Final Technical Report (FTR)

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Executive Summary:

The purpose of this project was to accelerate deployment of cost-effective US-based manufacturing of Solaria's unique c-Si module technology. This effort successfully resulted in the development of US-based manufacturing technology to support two highly-differentiated, market leading product platforms. The project was initially predicated on developing Solaria's low-concentration PV (LCPV) module technology which at the time of the award was uniquely positioned to exceed the SunShot price goal of $0.50/Wp for standard c-Si modules. The Solaria LCPV module is a 2.5x concentrator that leverages proven, high-reliability PV module materials and low silicon cell usage into a technology package that already had the lowest direct material cost and leading Levelized Cost of Electricity (LCOE). With over 25 MW commercially deployed globally, the Solaria module was well positioned to continue to lead in PV module cost reduction.

Throughout the term of the contract, market conditions changed dramatically and so to did Solaria's product offerings to support this. However, the manufacturing technology developed for the LCPV module was successfully leveraged and optimized to support two new and different product platforms. BIPV "PowerVision" and High-efficiency "PowerXT" modules.

The primary barrier to enabling high-volume PV module manufacturing in the US is the high manual labor component in certain unique aspects of our manufacturing process. The funding was used to develop unique manufacturing automation which makes the manual labor components of these key processes more efficient and increase throughput. At the core of Solaria's product offerings are its unique and proprietary techniques for dicing and re-arranging solar cells into modules with highly-differentiated characteristics that address key gaps in the c-Si market. It is these techniques that were successfully evolved and deployed into US-based manufacturing site with SunShot funding.

Today, Solaria is currently positioned to become the market leader with these two technologies over the coming 24 months largely due to the successful innovations of the underlying manufacturing technology. This success will leverage US-based manufacturing technology and the associated US-jobs to support. Solaria views the project as highly successful and a great example of SunShot funding enabling the creating of US jobs and the deployment of ubiquitous solar energy products.

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Background:

In the past 4 years since the start of this project the solar module market has changed dramatically. Nearly gone are major US-based manufactures of modules and the landscape is dominated by large, vertically integrated, over-seas players. At the same time there is less product differentiation from these same players. US companies still lead in product differentiation and innovation but the scale of manufacturing technology to support these products is marginal relative to the Tier 1 companies. Solaria aims to leverage these issues and address gaps in the current market namely, US-based product manufacturing of highly differentiated products that are cost effective.

The original scope of work was predicated on the Solaria Low-concentration PV (LCPV) module. The Solaria LCPV module is a 2x concentrator which combines standard c-Si module materials and construction with the benefit of a 50% reduction in cell usage to realize the same module power as a standard c-Si module of the same size. The value of this concentration is leveraging across all aspects of the supply chain and has positioned Solaria as the cost leader for c-Si PV module technology. The Solaria module is also a very reliable design which differentiates it from other divergent PV technologies such as high-concentration PV and thin film.

Throughout the term of the contract, market conditions changed dramatically and so to did Solaria's product offerings to support this. However, the manufacturing technology developed for the LCPV module was successfully leveraged and optimized to support two new and different product platforms. BIPV "PowerVision" and High-efficiency "PowerXT" modules.

The PowerVision module utilizes cell strings that were originally design for use in the Solaria LCPV module. Although the economic advantage of the LCPV module has diminished the core technology has remained very viable as a BIPV solution. Building Integrated Photovoltaics (BIPV) are specifically solar devices that replace a conventional building material to improve the energy efficiency of the construction while generating electricity and providing an aesthetically appealing appearance. BIPV has very strong market demands as explained above but few products are commercially available that meet all the requirements to be successfully deployed. Furthermore, we feel the market is currently constrained by the lack of configurability that architects currently want out of this technology. The most significant tradeoff in the industry has been efficiency vs aesthetics. Solaria Corporation's innovative building integrated photovoltaic (BIPV) approach offers many unique advantages over other entrants in the BIPV market without making the tradeoffs inherent in other products. Solaria's unique PV singulation and stringing technology enable BIPV modules that have a uniform view for the strict aesthetic requirements while utilizing the efficiency benefits of c-Si silicon. These advantages allow the opportunity for Solaria to develop a high-volume BIPV solution that has the potential to add up to 1 GW of solar capacity to the grid by 2020.

