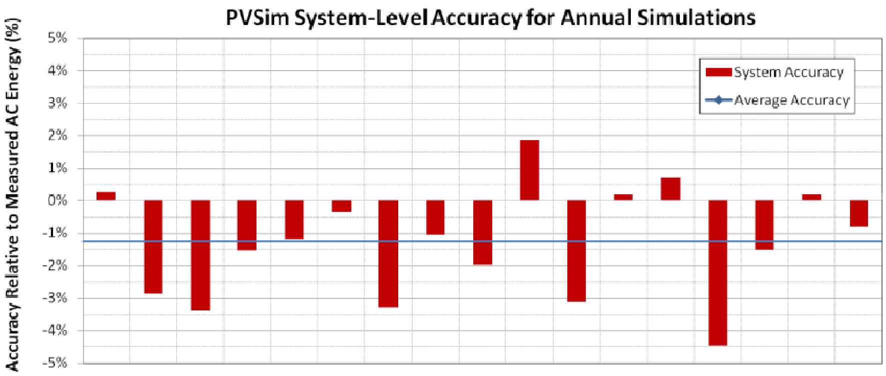


Figure 64. PVSim 1.1 accuracy of annual yield estimates using a 1-hour interval

Finally, **Error! Reference source not found.**compares the accuracy of PVGrid and PVSim since early 2007. While the current MBE is greater than 1%, on average, both the absolute MBE and the standard deviation have been reduced significantly relative to PVGrid v9.0.

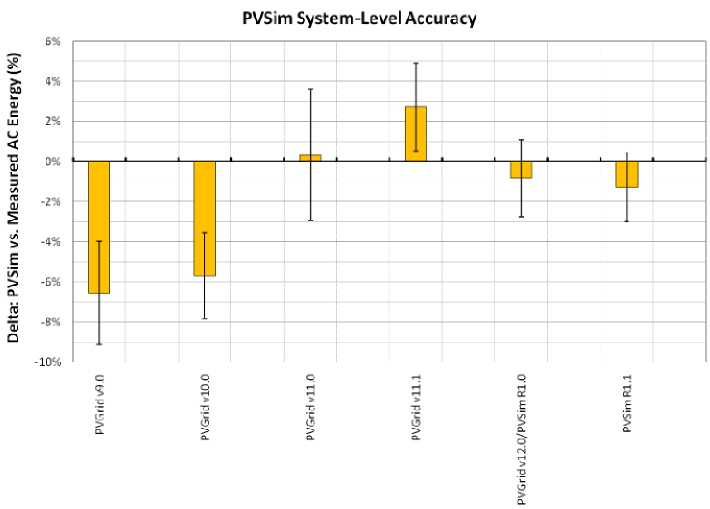


Figure 65. Progressive accuracy of PVGrid/PVSim

This update to the simulation engine was released into production and accessed by project designers through PVSim, developed and released under Task 7 of this program.

System Monitoring

Phase I
SunPower developed a web-based monitoring product and service, known as the SunPower Monitoring System. The primary purpose of this monitoring product was to ensure system performance by automatically tracking daily performance. The monitoring device also provided each client access to information on the performance of their solar power system by simply logging on to the SunPower website.

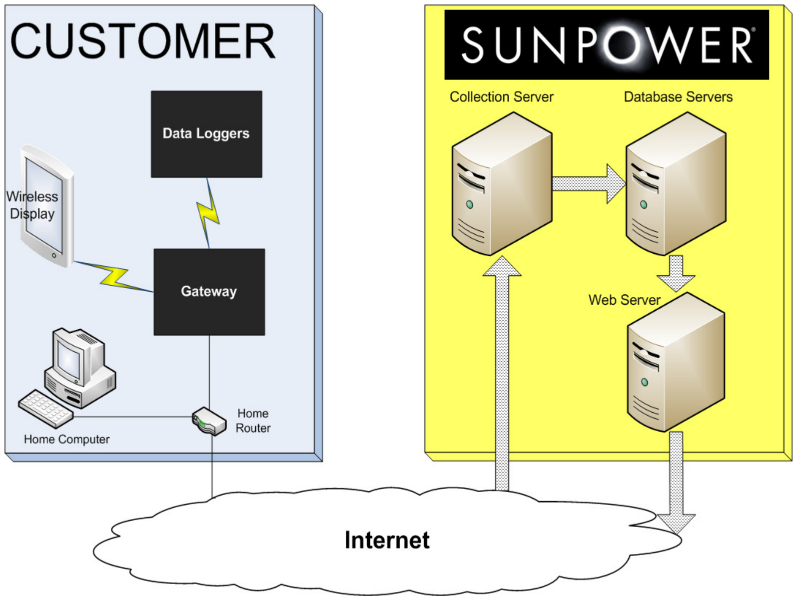


Figure 66: Schematic of SunPower Monitoring System architecture

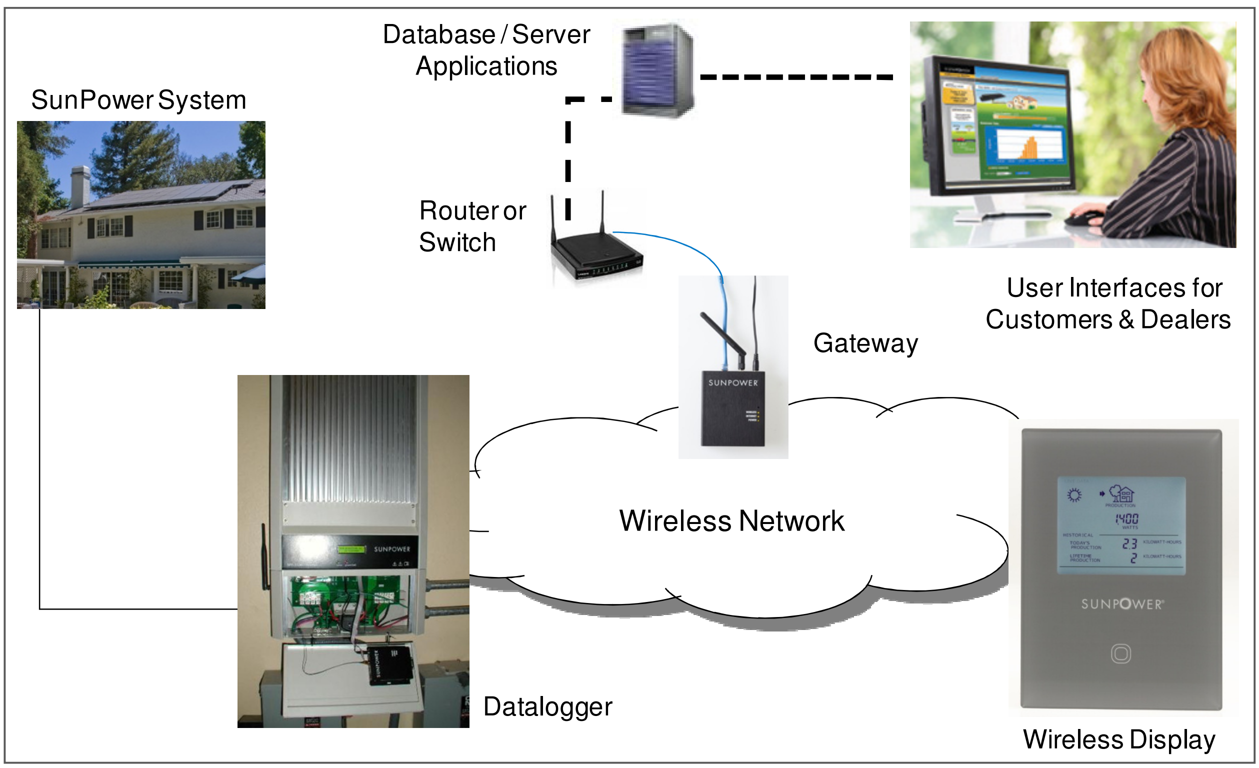


Figure 67: Schematic of SunPower Monitoring System

The product was designed to be installed with SunPower North American residential systems both through the dealer network and on production homes. The monitoring platform consisted of (i) a datalogger; (ii) gateway; (iii) wireless display; and (iv) web-based user interface. The datalogger pulls production data, as well as system alerts from the inverter. The gateway device links the system both to the SunPower servers and the in-home wireless display. This early release provided users with basic system production information.

During this phase, SunPower initiated pilot production of the monitoring hardware for field demonstration purposes. At the end of Phase I, SunPower had sent 10 units to local test sites and were in the process of installing those systems.

Phase II
Early in this phase, the team validated the SMS system design through the demonstration systems and entered pilot production of the hardware, deploying through both residential channels as planned. Additional launches in Italy, Spain, Germany, and France followed, during the final phase of the program. Additionally, the team added new functionality in order to support additional inverter types and manufacturers. This version of the residential monitoring product was in hardware *beta* testing at the close of this phase.

In order to provide additional value to both the dealers and system owners, SunPower focused efforts on further developing the web-based tools available, completely overhauling the web interface for both end customers and dealers to provide easier access to much more detailed information, in a more useful and compelling manner. The objective was to improve insight into residential system performance and make system maintenance more efficient and cost effective by giving dealers detailed diagnostic information online as well as via email alerts. For system owners, the team launched a custom iPhone application, an industry first, in order to give customers “on the go” access to view energy production of their solar system as well as their household’s electricity consumption.

Figure 68: iPhone implementation of SMS compared to in-home wireless display

Phase III
During the final phase of the program, SunPower broadened the existing monitoring platform to service both residential and commercial markets. Under SAI, development for the next-generation monitoring product completed alpha trials. Five alpha sites were deployed covering three different inverter types, two types of revenue grade meters, a high-quality meteorological station, an on-site tool available for monitoring system installers to verify proper device configuration and internet communication.