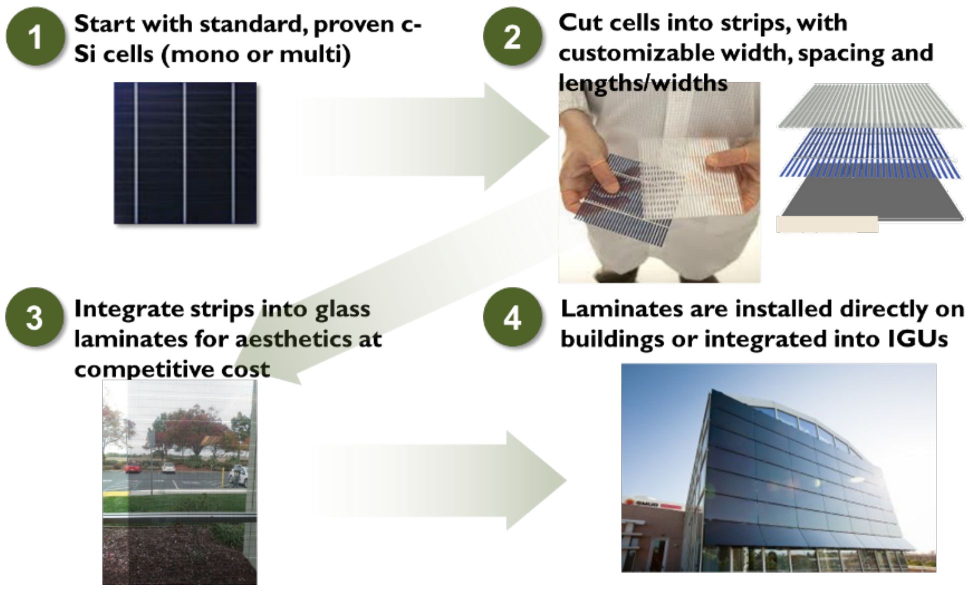


Figure 1: Solaria leverages reliable c-Si solution for innovative approach to BIPV

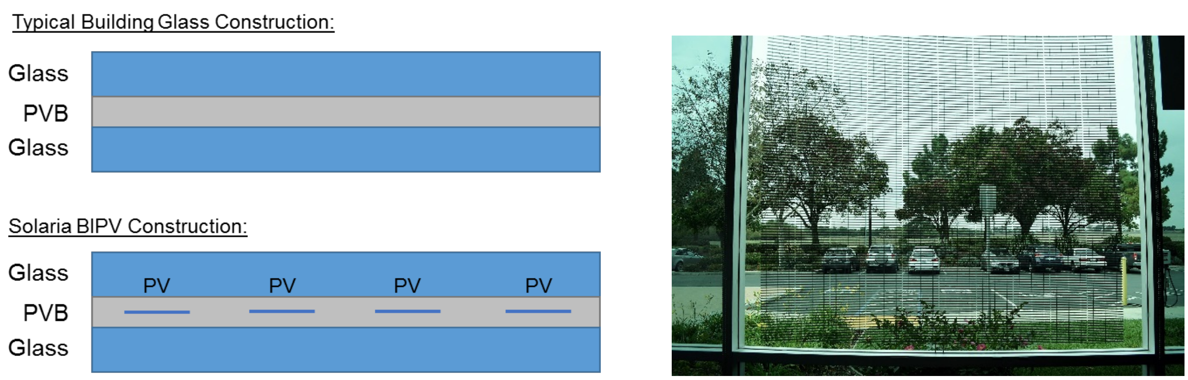


Figure 2: Simple construction leverages existing solar material supply chain for low incremental cost

Solaria's innovative BIPV module design leverages the cell dicing and stringing technology developed and commercialized for their LCPV module. Advantages of this technology are that it utilizes a Bill of Materials (BOM) that is virtually identical to standard double-layer building glass but with the addition of C-Si PV cells. The design enables a BIPV laminate to be easily integrated into standard Insulated Glass Units (IGU's) typical in new building construction (**Figure 1** and **Figure 2** above). This allows Solaria to leverage the current industry supply chain of low-cost, high-volume materials while retaining best in class reliability and construction methodology. However, the current equipment set at Solaria was optimized for the LCPV product which inherently use a single strip width and spacing. On the other hand, the BIPV solution is specifically valuable to architects and builders due to its accommodation of a wide variety of strip size, strip spacing, string length and string layout. These adjustable parameters allow architects and builder the ability to optimize for building glass features such as: light transmission, heat gain, power density all of which can vary greatly not only throughout the market but even on specific buildings.

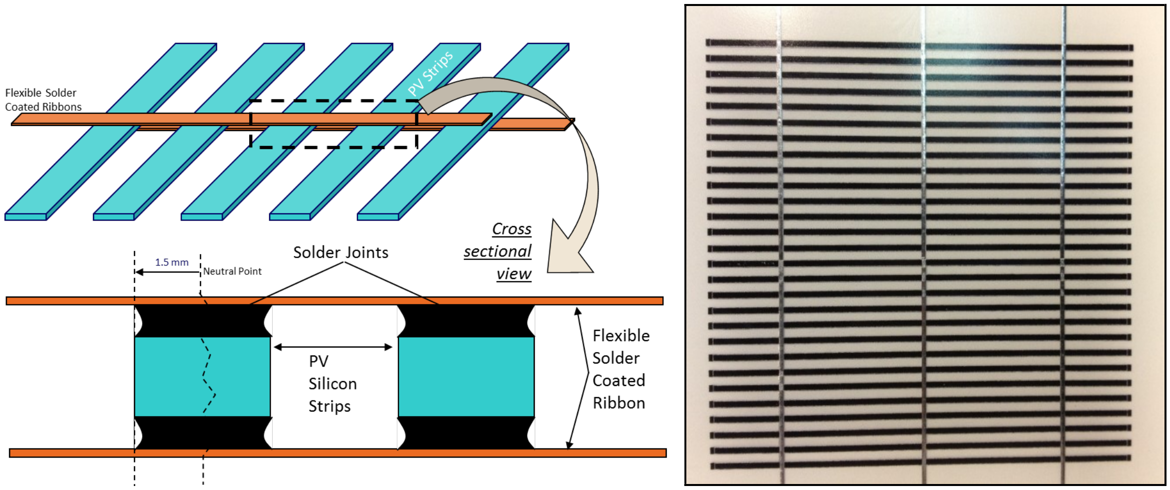


Figure 3: Solaria's redundant cell architecture dramatically improves long-term reliability