During the alpha trials, the product team gained valuable insight on many levels. Key takeaways included:

- A significantly simplified approach to product installation documentation is being well received by installers.
- Wiring harnesses provided with the product were changed to make installation simpler and present fewer opportunities for mistakes and misinterpretation of installation instructions.
- Different inverter manufacturer communication rates and protocols can present issues when trying to support systems with a large number of inverters.
- Behavior of certain hardware reset buttons required updates to ensure hardware could be returned to a known good state, thereby decreasing RMA requests.

- An on-site communication troubleshooting application was built based on feedback from early alpha installations.

SunPower endeavored to make the PV monitoring system installation process as simple as possible, since this can be a complex task. To do so, SunPower implemented an onsite diagnostic tool, hosted by the PV Supervisor itself, that can be used by the installer to verify proper device communication and internet connectivity. This application is called the PV Supervisor Management Console. The dealer plugs a laptop into a dedicated network port, launches the PV Supervisor Management Console, and then has the ability to determine with absolute certainty whether or not all devices are operating as expected by using the tools available on the “Devices” tab and “Communication” tabs. This is an extremely useful tool for installers to understand and troubleshoot any installation or communication issues independently and efficiently.

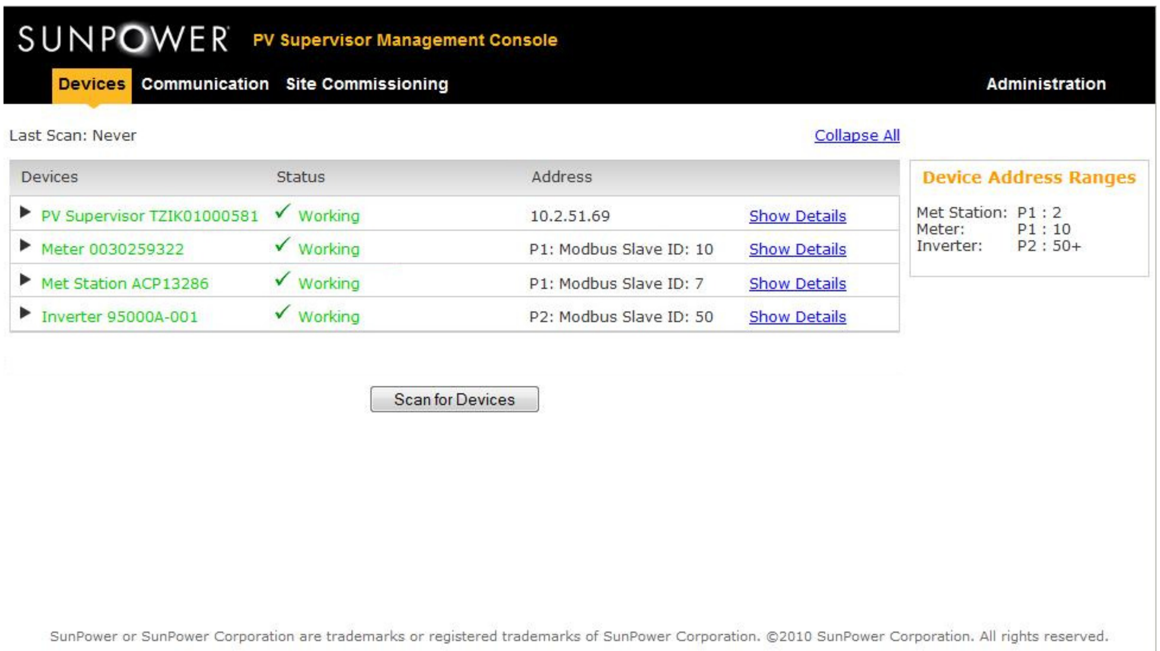


Figure 69: Sample of the Devices Tab in the PV Supervisor Management Console. Devices that can be automatically detected are listed after the “Scan for Devices” button is clicked. If an installer notices a device missing, on-site troubleshooting of wiring, communication settings, etc. can be performed, followed by another click on the “Scan for Devices” button.

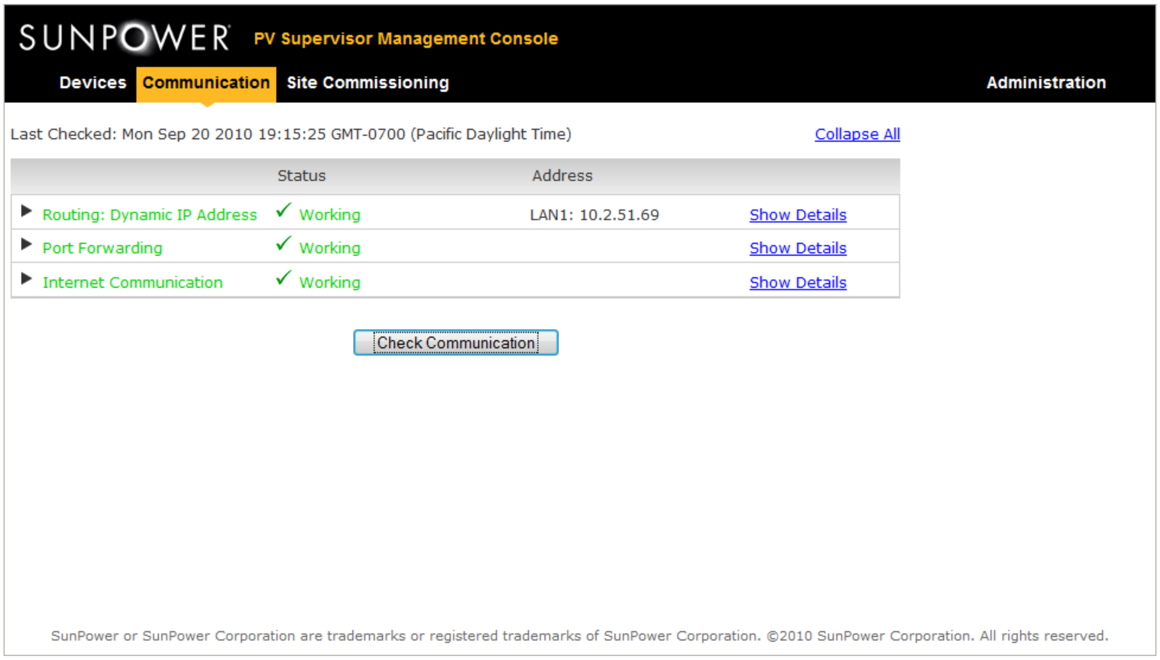


Figure 70: Sample of the Communication Tab in the PV Supervisor Management Console. Clicking on the "Check Communication" button performs tests to ensure all on-site TCP/IP network functionality is working as expected, and that SunPower's servers can be reached from the system location.

Following system installation and commissioning, dealers can then use the upgraded user interface to track the health of their installed fleet and troubleshoot many issues remotely.

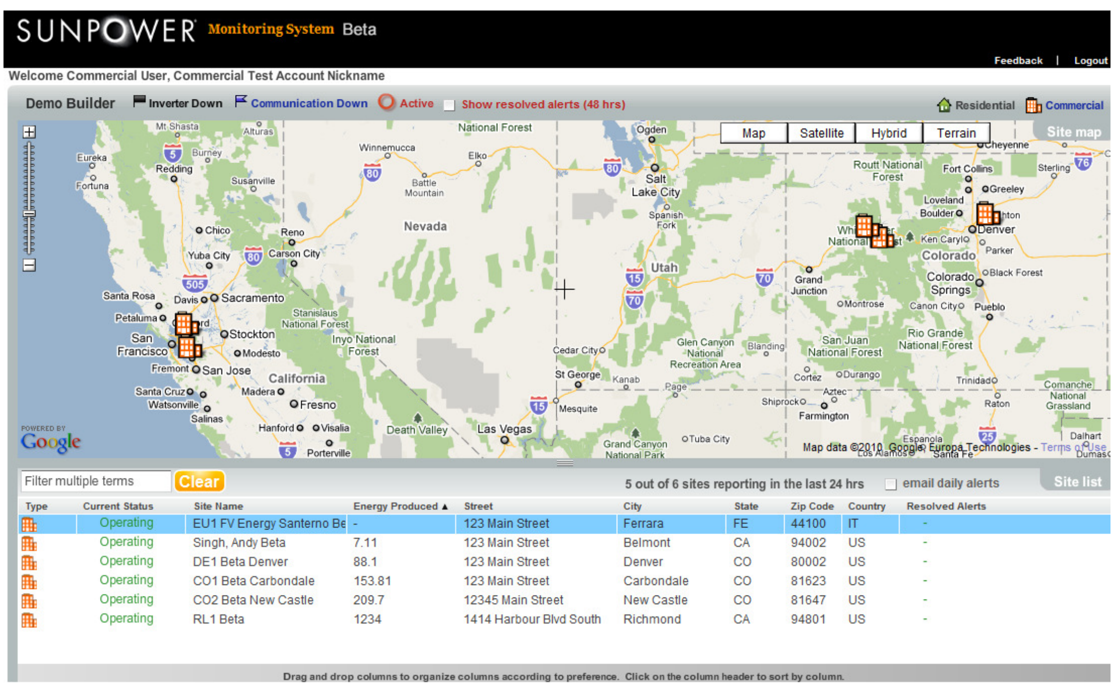


Figure 71: Screenshot of dealer landing page, showing commercial systems monitored at test locations

From the landing page, double clicking on a particular PV system allows the customer or SunPower Dealer to view many details about the operation of the PV system. In the upper portion of the screen, system diagnostic tools show the status of each device on site. The graph shows aggregate system AC real power production, reactive power production, as well as accumulated lifetime energy produced, as measured by the on-site revenue grade meter.

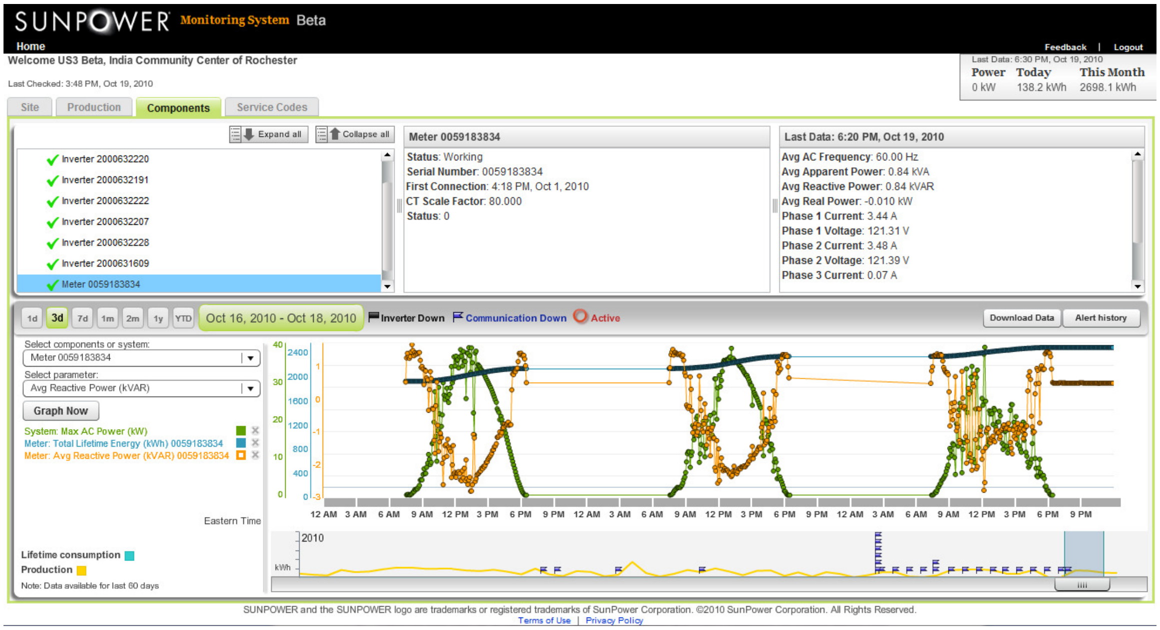


Figure 72: Screenshot showing system status and energy production information for a sample system.

During this final phase, SunPower also introduced a new energy consumption tracking feature to the system. The new components report whole-house electrical energy consumption, which is then displayed in the same customer user interfaces used to show PV system energy generation. These measurements can be seen as the blue lines in the bar chart in the residential end-customer product screenshot below.

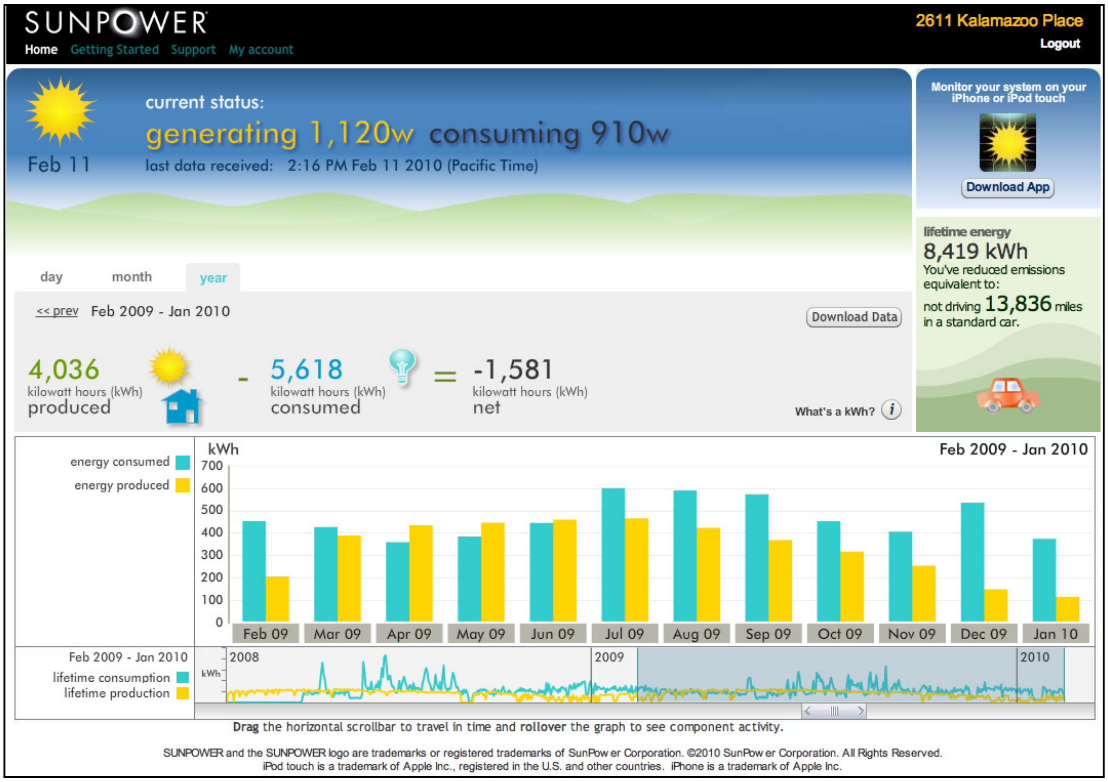


Figure 73: SunPower's updated customer user interface

Task 10: 15-Year Warranty Inverter

TPP Task Participants: Xantrex Technologies — *Phase I*
SolarBridge Technology — *Phases II & III*
Tigo Energy — *Phases II & III*

Task Objective
Develop and qualify an inverter design capable of a 15-year useful field life

Highlights

- Launched ACPV module through SunPower – Solar Bridge partnership
- Demonstrated energy production profile using Tigo Energy Maximizers under shade conditions

Milestone Summary

	Milestone	Status as of Phase Completion
	Phase I	
30%	*Xantrex*: Demonstrate minimum of 2:1 performance ratio, defined as 20% reliability improvement for 10% more cost	• Early results from Multiple Environmental Overstress Testing (MEOST) approach demonstrated the potential to achieve 2:1 performance ratio as define • Based on lag in development work, follow-on work cancelled
	Phase II	
√	*Solar Bridge*: Design and develop innovative AC panel-mounted inverter with beta units available in late 2009	Completed preliminary design and initiated integration work
√	*Tigo Energy:* Monitor system performance, measuring improvement in A/B comparison	Fielded arrays for side-by-side comparison
√	*Tigo Energy:* Install two strings of SunPower 230-Wp modules in system configuration with distributed inverter technology	
	Phase III	
√	Demonstrate development and qualification of an inverter design capable of a 15-year useful field life	Demonstrated product life through ALT testing
√	Demonstrate commercialization of improved inverter with UL1741 compliance and California Energy Commission (CEC) efficiency testing completion	Completed with SolarBridge product launch and CSA certification

Technical Accomplishments

<u>SolarBridge Technologies</u>

SolarBridge designs and manufacturers an innovative microinverter and monitoring system that improves reliability, increases energy production, and simplifies installation in residential and small commercial systems. The company's proprietary technology enables its module-integrated microinverter to have an industry-first 25 year warranty, matching module life expectancy. The ACPV purchase price will be competitive with today's central inverters, but the installation cost savings, increased energy harvest, and 25 year warranty will easily shift the LCOE advantage over 25 years toward ACPV.

Under this program, SunPower and SolarBridge partnered to explore integration with our 72-cell module platform. To pilot this concept, SolarBridge integrated its 225-Wp microinverter into a SunPower 225W PV module to create an integrated ACPV solution.

In addition to the development of the microinverter, SolarBridge also worked on the development of a Power Manager (PM), which provides local monitoring for the PV system, tracking the performance of each ACPV module. In addition, Power Portal, expands the capability of Power Manager by providing web-based data access.

Phase II
In order to achieve a 25-year design life, the SolarBridge team developed the microinverter's innovative architecture to avoid failure prone components, such as electrolytic capacitors, opto-isolators and tantalum capacitors. These components limit reliability in central inverters and competing microinverters. This extended lifetime, which matches industry standards for the module, eliminates the need to replace the inverter during the life of the module, resulting in a considerable LCOE benefit.

In designing this new platform, SolarBridge used the following guidelines to govern product development:

- Identification and elimination of failure prone components found in today's inverters (e.g. electrolytic capacitors, opto-isolators)
- Minimization of component count
- 15 year cumulative failure rate < 3%
- Optimization of SolarBridge hardware around SunPower's PV modules
- Validation of designs with extensive in-house and 3rd party testing
- Achievement of UL1741 approval and CEC certification
- Development of rigorous production-line testing and process control

During this phase, SolarBridge developed a topology that enabled the elimination of electrolytic capacitors and opto-isolators, as well as reduced the number of required film capacitors. Overall, this design greatly improved the reliability of the microinverter.

Under this program, SolarBridge initiated an effort to design and qualify the microinverter for integration with SunPower modules. Through this effort, SolarBridge updated electrical design to reduce mechanical footprint and to improve efficiency. In parallel, the team developed the DC and AC interfaces, as well as mechanical attachment solutions, to meet requirements of true ACPV modules. In order to ensure product safety and mitigate permitting risks, SolarBridge also worked with industry experts to identify mitigation practices to eliminate risk of DC arc induced fires.

Using prototypes of the updated design, SolarBridge completed preliminary qualification and reliability testing. This evaluation included a subset of UL1703 certification tests, as well as material qualification for the mechanical attachment and field testing to validate performance.

In parallel with the development efforts, SolarBridge selected a contract manufacturer with focus on process control, best in class test, failure analysis and corrective action capabilities.

Phase III
Early in the final phase of the program, SolarBridge complete the microinverter hardware design and qualification. In order to validate estimated product lifetime, SolarBridge initiated a rigorous Design for Reliability review process with DfR Solutions, a consulting firm specializing in Physics of Failure approaches to achieve high reliability. Outputs from this work further informed the final design using state of the art modeling to confirm long term surface mount solder joint and PCB via reliability. The Sherlock model showed <0.1% cumulative failure rate after 15 years for these failure mechanisms.