The Solaria PowerXT module is a high efficiency module design that actually increases cell density by means of "shingling" or overlapping adjacent cells (**Figures 4 & 5**). The concept of cell shingling is not new to the solar industry but the manufacturing technology needed to make it reliably did not exist prior to this award. Like LCPV it is based on standard c-Si BOM so leverages the existing industry supply chain. The resulting PowerXT concept leverages unique technology and processes developed for LCPV to create high-efficiency modules with superior aesthetics which address a key gap in the US market that Tier 1, overseas module suppliers are unable to address.

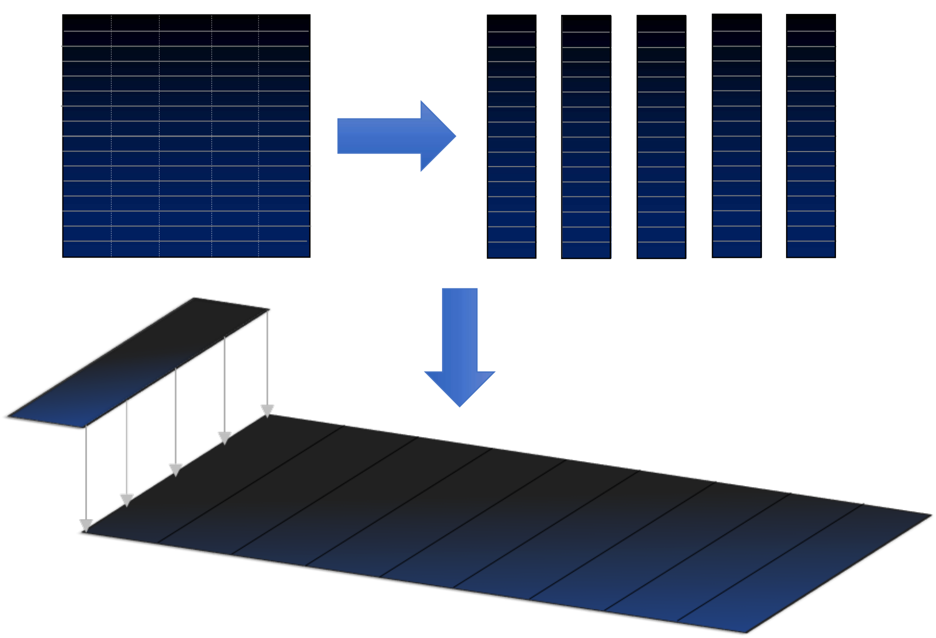


Figure 4: PowerXT "cell shingling" concept utilized in PowerXT product

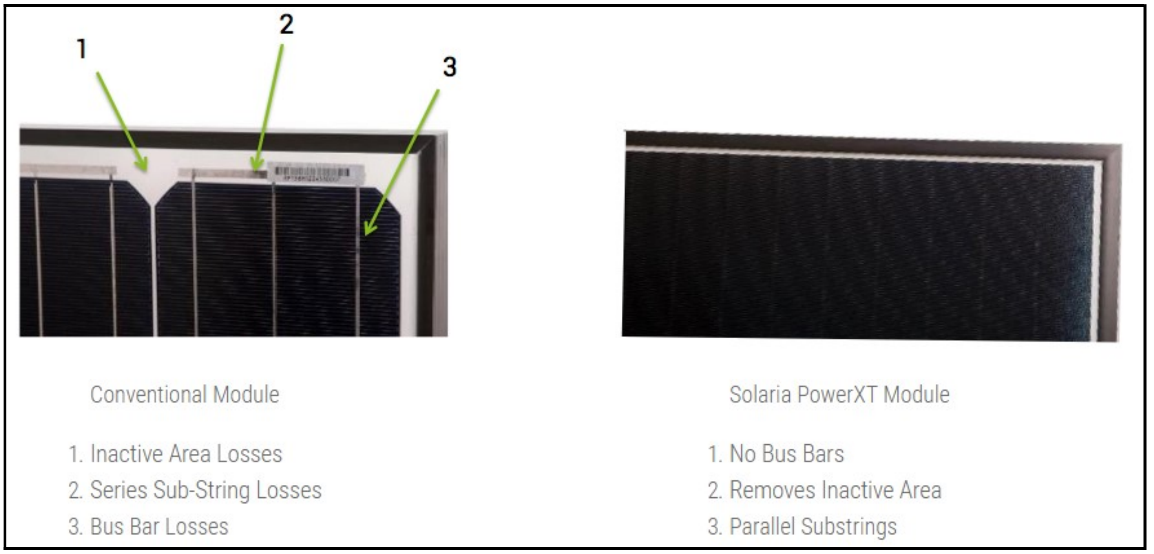


Figure 5: Module Comparison Close-Up: PowerXT vs. Conventional

The Solaria PowerVision and PowerXT module designs are very unique in the industry. They have the advantage of optimizing concentration and silicon content based on market demands without compromising reliability or bankability which has challenged other more divergent technologies such as high-concentration PV and thin-film technologies. The Solaria module technology is protected by patents covering manufacturing equipment, process and module design. Solaria's IP portfolio is our competitive advantage. It has been proven valuable to our investors, partners, suppliers, and customers. It gives us freedom to operate while at the same time providing barriers to entry for our competitors. Improving our competitiveness and protecting that advantage with intellectual property rights is essential for Solaria. It will allow us to achieve and maintain a competitive advantage in the market place.