ACPV testing was conducted at Atlas Outdoor Weathering Services Group. The purpose of this test was to expose a working ACPV module to simulated worst case ambient temperatures, insolation and airflow. These tests were conducted in a large indoor chamber with lamps designed to mimic the Solar Radiation Spectrum. With 1000W/m2 irradiance, 45C ambient and no airflow, inverter and module temperature data was captured and confirmed to match SolarBridge predictions (Figure 74). These tests were also used to confirm internal component temperatures stayed well within their safe operating limits.

ACPV modules underwent outdoor tests on the SolarBridge Champaign and Austin office rooftops as well as Atlas outdoor test sites in Phoenix, Miami and Flagstaff (Figure 75). Data collected from SolarBridge's Solar Information Module (SIM) as well as from an external data acquisition system. Data showed close correlation between solar insolation levels and input power levels indicating excellent Maximum Power Point Tracking (Figure 76).

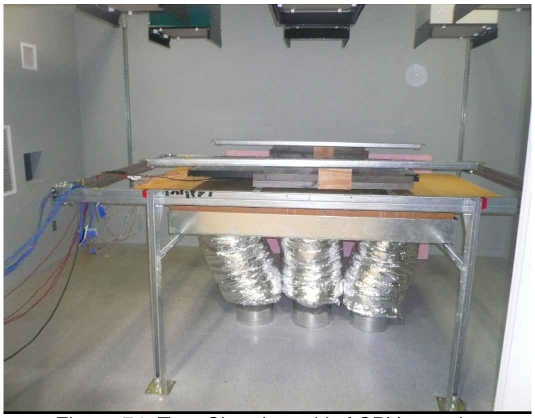


Figure 74: Test Chamber with ACPV sample

Figure 75: Setup for outdoor testing of SP225 PV modules

At the close of the final phase, SolarBridge is continuing long-term field testing at multiple sites, including at its headquarters and at SunPower facilities. Performance monitoring showed SolarBridge energy harvest to be at least equal to that of central inverter and DC/DC solution.

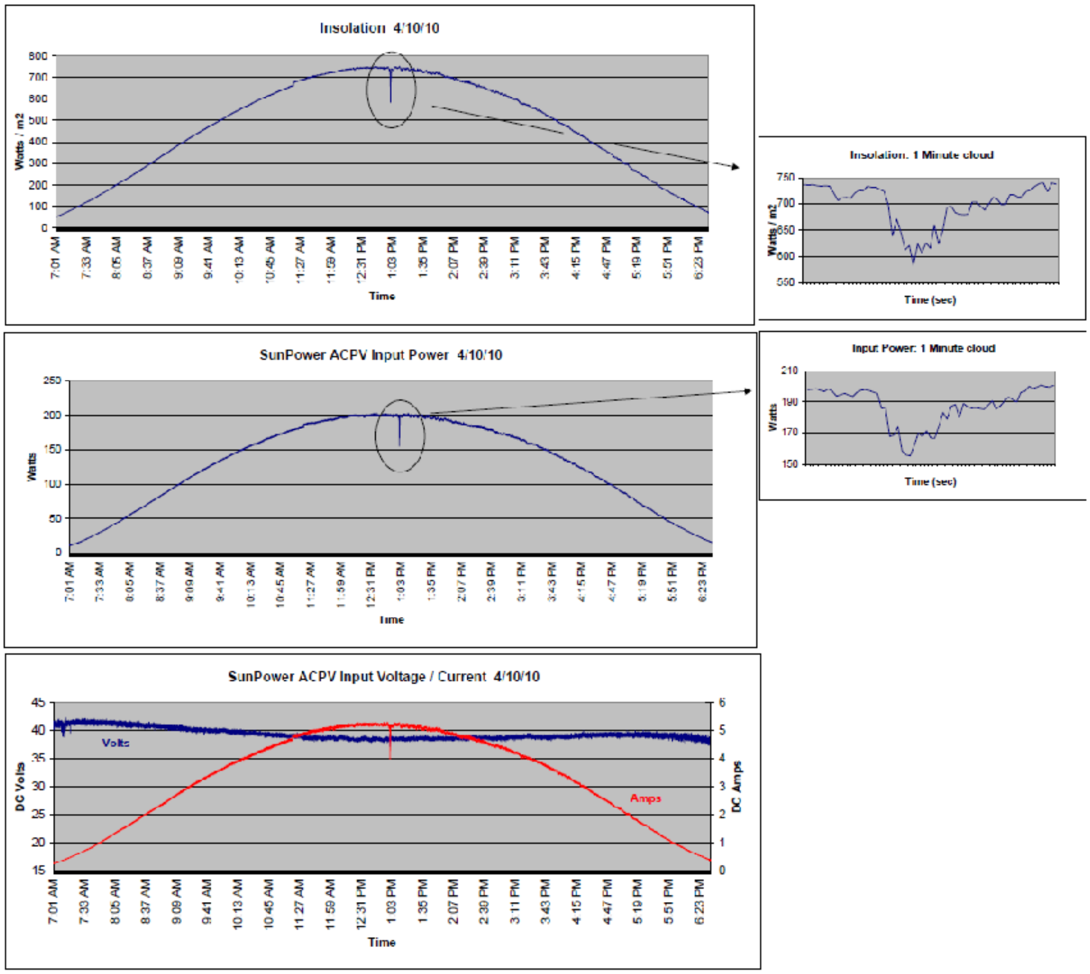


Figure 76: Input power tracking with measured insolation showing MPPT effectiveness

A number of accelerated tests have been performed that demonstrate that the SolarBridge Microinverter will operate for 15 years with minimal degradation in energy harvest. These include Powered Thermal Cycling (PTC), High Temperature Operating Bias (HTOB), Damp Heat (DH) and Humidity Freeze (HF).

In addition to ramping component production and building a supply base for critical components, SolarBridge initiated coordination with SunPower's manufacturing team to evaluate possibilities to integrate attachment of the docking station and microinverter into SunPower's module manufacturing process.

In October, SolarBridge publicly introduced the Pantheon microinverter and Power Manager at the Solar Power International conference. In collaboration with SunPower, the SolarBridge ACPV module was exhibited in the SolarBridge booth. In early 2011, SolarBridge received CSA certification for the product.

<u>Tigo Energy</u>

Phase II

In June of 2009, Tigo Energy has installed two strings of 13 SunPower 230W PV modules on the roof-top of Company's headquarters, in a system configuration which includes the Tigo Energy Maximizer system. This system includes Tigo Energy Module Maximizers, Maximizer Management Unit, and a central DC/AC power conditioner developed by Kaco new energy GmbH for the Tigo configuration. The system provides data capture, analytics and reliability / performance monitoring at PV module level granularity.

The system was monitored and evaluated for production performance, conversion efficiencies, and functional integrity. This configuration successfully demonstrated a fully operational photovoltaic subsystem based on the Tigo Energy distributed architecture. A comparative analysis was made between a traditional centralized configuration (central or string inverter) and the distributed architecture. The baseline data should establish that the distributed architecture provides advantages in generation while delivering parity in overall conversion efficiency and balance-of-system cost.

Figure 77: Two strings of SunPower modules installed in Los Gatos for SAI inverter reliability study

During the first stage of the project extensive operating data was captured to ensure the system operated to expectation in function, performance and initial reliability. Each module in both the control string (series connected string feeding traditional isolated inverter) and the new configuration (branch with Tigo Energy Modules Maximizers and optimized inverter) was instrumented for voltage, current, and temperature readings. By observing the voltage output of each string, Tigo determined the quality of the MPPT implementation and DC input signal.

Figure 78 indicates voltage levels during irradiance change (clouds) for modules within each string, representing the most difficult environmental conditions for performance and inverter stress. The modules from the control string are colored purple while the modules from the new configuration are yellow. These results demonstrate the stability of the voltage levels of the modules in the Tigo string indicating the power harvest remains optimal despite changing irradiance.

Figure 78: Voltage stability of module output from traditional (purple) vs. Tigo (yellow) strings

To track benefit of the Tigo technologies, the Tigo Energy monitoring system displays real-time power output reading from each of the modules during operation. Figure 79 depicts module state during operation in an array with shading. The top string was the control string while the lower modules were equipped with the Tigo Energy system. In this scenario, two modules on each string were subjected to equal shade patterns. The data showed that not only did the Tigo Energy Maximizer system prevent the shaded modules from triggering the by-pass diode (a significant boost in module reliability as well as incremental energy output), but it also prevented degradation of the un-shaded modules. The incremental output in this scenario from the new inverter topology was approximately 15%.

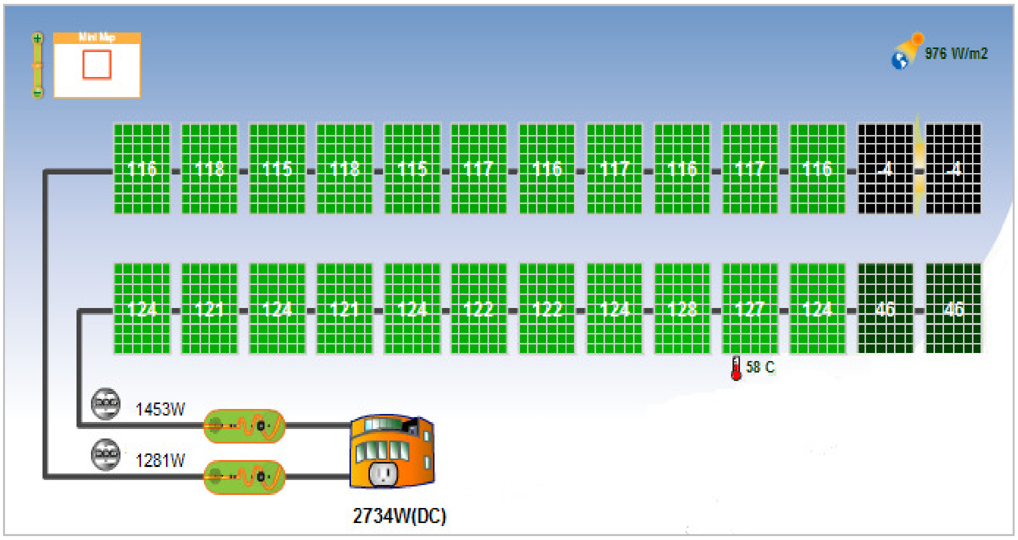


Figure 79: Schematic of trial array demonstrating operation during shading experiment

System component reliability was observed throughout the period. While no failures in any part of the system were observed, the duration of the period was not sufficient to draw conclusions. Accelerated life-testing, component stress testing and other statistical methods were deployed for more definitive conclusions during the next phase of the project.