The objective of this project is to reduce US-based manufacturing cost of the unique Solaria module technologies to accelerate them to market. Although, the Solaria module products are very similar to standard c-Si modules from a materials standpoint, they have unique process steps that must be developed to keep the technology competitive for US-based manufacturing. Opportunities have been identified to radically reduce manufacturing costs and make Solaria the cost leader for c-Si PV module technology.

For the LCPV product (later changed to BIPV) the goal is to reduce manufacturing cost by $0.10/Wp in one year (BP1). The project is comprised of 3 Tasks. Each task targets a unique step of the LCPV module manufacturing process.

For the PowerXT Module the goal is to develop a 25MW pilot line with capex and throughput targets which will demonstrate a total module cost advantage at the system level of >$0.05/Wp compared with conventional c-Si modules (BP2). Note, that through the course of the project we referred to this technology as "HD" (High-Density") but for purposes of the final report refer to it by its now trademarked product name, "PowerXT".

Project Objectives:

For the LCPV product the goal was to reduce manufacturing cost by \$0.10/Wp in one year (BP1). The project is comprised of 3 Tasks. Each task targets a unique step of the LCPV module manufacturing process.

For the POWERXT Module the goal is to develop a 25MW pilot line with capex and throughput targets which will demonstrate a total module cost advantage at the system level of >\$0.05/Wp compared with conventional c-Si modules (BP2).

The objectives are detailed in the following technical work plan. Budget Period 1 was focused on LCPV technology and Budget Period 2 was focused on POWERXT technology.

BUDGET PERIOD 1 (12 Months)

Task 1: Next Generation Stringer
The current stringer technology is stable but narrow in scope and relies on high direct labor from the upstream ((PV assembly)) process. The next generation stringer will ((eliminate the upstream manual steps)) thus dramatically reducing HC while increase throughput relative to capital expenditure. The final buyoff of this machine is contingent on developing the machine to increase the throughput, reduce manual labor and integrate in-line metrology to improve outgoing string quality while embedding a feedback loop for continuous process improvement.

Additionally the current upstream Singulation machine will be modified to improve integration with next generation stringer. ((The new stringer utilizes a unique cell material handling methodology, “strip stacking” that helps enable higher throughput. The upstream process that feeds the stringer is the Singulator. The singulator will be modified to utilize the same strip stacking on its output so it can directly feed the stringer with adding labor. This modification can be done to the existing machines.))

- Deliverable 1.1: Vendor site acceptance and approval of Next Gen Stringer tool
- Deliverable 1.2: Demonstrate integration of in-line metrology ((including dark IV)) with relative reproducibility of σ=1% or better and string length measurement absolute reproducibility of σ = 50 um
- Deliverable 1.3: ((Integrate large capacity strip stacker magazine into singulator machine to make them compatible with next gen stringer))
- Deliverable 1.4: ((Demonstrate throughput of 90 strings per hour with step yield of 99%, and availability of 95% with 2 operators.))
- **Milestone 1:** Demonstrate stringer, singulator & associated manufacturing process that decreases manufacturing costs associated with cell soldering and stringing by at least \$0.06/Wp relative to current methodology.

Task 2: Auto Layup
The current process for placing cell strings and lamination materials is manual. Although the specifications are objective the manual methodology is less repeatable and has high labor content. By developing automation around pre-lamination string and material layup Solaria has opportunity to improve alignment repeatability, increase throughput and reduce associated labor.

- Deliverable 2.1: Develop machine spec and submit vendor PO
- Deliverable 2.2: Vendor site acceptance and buy-off ((with demonstrated capability of 20 modules per hour))
- Deliverable 2.3: Install and qualify tool at Solaria, Fremont facility
- Deliverable 2.4: ((Demonstrate throughput of 20 modules per hour with step yield of 99%, and availability of 95% with 4 operators.))
- **Milestone 2:** Demonstrate layup gantry ((with target throughput of 20 modules per hour)) with reduction of direct labor content for a total savings of \$0.01/Wp.

Task 3: Alternative Scribe
In Solaria's current process ((mechanical dicing saws are used to scribe the wafers)). This technology is stable and well understood but is very resource and consumable intensive. ((The process entails a large amount of reverse osmosis (RO) purified water as well as mechanical dicing blades. Additionally, the machines have a relatively high maintenance requirement.)) Alternative scribing technologies offer potential to reduce maintenance labor and consumable costs of this process. Solaria has already demonstrated forms of alternative dicing in prototype quantities but has some technical challenges to surmount before deploying into high volume manufacturing. ((Due to the ablation technique employed by the laser the resulting micro-level surface damage can significantly reduce the strength of the strip (die strength). This leads to strip breakage which can affect quality yields. By employing a mechanical edge treatment or secondary laser technique we can control the micro-cracking and stabilize the process to increase ME yield and dramatically reduce consumable costs for the scribing process.))