Phase III

Following preliminary validation in Phase II of the program, Tigo worked with SunPower on integration with the existing module platform. This integration required significant redesign of the Tigo unit, primarily achieved through component reduction and efficiency enhancement. The device was substantially reduced in size from its original form factor; see figures for a comparison.

The new Tigo box has a much more compact form factor and has a reduced part count. This box has shrunk to a form factor of 4.75 inches by 4 inches by 1 inch deep. The power electronics will fit inside of a SunPower junction box, which is approximately 5 inches by 6 inches by 1 inch deep.

Figure 80: Original Maximizer unit

Figure 81: Redesigned Maximizer unit with reduced footprint and thickness

Additionally, based on the SunPower design, Tigo made modifications in order to meet SunPower's requirements of an optional bypass diode option.

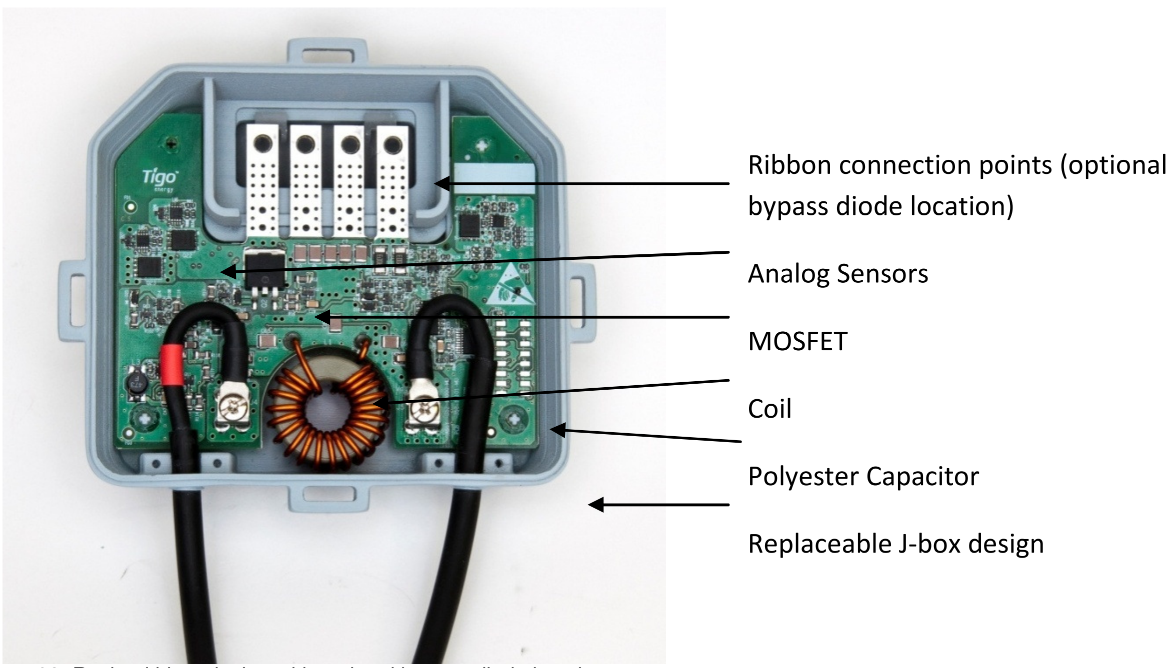


Figure 82: Revised j-box desing with optional bypass diode location

This design has been modified to meet the reliability, heat, efficiency, and cost thresholds needed by SunPower to deliver energy at MPP of every module while maintaining the integrity and low-cost price point of the existing module technology. This topology enabled module integration with less than 0.2 Watts of heat on a 215W module, 99.6% overall conversion efficiency, and operation at the true MPP of each module.

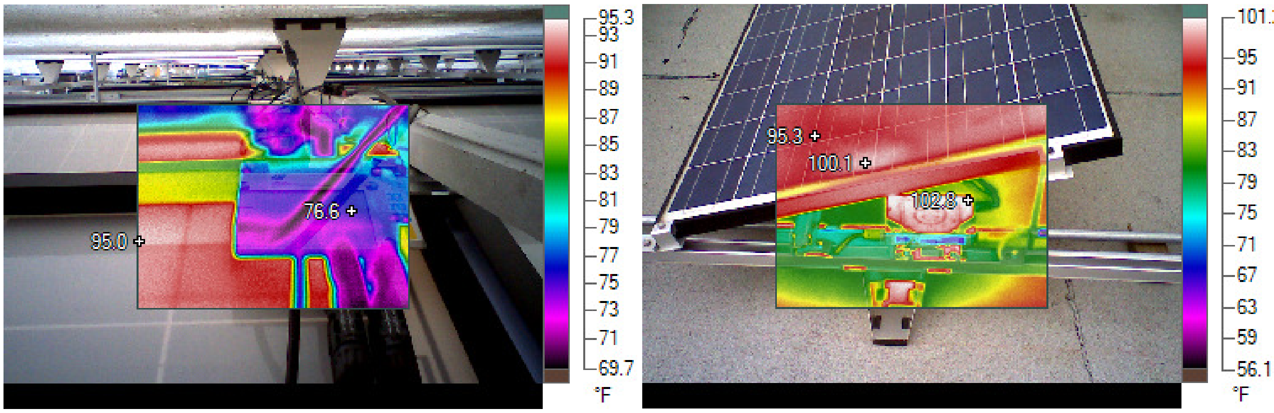


Figure 83: Thermal profile comparison of of (i) Tigo Maximizer and (ii) microinverter, demonstrating lower operating temperature of Tigo solution.

As a follow-on integration activity, Tigo Energy modified several SunPower modules to affix the j-box technology to the module. This was accomplished by removing the original J-box and attaching the cell-string ribbons to the inputs of the j-box Maximizer (See Figure 84). These units underwent testing for several months with positive results.

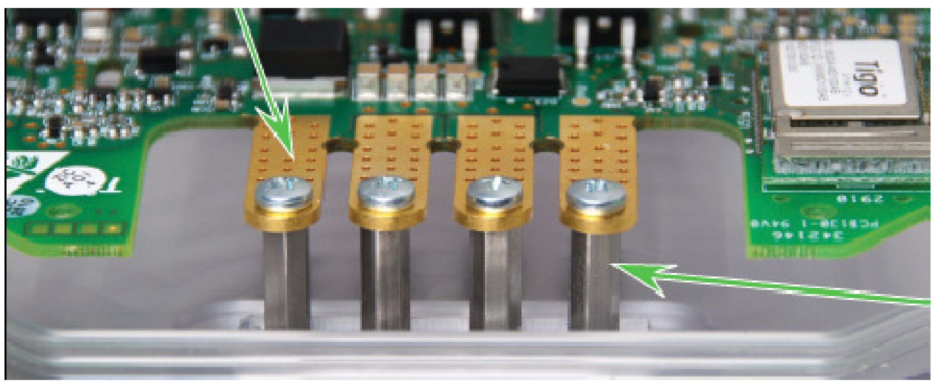


Figure 84: Terminations to connect to ribbons

Figure 85: Integrated Tigo J-box Module

With the integrated modules and inverters the system architecture will be set up similar to the architecture in Figure 7. The Maximizers, however, will disappear into the module, and the management unit will disappear into the modified inverter. The modified inverter will receive a cleaner IV curve from the panels and will operate more efficiently as per comments in earlier quarterly reports.

In parallel with design integration work, Tigo focused efforts on confirming product reliability predictions. As part of this effort, Tigo contracted with DfR Solutions to analyze the product. This analysis demonstrated a 99% confidence that the Tigo Maximizer design to last 20 years in typical operating conditions. The highlight results are below.

The ES50 Maximizer will meet life requirements with regards to fatigue of 20 years and 99% reliability
- Verify PTH spacing at corner of U51
- Vibration and shock robustness excellent
- Acceleration factor
- Powered accelerated life test between -40℃ and 70℃
    - Unit is assumed to be off at -40℃
    - Unit is assumed to be on at 70℃ which generates an
    - additional temperature rise of about 25℃
- Field, diurnal thermal cycle
    - Between 10 and 15℃ change in temperature
    - Additional temperature rise due to operation
- AF = 270
    - 1 ALT cycle is equivalent to 270 days in the field
    - environment
    - Assumes one cycle per day in the field

Potting Material
- Tigo Energy utilizes Sygard 160, silicone elastomer
    - Glass transition temperature < -50℃
    - Low modulus

- Glass transition temperature does not fail within the field or test temperature ranges so the potting will maintain its mechanical properties
- Low modulus and low tensile strength will not impart additional stresses to the electronics changing their fatigue behavior

During this period, Tigo initiated HALT and HASS testing of the Maximizer design. The Maximizers were subjected to over 3,745,273 hours of accelerated life testing with no wear-out failures. Wake up and sleep modes were accelerated on individual Maximizers, which have experienced 25 plus years of accelerated cycling. These results help to validate improved component lifetimes.