- Deliverable 3.1: Identify minimum die strength requirements for strips and present to DOE.
- Deliverable 3.2: Identify dicing technology approach and present to DOE
- Deliverable 3.3: Develop machine spec and submit vendor PO
- Deliverable 3.4: Install and qualify tool at Solaria, Fremont facility
- Deliverable 3.5: ((Present results of marathon testing to DOE demonstrating throughput of 125 cells/hour with step yield of 99% and availability of 95% with 1.5 operators.))
- **Milestone 3:** Demonstrate ((laser scribe)) tool compatible with next gen singulator and stringer developed under Task 1 with reduction in total cost of ownership relative to mechanical scribing of \$0.01/Wp.

Go/No-Go Review of Budget Period 1

- Deliverable: Present to DOE a validated cost model demonstrating total savings meet targets proposed for Milestones 1, 2, and 3.

BUDGET PERIOD 2 (30 months)

Task 4: PowerXT Stringer
The POWERXT Module leverages the induction soldering hardware and process developed in BP1 but requires wider PV strips relative to the LCPV stringer. It has a much higher cell throughput requirement but also less precision in placement due to the larger cell size. Thus, the POWERXT product requires a unique tool. Solaria will develop a new tool that uses the induction process developed in BP1 but with upgraded cell handling to accommodate the wider strips. ((Currently, the strings for POWERXT modules are made 100% manually. The POWERXT stringer will eliminate the manual process and create a stringing process with capex of $0.005/Wp)) thus dramatically reducing headcount while increasing throughput relative to capital expenditure. The final buyoff of this machine is contingent on developing the machine to meet throughput targets and reduce manual labor.

- Deliverable 1.1: Develop specification and issue PO with approved supplier
- Deliverable 1.2: Vendor site acceptance of equipment and approval to ship
- Deliverable 1.3: ((Install at US-based manufacturing site))
- Deliverable 1.4: ((Demonstrate throughput of 600 cells per hour with step yield of >95%, and availability of 95% with 2 operators.))
- **Milestone 4:** Demonstrate stringer & associated manufacturing process that support production targets outlined in Deliverable 1.4 to support 25MW capacity.

Task 5: PowerXT Laser Scribe and Singulator Upgrades
The POWERXT Module requires a much higher cell throughput at the Laser Scribe and Singulation process steps due to the larger size of the cells. The primary upgrades relative to the existing machines and processes are associated with automating the cell loading, unloading and fixturing to accommodate this throughput. The goal is to develop integration automation between the POWERXT Laser Scribe and POWERXT Singulator machines and associated processes ((to reduce the manual labor associated with loading and unloading cells with a total capex for these steps at $0.005/Wp or less)). This will increase the throughput of the complete singulation process to meet the demands of high volume POWERXT Module manufacturing.

- Deliverable 5.1: Define specs, select vendor, and initiate PO
- Deliverable 5.2: Vendor site acceptance of equipment and approval to ship
- Deliverable 5.3: ((Install at US-based manufacturing site))
- Deliverable 5.4: ((Demonstrate throughput of 600 cells per hour with step yield of >95%, and availability of 95% with 1 operators.))

- **Milestone 5:** Demonstrate integrated scribe and singulation process that support production targets outlined in Deliverable 5.4 to support 25MW capacity.

Task 6: PowerXT Layup
The strings produced by the upstream tools in Tasks 4-6 require some unique handling requirements at layup that are currently done manually. The layup is in a different orientation than the LCPV module and the strings have different handling requirements. The goal is to develop an POWERXT Layup tool and associated process ((to reduce manual labor and increase the accuracy and repeatability of the process associated with string layup with a capex of $0.002 or less)). This will increase the throughput of the layup process and make the labor more efficient.

- Deliverable 6.1: Define specs, select vendor, and initiate PO
- Deliverable 6.2: Vendor site acceptance of equipment and approval to ship
- Deliverable 6.3: ((Install at US-based manufacturing site))
- Deliverable 6.4: ((Demonstrate throughput of 575 cells per hour with step yield of >95%, and availability of 95% with 2 operators.))
- **Milestone 6:** Demonstrate Layup Tool(s) that support production targets outlined in Deliverable 6.4 to support 25MW capacity.

Task 7: 25 MW Line Demonstration
The result of the cumulative work done on Tasks 4 through 6 will be the installation of 25 MW line in North America demonstrating the scalable manufacturing technology for the POWERXT Module. The target location for this line is the Solaria HQ facility. The final deliverable for this task will be a 24 hour marathon run demonstrating the cost effective throughput and quality metrics to demonstrate scalable POWERXT module production in North America.

- Deliverable 5.1: ((Demonstrate throughput equivalent of 25 MW annual with step yield of >95%, and availability of 95%))
- **Milestone 5:** Presentation of marathon results and detailed cost model demonstrating the total actual cost advantage of POWERXT Module production in North America at a system level of >$0.05/Wp relative to standard c-Si module technology.

Project Results and Discussion:

Budget Period 1: Summary of Results

The cumulative cost reduction goal of the three tasks that comprise Budget period 1 is $0.08/Wp. We have fully developed and demonstrated a $0.10/Wp reduction relative to the baseline costs established at the start of the contract. Most of this was accomplished with Task 1 improvements to the stringer and singulator. The net result was a successful accomplishment of not only the goals of budget period 1, on-time and under budget but also the total cost reduction goals of the full contract proposal. A summary of the validated cost model based on production data is presented in Table 1 and a brief summary of the cost reduction goals and results by task is as follows:

Task 1: Stringer

The goal of this task was to reduce the manufacturing cost of the Solaria module by $0.06/Wp by focusing on advanced automation and soldering technology of the stringing and singulation processes. The actual savings are $0.06/Wp and was met on time and on budget.

Task 2: Layup

The goal of this task was to reduce the manufacturing cost of the Solaria module by $0.01/Wp by reducing headcount, increasing throughput and increasing the quality of the lay-up process. This was met on time and ahead of budget. Switching from full automation to semi-automation resulted in a significant decrease in capex while still maintaining the direct labor headcount reduction and throughput targets. The result was total cost savings of $0.01/Wp on time and under budget.

Task 3: Laser

The goal of this task was to reduce the manufacturing cost of the Solaria module by $0.01/Wp. The goal was to explore alternate methods of laser dicing to solve issues around die strength of the strips. The stringer and singulation steps were so successful that the downstream process was a lot more tolerant of the upstream laser scribe process. Additionally process work on the existing equipment set resulted in higher through put with no compromise on die strength requirements. The result was total cost savings of $0.02/Wp on time and under budget.

Task #	Description	Metric	Baseline Pre-BP1	Results Post-BP1	Savings ($/Wp)
1	Stringer				
		UPH	4	6.75	
		Yield	98.0%	99.0%	
		Capacity (W)	9,443,280	16,098,143	
		Headcount	6	2	
		Capex	$ 400,000	$ 650,000	
		Capex Depreciation	$ 0.0061	$ 0.0058	
		DL	$ 0.0818	$ 0.0162	
		$/Wp (Mfg)	$ 0.0879	$ 0.0219	$ 0.066
2	Layup				
		UPH	5	10	
		Yield	99.0%	99.0%	
		Capacity (MW)	11,924,550	23,849,100	
		Headcount	2	2	
		Capex	$ 2,000	$ 30,000	
		Capex	$ 0.0000	$ 0.0002	
		DL	$ 0.0218	$ 0.0109	
		$/Wp (Mfg)	$ 0.0218	$ 0.0111	$ 0.011
3	Laser Scribe				
		UPH	3.6	3.8	
		Yield	99.0%	99.0%	
		Capacity (MW)	8,585,676	9,062,658	
		Headcount	2	0.5	
		Capex	$ 450,000	$ 420,000	
		Capex	$ 0.0075	$ 0.0066	
		DL	$ 0.0303	$ 0.0072	
		$/Wp (Mfg)	$ 0.0378	$ 0.0138	$ 0.024
	TOTAL				**$ 0.101**

Table 1: Detailed cost model showing net savings as a result of Budget Period 1 progress

Budget Period 2: Summary of Results

For the PowerXT Module the goal was to develop a 25MW US-based pilot line with capex and throughput targets that demonstrate a total module cost advantage at the system level of >$0.05/Wp compared with conventional c-Si modules. Solaria has successfully developed, installed and demonstrated the unique front-end tooling to support 25MW of production at our HQ facility in Fremont, CA. Given the inherent efficiency advantages of the PowerXT technology over conventional solar modules we can also show a $0.05/Wp advantage of this technology. Solaria was not successful in completing the final task (Task 7) of running a 24-hour marathon of the entire line. This is mostly due to schedule relative to the contract term and we fully expect to complete this within the next quarter.

Task 4: PowerXT Stringer

The goal of this task was to develop a unique manufacturing tool to create high-density (PowerXT) strings by means of shingling. At the time of this award no such tooling existed and this piece is crucial to the cost-effective deployment of this product technology. Solaria successfully designed, installed and qualified a 25MW stringer at our HQ facility in Fremont, CA.

Task 5: PowerXT Scriber/Singulator

The goal of this task was to leverage the scribing and singulating technology developed in BP1 and apply it to PowerXT strings rather than LCPV strings. The primary difference is the strip size of these two products. The PowerXT has much larger strips relative to the LCPV product so the automation has to be updated accordingly.

Task 6: PowerXT Layup

We unfortunately did not complete this task although work was completed on design concepts and some preliminary costing for our Fremont facility. We did deploy semi-automatic layup automation in our overseas PowerXT manufacturing facility where the value of this work was more immediately recognizable for Solaria.

Task 7: 25MW Line Demonstration

Solaria successfully started up and are running a 50MW nameplate PowerXT manufacturing line in S Korea. However, we were not able to run the entire 24-hour marathon on the US-based version of the equipment at our Fremont facility. We fully intend to do this within the next quarter but the schedule did not end up within the contract period as originally planned. It should be noted that 100% of the product manufactured in S Korea goes to the US market. In that sense, the work done there is contributing to SunShot goals of low-cost, solar ubiquity in the US.