Deliverables

	Deliverable	Status as of Phase Completion
	Phase I	
√	5 cells with target efficiency of 22%; success at > 21%	Hardware deliverables submitted to NREL for verification
√	Prototype laminate for class A fire rating	
√	Prototype module optimized for roof-top commercial	
√	Prototype module optimized for ground commercial	
√	Energy production data from prototype modules	
√	Demonstrate baseline pilot line equipment required for unitary product manufacturing for commercial applications	Finished T5 commercial rooftop product from pilot manufacturing run displayed to demonstrate manufacturing capability
√	Demonstrate of ETO design software capabilities	Live software demonstration provided at DOE Stage Gate I meeting
	Phase II	
√	5 cells with target efficiency of 23%; success at > 22.5%	Hardware deliverables submitted to NREL for verification
√	5 cells produced with autoline-compatible processes with efficiency greater than 20%	
√	2 modules with target efficiency of 20.4% and able to meet reliability requirements	
-	Production laminate for class A fire rating	Delivered status report to NREL in lieu of hardware
√	Production module for commercial applications	96-cell and 128-cell modules submitted to NREL
-	Prototype inverter for performance and reliability testing	Lag due to change in subcontractors between Phases I and II
	Phase III	
√	5 cells produced with autoline-compatible processes with target efficiency of 23%	Hardware deliverables submitted to NREL and/or SNL for verification
√	Second generation module using cost-reduced, new-generation components	
√	Autoline-produced laminate for residential or commercial application	
√	Production inverter	

Publications

Project Overview

- Jester, T.L.; Brown, K.E.; Mulligan, B. (2008) “Grid Competitive Residential and Commercial Fully Automated PV Systems Technology,” paper presented at IEEE 33rd PV Specialist Conference, San Diego, CA. 11-16 May 2008.

Task 2: Wafering Technology Development

- Henley, F.; Lamm, A; Kang, S.; Liu, Z.; Tian, L. (2008) “Direct Film Transfer (DFT) Technology for Kerf-Free Silicon Wafering," 23rd European PV Conference, Valencia, Spain. September 2008.
- Henley, F.; Brailove, A.; Lamm, A.; Heerwagenm T.; Sauar, E.; Nese, M.; Steeman, R.; Hammel, B. (2008) “Kerf-Free Silicon Wafering Equipment Configuration Using Beam-Induced Cleave,” paper presented at 23rd European PV Conference, Valencia, Spain. September 2008.

Task 3: Automated In-line manufacturing of High Performance Back-Contact Solar Cells

- Cousins, P.; Smith, D.; Hsin-Chiao L.; Manning, J.; Dennis, T.; Waldhauer, A.; Wilson, K.; Harley, G.; Mulligan, W. (2010) “Generation 3: Improved Performance at Lower Cost,” paper presented at IEEE PVSC conference, Honolulu, Hawaii. 20-25 June 2010.

Task 4: Low Cost, High Performance Modules for Easy System Integration

- DeGraaff, D.; Caldwell, S.; Lacerda, R.; Bunea, G.; Terao, A.; Rose, D. (2010) “Qualification, Manufacturing, and Reliability Testing Methodologies for Deploying High-Reliability Solar Modules,” paper presented at EU PVSEC conference, Valencia, Spain. 10 September 2010.

Task 5: Unitary Product Design

- Botkin, J.; Culligan, M. (2009) “The Unitary Ideal in Commercial Photovoltaic System Product Design,” paper presented at IEEE 34th PV Specialist Conference, Philadelphia, PA. 7-12 June 2009.

Task 9: Performance Monitoring

- Kimber, A.; *et. al*. (2009) “Improved Test Method to Verify the Power Rating of a Photovoltaic (PV) Project,” paper presented at IEEE 34th PV Specialist Conference, Philadelphia, PA. 7-12 June 2009.
- Donovan, M.; Bourne, B.; Roche, J. (2010) “Efficiency vs. Irradiance Characterization of PV Modules Requires Angle-of-Incidence and Spectral Correction,” poster presented at at IEEE PVSC conference, Honolulu, Hawaii. 20-25 June 2010.
- Rose, D.; Koehler, O.; Bourne, B.; Kavulak, D.; Nelson, L. (2010) “High-Confidence Prediction of Energy Production from High-Efficiency Photovoltaic Systems,” paper presented at EU PVSEC conference, Valencia, Spain. 10 September 2010.

Patent Applications & Awards

Over the course of the program, SunPower Corporation generated over 130 invention disclosures and elected to file patents on 75 inventions. At the close of the agreement, disposition of additional disclosures was under review.

Additional inventions generated by subcontractors is not reflected in the above figures.

Solar Advisor Model Inputs & Results Summary

DOE/SETP-defined inputs
In order to provide a consistent framework for comparison, all TPPs under the DOE SAI program use the following inputs to calculate baseline and future LCOE targets.

	Commercial	Residential
PROGRAM		
Technology	PV	PV
Market	Commercial	Residential
ENVIRONMENT		
Climate	Phoenix	Phoenix
Utility Rate – Flat	12 ¢/kWh	12 ¢/kWh
FINANCIALS		
Type of Financing	Commercial Loan	Residential Mortgage
General		
Analysis Period	30 yrs	30 yrs
Inflation Rate	2.5%	2.5%
Real Discount Rate	5.5%	5.5%
Taxes & Insurance		
Federal Tax	35.0%	28.0%
State Tax	7.0%	7.0%
Property Tax	0.0%	0.0%
Insurance	0.0%	0.0%
Depreciation	MACRS: Mid-Quarter	n/a
Loan		
Loan (Debt) Percentage	50.0%	100.0%
Loan Term	15 yrs	30 yrs
Loan Rate	6.0%	6.0%
Tax Credit Incentives		
Federal	10.0%	n/a
State	n/a	n/a
Constraining Assumptions		
PPA Escalation Rate	n/a	n/a
Target Internal Rate of Return	n/a	n/a
Target Min. Debt Service Coverage Ratio	n/a	n/a
Positive Cash Flow	n/a	n/a

Commercial: Ground Mount Systems
In the final phase of SunPower's TPP, SunPower developed and prototyped a new horizontal tracker platform for large-scale deployments. This new platform builds on the design improvements and principles employed in the new T20 tracker developed and released under Phases I and II, while achieving more power density on a given parcel of land. The SG3 SAM analysis is based on large arrays using the next-generation horizontal tracker with SunPower's 128-cell module format.

Current / Baseline LCOE: *Commercial Ground*

	2006 Proposal	2008 SG1	2009 SG2	Current SG3
SYSTEM				
Configuration	Flat Plate	Flat Plate	Flat Plate	Flat Plate
Mounting				
Array				
Layout				
Modules per string	15	15	12	10
Strings in parallel	298	298	265	144
Array Power (calculated)*	1000	1000	1000	1881
# Inverters	5	5	5	2
Total Inverter Power (calc)				
Performance				
System Derate Factor	19.0%	19.0%	19.0%	20.62%
System Degradation	0.5%	0.5%	0.5%	0.5%
Tracking Type	1-axis	1-axis	1-axis	1-axis
Orientation				
Tilt	0	0	20	0
Azimuth	0	0	0	0
Ground Reflectance	0.0	0.2	0.2	0.2
Module				
Power (calculated)	300	300	305	435
Efficiency	16.1%	18.0%	19.1%	20.4%
Temperature Coefficient	-0.50	-0.50	-0.35	-0.38
Area	1.63	1.63	1.63	2.14
Inverter				
Power	225	225	225	760
Efficiency	95%	95%	95%	96.2%
COSTS				
Module	2.79	2.79	2.55	2.35
Inverter	0.22	0.22	0.24	0.30
BOS	0.41	0.41	0.40	0.50
Installation	1.34	1.34	0.35	0.35
Indirect and other cost	1.59	1.59	0.80	1.00
Total Installed Costs (calculated)	6.34	6.34	4.34	4.50
Annual O&M	16,000	16,000	15,500	22,500
LCOE ($/kWh)	**0.1566**	**0.1165**	**0.0917**	**0.0776**

2010 LCOE: *Commercial-Ground*

	2010 LCOE Projections			
	Proposal	SG1	SG2	SG3
SYSTEM				
Configuration	Flat Plate	Flat Plate	Flat Plate	Flat Plate
Mounting				
Array				
Layout				
Modules per string	15	15	15	10
Strings in parallel	218	218	218	144
Array Power (calculated)*	1000	1000	1000	1881
# Inverters	5	5	5	2
Total Inverter Power (calc)				
Performance				
System Derate Factor	19.0%	19.0%	19.0%	20.62%
System Degradation	0.5%	0.5%	0.5%	0.5%
Tracking Type	1-axis	1-axis	1-axis	1-axis
Orientation				
Tilt	20	0	20	0
Azimuth	0	0	0	0
Ground Reflectance	0	0.2	0.2	0.2
Module				
Power (calculated)	300	300	305	435
Efficiency	22.0%	20.0%	20.0%	20.4%
Temperature Coefficient	-0.5	-0.5	-0.5	-0.38
Area	1.63	1.63	1.63	2.14
Inverter				
Power (kW)	225	225	225	760
Efficiency	95%	95%	95%	96.2%
COSTS				
Module	1.99	1.99	2.36	2.35
Inverter	0.18	0.18	0.24	0.30
BOS	1.03	1.03	0.36	0.50
Installation	0.47	0.47	0.35	0.35
Indirect and other cost	1.10	1.10	0.79	1.00
Total Installed Costs	4.77	4.77	4.10	4.50
Annual O&M	13,755	13,755	13,755	22,500
LCOE ($/kWh)	**0.0970**	**0.0943**	**0.0883**	**0.0776**
SunPower TPP Target	**0.10**			
DOE Target Range	**0.09 – 0.12**			

2015 LCOE: *Commercial Ground*

	2015 LCOE Projections			
	Proposal	SG1	SG2	SG3
SYSTEM				
Configuration	Flat Plate	Flat Plate	Flat Plate	Flat Plate
Mounting				
Array				
Layout				
Modules per string	15	15	15	12
Strings in parallel	193	193	193	660
Array Power (calculated)*	1000	1000	1000	3783
# Inverters	5	5	5	2
Total Inverter Power (calc)	1,125	1,125	1,125	
Performance				
System Derate Factor	19.0%	19.0%	19.0%	20.62%
System Degradation	0.5%	0.5%	0.5%	0.5%
Tracking Type	1-axis	1-axis	1-axis	1-axis
Orientation				
Tilt	20	0	20	0
Azimuth	0	0	0	0
Ground Reflectance	0	0.2	0.2	0.2
Module				
Power (calculated)	300	300	305	457
Efficiency	24.0%	22.0%	22.0%	21.4%
Temperature Coefficient	-0.5	-0.5	-0.5	-0.4
Area	1.63	1.63	1.63	2.14
Inverter				
Power (kW)	225	225	225	1.5
Efficiency	95%	95%	95%	96.2%
COSTS				
Module	1.53	1.53	1.34	1.27
Inverter	0.14	0.14	0.17	0.12
BOS	0.70	0.70	0.30	0.29
Installation	0.34	0.34	0.35	0.15
Indirect and other cost	0.76	0.76	0.45	0.32
Total Installed Costs	3.48	3.48	2.61	2.15
Annual O&M	9,065	9,065	9,065	22,500
LCOE ($/kWh)	**0.0695**	**0.0669**	**0.0554**	**0.0376**
DOE Target Range	**0.06 – 0.08**			

Commercial Roof
Through the DOE TPP, SunPower developed and released the T5 Solar Roof Tile. The SG3 SAM analysis is based on a 422-kWp array using the 5-degree tilted tile with SunPower's 96-cell module format.