Task 1: Stringer

The primary achievement and a bulk of the cost savings under budget period 1 was the successful implementation of the new stringer and the associated production qualification. Project time and resource in Q413 through Q114 was primarily focused on this task. The new stringing tool was successfully bought off in early September and delivered to Solaria HQ. The buy-off was based on demonstrated sprint UPH (Units Per Hour) of 80 strings per hour. The base line for this project with the old stringing technology was 43 strings per hour and with 4x the HC to run the process. Much of the work in Q4 2013 was focused on stabilizing the process, integrating it with the upstream singulation process and adding the in-line metrology tools.

The new stringer integrates multiple process steps that were previously done manually or semi-manually. In doing so it significantly reduced HC and lower overall Capex. These process steps are busbar cutting, PV assembly and stringing. Additionally, the stringer utilizes a touchless, induction solder methodology that improved the mechanical yield of the process.

Figure 1.1: Photo of new stringer as installed at Solaria, Fremont HQ (Deliverable 1.1)

Additionally, the upstream Singulation process and machine was modified to improve integration with the next generation stringer. The new stringer utilizes a unique cell material handling methodology, “strip stacking”, which helps enable higher throughput. The Singulator was successfully modified to utilize the same strip stacking on its output so it can directly feed the stringer without adding labor. The completed Singulator tool is shown in Figure 2.

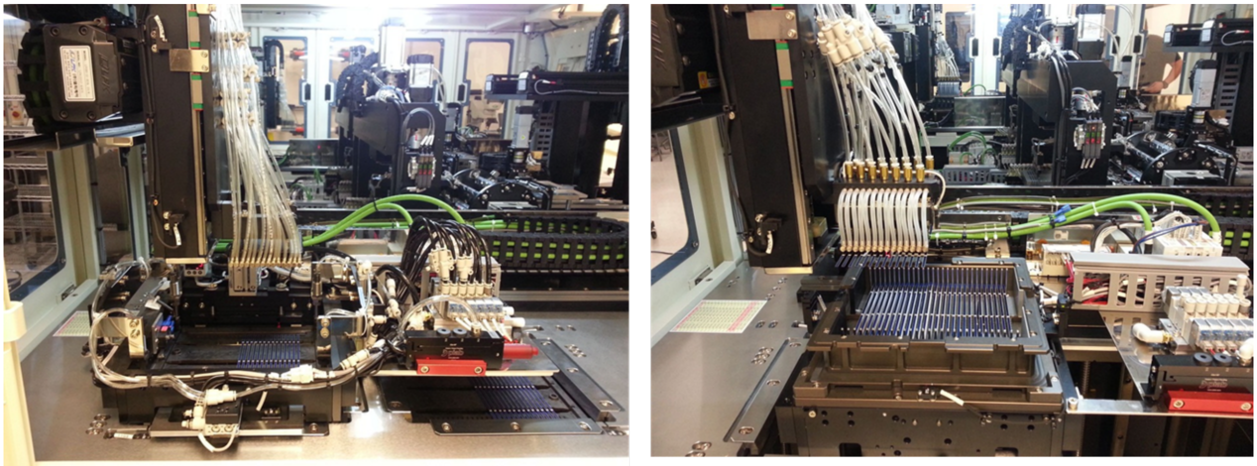
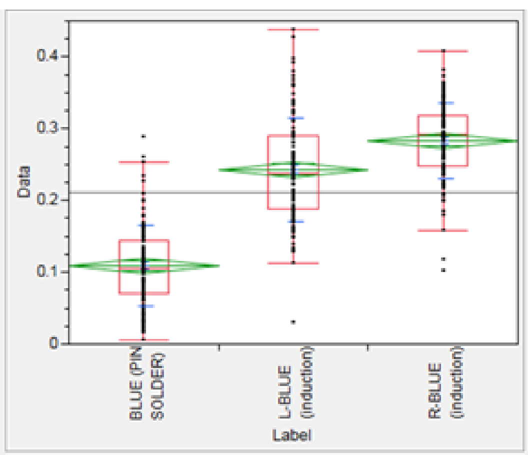


Figure 1.2: Singulator upgrade with new strip stacker (Deliverable 1.3)

The primary risk around this new machine is the induction soldering methodology which has not been utilized in the Solaria manufacturing process previously. To validate this solder technology pull tests were used to validate the effectiveness of the bond. Figure 1.3 shows the results which showed a marked improvement over the previous hot bar method with over double the pull strength value on average. This is an important milestone and gives us confidence in the reliability of this process.