<u>Current / Baseline LCOE: *Commercial Roof*</u>

	2006	2008	2009	Current
	Proposal	SG1	SG2	SG3
SYSTEM				
Configuration	Flat Plate	Flat Plate	Flat Plate	Flat Plate
Mounting				
Array				
Layout				
Modules per string	15	13	11	8
Strings in parallel	104	104	101	161
Array Power (calculated)*	350	350	350	422
# Inverters	1	1	1	1
Total Inverter Power (calc)				
Performance				
System Derate Factor	23.0%	19.0%	19.0%	20.62%
System Degradation	0.5%	0.5%	0.5%	0.5%
Tracking Type	Fixed	Fixed	Fixed	Fixed
Orientation				
Tilt	10.0	10.0	15.0	5.0
Azimuth	0	0	0	0
Ground Reflectance	-	-	-	-
Module				
Power (calculated)	220	220	220	327
Efficiency	16.0%	19.0%	19.1%	20.4%
Temperature Coefficient	-0.50	-0.38	-0.38	-0.38
Area	1.63	1.63	1.63	1.60
Inverter				
Power	350	350	350	350
Efficiency	95%	95%	95%	95%
COSTS				
Module	3.79	3.79	3.54	2.35
Inverter	0.24	0.19	0.24	0.20
BOS	0.31	0.31	0.77	0.43
Installation	0.66	0.66	0.15	0.21
Indirect and other cost	1.28	1.28	0.53	0.61
Total Installed Costs (calculated)	6.27	6.22	5.23	3.80
Annual O&M	7,700	7,700	7,700	5,516
LCOE ($/kWh)	**0.182**	**0.118**	**0.096**	**0.090**

2010 LCOE: *Commercial-Roof*

	2010 LCOE Projections			
	Proposal	SG1	SG2	SG3
SYSTEM				
Configuration	Flat Plate	Flat Plate	Flat Plate	Flat Plate
Mounting				
Array				
Layout				
Modules per string	15	15	13	8
Strings in parallel	76	76	86	161
Array Power (calculated)*	350	350	350	422
# Inverters	1	1	1	1
Total Inverter Power (calc)				
Performance				
System Derate Factor	19.0%	19.0%	19.0%	20.6%
System Degradation	0.5%	0.5%	0.5%	0.5%
Tracking Type	Fixed	Fixed	Fixed	Fixed
Orientation				
Tilt	15	15	15	5
Azimuth	0	0	0	0
Ground Reflectance	-	-	-	-
Module				
Power (calculated)	220	220	220	327
Efficiency	22.0%	22.0%	19.3%	20.4%
Temperature Coefficient	-0.5	-0.32	-0.32	-0.38
Area	1.63	1.63	1.63	1.605
Inverter				
Power (kW)	350	350	350	350
Efficiency	95%	95%	95%	95%
COSTS				
Module	2.90	2.90	3.27	2.35
Inverter	0.24	0.18	0.24	0.20
BOS	0.19	0.19	0.72	0.43
Installation	0.41	0.41	0.13	0.21
Indirect and other cost	0.85	0.85	0.53	0.61
Total Installed Costs	4.59	4.53	4.89	3.80
Annual O&M	5,516	5,516	5,516	5,516
LCOE ($/kWh)	**0.109**	**0.078**	**0.088**	**0.090**
DOE Target Range	**0.09-0.12**			

2015 LCOE: *Commercial Roof*

	2015 LCOE Projections			
	Proposal	SG1	SG2	SG3
SYSTEM				
Configuration	Flat Plate	Flat Plate	Flat Plate	Flat Plate
Mounting				
Array				
Layout				
Modules per string	15	15	15	8
Strings in parallel	68	68	74	154
Array Power (calculated)*	350	350	350	423
# Inverters	1	1	1	1
Total Inverter Power (calc)	350	350	350	350
Performance				
System Derate Factor	19.0%	19.0%	19.0%	20.6%
System Degradation	0.5%	0.5%	0.5%	0.5%
Tracking Type	Fixed	Fixed	Fixed	Fixed
Orientation				
Tilt	30	30	30	5
Azimuth	0	0	0	0
Ground Reflectance	-	-	-	-
Module				
Power (calculated)	220	220	220	343
Efficiency	24.0%	22.0%	21.5%	21.4%
Temperature Coefficient	-0.5	-0.31	-0.31	-0.38
Area	1.63	1.63	1.63	1.61
Inverter				
Power (kW)	350	350	350	350
Efficiency	95%	95%	95%	95%
COSTS				
Module	2.23	2.23	1.77	1.27
Inverter	0.24	0.17	0.17	0.19
BOS	0.13	0.13	0.56	0.40
Installation	0.26	0.26	0.08	0.16
Indirect and other cost	0.59	0.59	0.41	0.40
Total Installed Costs	3.45	3.38	2.99	2.42
Annual O&M	3,636	3,636	3,636	3,636
LCOE ($/kWh)	**0.077**	**0.058**	**0.054**	**0.057**
DOE Target Range	**0.06-0.08**			

Residential
During SunPower's TPP, the residential housing market experienced significant setbacks in the recession. As such, the TPP was restructured with reduced focus on residential products. Instead, SunPower worked to leverage gains from the commercial market product and transitioned to larger-format modules. The SG3 SAM analysis is based on arrays using SunPower's 96-cell module format.

SunPower anticipates additional LCOE reduction beyond the reported 2015 projections. However, estimates generated for the purposes of this report are conservative and limited to the scope of innovations generated under this agreement.

Current / Baseline LCOE: *Residential*

	2006 Proposal	2008 SG1	2009 SG2	Current SG3
SYSTEM				
Configuration	Flat Plate	Flat Plate	Flat Plate	Flat Plate
Mounting				
Array				
Layout				
Modules per string	11	10	10	8
Strings in parallel	2	2	2	2
Array Power (calculated)*	4.5	4.5	4.5	5.5
# Inverters	1	1	1	1
Total Inverter Power (calc)	4.0	4.0	4.5	5.0
Performance				
System Derate Factor	5.0%	5.0%	5.0%	5.0%
System Degradation	0.5%	0.5%	0.5%	0.5%
Tracking Type	Fixed	Fixed	Fixed	Fixed
Orientation				
Tilt	18	18	18	18
Azimuth	0	0	0	0
Ground Reflectance	-	-	-	-
Module				
Power (calculated)	220	220	220	327
Efficiency	16.1%	18.0%	19.1%	20.4%
Temperature Coefficient	-0.50	-0.50	-0.35	-0.38
Area	1.63	1.63	1.63	1.60
Inverter				
Power	4.0	4.0	4.5	5.0
Efficiency	95%	96%	95%	95%
COSTS				
Module	3.79	3.79	3.10	2.35
Inverter	0.47	0.47	0.50	0.35
BOS	0.22	0.22	1.02	0.81
Installation	0.84	0.84	0.51	0.56
Indirect and other cost	2.44	2.44	1.62	1.93
Total Installed Costs (calculated)	7.77	7.77	6.74	6.00*
Annual O&M	348	348	283	133
LCOE ($/kWh)	**0.225**	**0.214**	**0.179**	**0.162**

*Reflects supply-constrained environment in Q1'11. ASP subsequently dropped reflecting changes in market conditions.

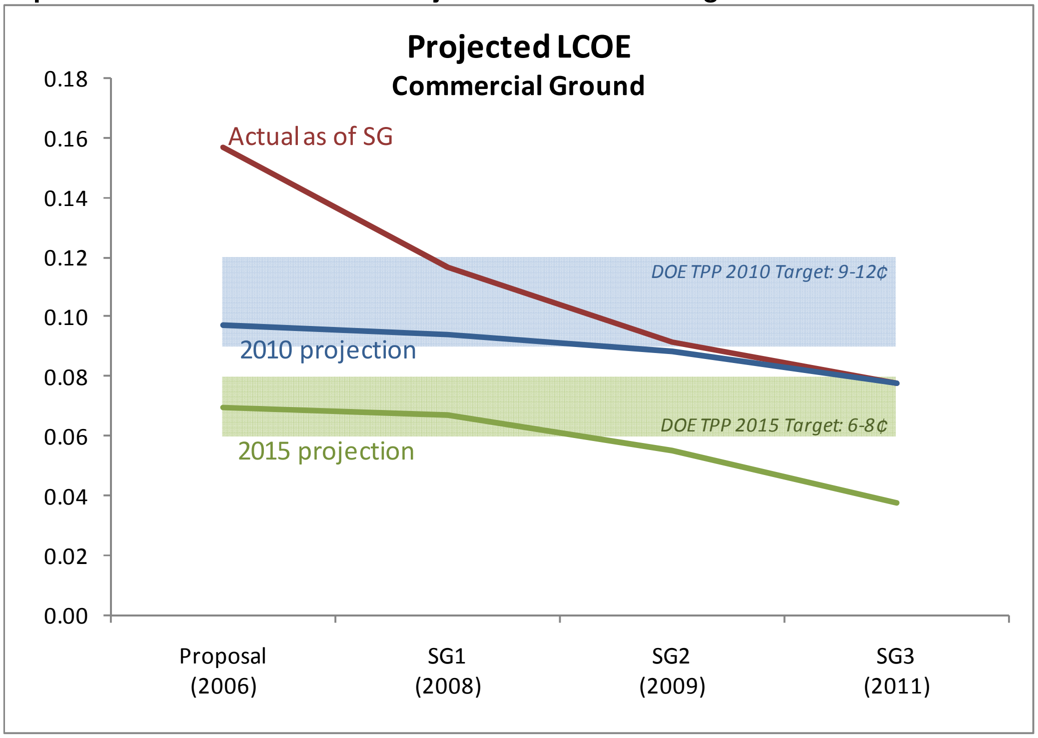
2010 LCOE: *Residential*

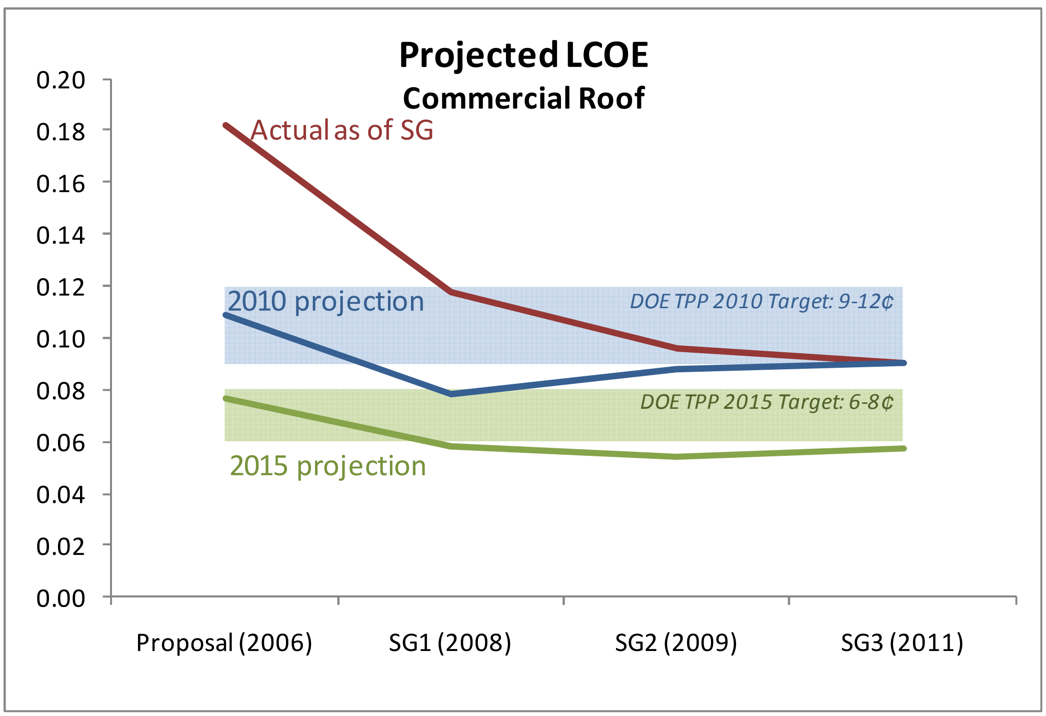
	2010 LCOE Projections			
	Proposal	SG1	SG2	SG3
SYSTEM				
Configuration	Flat Plate	Flat Plate	Flat Plate	Flat Plate
Mounting				
Array				
Layout				
Modules per string	11	10	10	8
Strings in parallel	2	2	2	2
Array Power (calculated)*	4.5	4.5	4.5	5.5
# Inverters	1	1	1	1
Total Inverter Power (calc)	4.0	4.0	4.5	5.0
Performance				
System Derate Factor	5.0%	5.0%	5.0%	5.0%
System Degradation	0.5%	0.5%	0.5%	0.5%
Tracking Type	Fixed	Fixed	Fixed	Fixed
Orientation				
Tilt	18	18	18	18
Azimuth	0	0	0	0
Ground Reflectance	-	-	-	-
Module				
Power (calculated)	220	220	220	327
Efficiency	16.1%	18.0%	19.1%	20.4%
Temperature Coefficient	-0.50	-0.50	-0.35	-0.38
Area	1.63	1.63	1.63	1.60
Inverter				
Power	4.0	4.0	4.5	5.0
Efficiency	95%	96%	95%	95%
COSTS				
Module	2.54	2.54	2.90	2.35
Inverter	0.39	0.39	0.35	0.35
BOS	0.20	0.20	0.90	0.81
Installation	0.35	0.35	0.59	0.56
Indirect and other cost	1.70	1.70	1.31	1.93
Total Installed Costs (calculated)	5.17	5.17	6.05	6.00*
Annual O&M	133	133	133	133
LCOE ($/kWh)	**0.121**	**0.125**	**0.149**	**0.162**
SunPower TPP Target	**0.13**			
DOE Target Range	**0.13-0.18**			

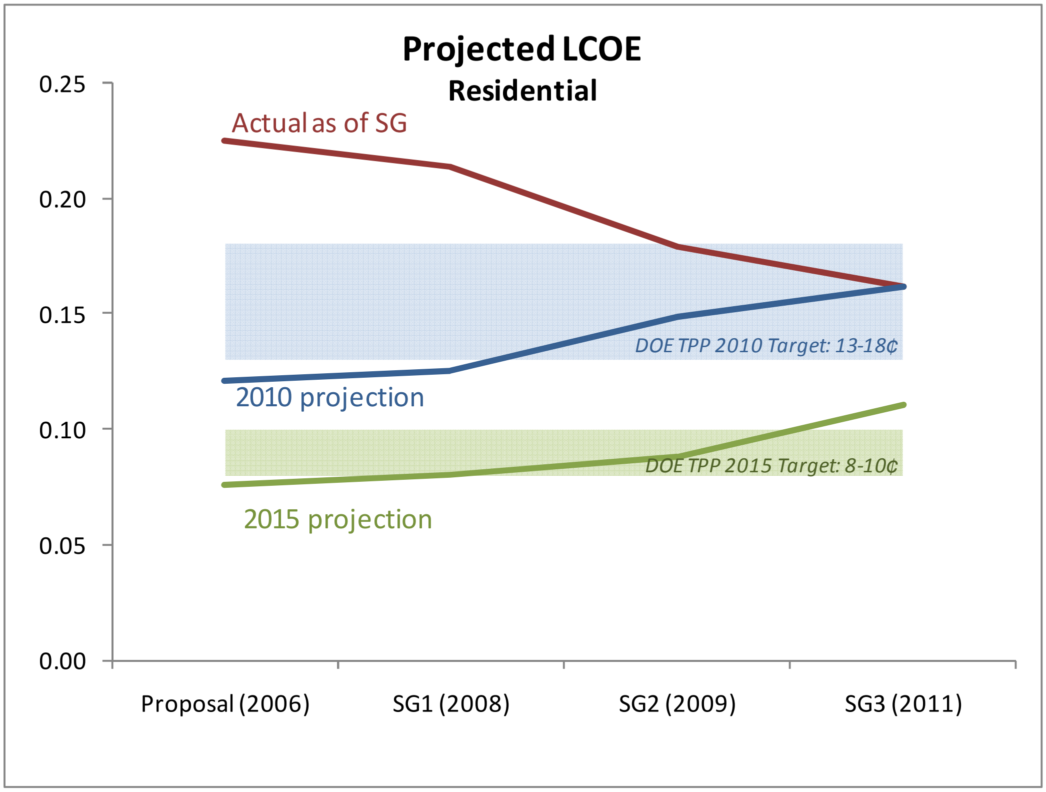
2015 LCOE: *Residential*

	2015 LCOE Projections			
	Proposal	SG1	SG2	SG3
SYSTEM				
Configuration	Flat Plate	Flat Plate	Flat Plate	Flat Plate
Mounting				
Array				
Layout				
Modules per string	9	9	9	8
Strings in parallel	2	2	2	2
Array Power (calculated)*	4.5	4.5	4.8	5.5
# Inverters	1	1	1	1
Total Inverter Power (calc)	4.8	4.8	4.8	5.0
Performance				
System Derate Factor	5.0%	5.0%	5.0%	5.0%
System Degradation	0.5%	0.5%	0.5%	0.5%
Tracking Type	Fixed	Fixed	Fixed	Fixed
Orientation				
Tilt	18	18	18	18
Azimuth	0	0	0	0
Ground Reflectance	-	-	-	-
Module				
Power (calculated)	220	220	220	343
Efficiency	20.8%	20.8%	21.5%	21.4%
Temperature Coefficient	-0.31	-0.31	-0.31	-0.38
Area	1.24	1.24	1.24	1.61
Inverter				
Power (kW)	4.8	4.8	4.8	5.0
Efficiency	97%	96%	96%	96.5%
COSTS				
Module	1.80	1.80	1.59	1.27
Inverter	0.30	0.30	0.27	0.27
BOS	0.16	0.16	0.55	0.55
Installation	0.17	0.17	0.55	0.55
Indirect and other cost	0.99	0.99	0.81	1.81
Total Installed Costs	3.42	3.42	3.76	4.45
Annual O&M	81	81	81	81
LCOE ($/kWh)	**0.076**	**0.08**	**0.088**	**0.110**
DOE Target Range	**0.08-0.10**			

LCOE Comparison between SunPower Projections and DOE Targets







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