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
BLUE (PIN SOLDER)	0.006	0.0334	0.071	0.106	0.145	0.1786	0.288
L-BLUE (induction)	0.03	0.1554	0.1875	0.238	0.29	0.3424	0.438
R-BLUE (induction)	0.102	0.22	0.2475	0.291	0.318	0.3446	0.408

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
BLUE (PIN SOLDER)	126	0.109000	0.055417	0.00494	0.09923	0.11877
L-BLUE (induction)	126	0.243000	0.071931	0.00641	0.23032	0.25568
R-BLUE (induction)	126	0.283016	0.052417	0.00467	0.27377	0.29226

Figure 1.3: Statistical results of pull tests comparing new induction solder to previous method

One minor challenge encountered in this task was the in-line Dark IV metrology tool. For Dark IV we needed to establish a repeatability of the measurement and threshold value from which it could reject strings. The threshold value needed to be outside the repeatability and natural variance of the test value while still ensuring that there will be no false positives. We successfully established this capability. The challenge encountered was the fact that this tool is central to the machine and services the two “lanes” of the stringer. There was initially a hardware interlock problem that prevented the tool from being able to switch between lanes without manual intervention. The issue was a result of interference from the induction soldering coils creating too much noise in the solid state relays. The solid state relays were removed and the problem was addressed with a software based interlock.

Another issue encountered on this task was that the total throughput of the machine was lower than expected. After running trials, the expected the machine max speed is about 84 strings per hour rather than the target value of 90 strings per hour. However, this still proved to be a significant increase over the baseline value of 48 strings per hour of the previous tool. Additionally, lower than expected number of operators and higher quality of the process provided cost advantages. Thus, the total $/Wp savings remained on target at $0.06/Wp relative to the baseline process.

Singulator modification was also verified after strip stacker installation. There were no changes in machine throughput but shows better material handling with the new stringer. A single strip stacker replaces 230 individual PV assembly trays and associated carts for transportation.

Task 2: Layup

The baseline process for placing cell strings and lamination materials was entirely manual. Manual methodologies are typically less repeatable and have higher labor content than more automated processes. Solaria sought to improve alignment repeatability, increase throughput and reduce associated labor by developing automation around pre-lamination string and material layup.

An auto Layup machine specification was created, provided to vendor, machine was manufactured and vendor site acceptance was performed. This auto layup machine was installed in Solaria HQ and a capability of 16 modules per hour was achieved (Figure 2.1).

Figure 2.1: Automated Layup tool installed in Solaria Fremont

Software and hardware performance for the auto layup machine continued to create major issues in terms of string handling and placement. Multiple modules produced showed variations in string placement and inaccuracies. It was collectively decided to develop a simpler tool for string handling and placement as long as the program objectives were met.

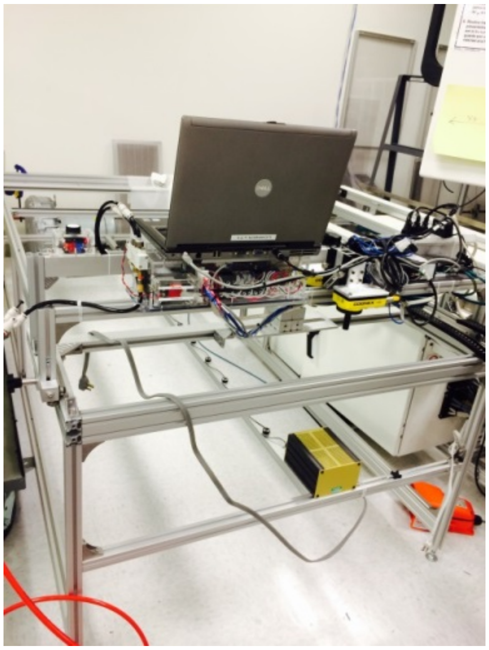


Figure 2.2: Semi Auto Layup tool designed, tested and qualified for production

The new semi-auto layup tool was designed and tested at a fractional cost of the original fully automated layup tool (Figure 2.2). The 2nd Generation stringer performance is key to this success. The new stringer allows for accurate string builds based on glass data and hence alignment of strings to glass lens becomes simple and repeatable.

For initial study of the viability of the tool, 3 full size modules were built. The strings were produced using our laser scribe, auto singulator and 2nd generation stringer. Local alignment of strings to the glass was achieved using the camera installed on the layup tool. Figure 2.3 describes the alignment process using the shadow of the strips and the concentrated light coming through individual lenses. The strings are aligned using one of the strips in the center. The accuracy of the pitch and accuracy of the length of the string allows automatic alignment of the rest of the strips on the string as long as the center is aligned.

After lamination process the following were observed:

1. The power of the modules were high and as expected based on the cells used. In addition the power of the modules were repeatable (283 to 284 W at STP.
2. The AOI was repeatable : +/- 4 degrees
3. Very few broken tips after lamination (well within allowable limits of < 40 per module, set by our quality and production process). Laser scribed cells were used for these builds. Induction soldering in Gen 2 stringer allows for much smaller stresses applied to the strips during string assembly and hence less damage to the strips after lamination. EL results confirm very few strip damage in the module.

Figure 2.3: PV Strip Edge alignment to light distribution from glass lenses

Alignment was adjusted by less than 200 microns at both ends of the strip using light distribution image at the glass lens as shown in Figure 6 above. A one hour continuous production simulation to measure throughput was accomplished using 10 production modules and with production engineers. Actual man hour used per module is 1.5.

Production run results are shown on Table 1. Average time for layup was measured to be 8 minutes with 1.5 operator hours. With 4 operators working on multiple tables this equates to 20 modules/hour throughput.

Module ID	Isc (A)	Voc(V)	FF%	Pmax (W)	Cell Eff	AOI
FR00000034085	8.615	44.771	75.591	291.542	18%	+/- 5
FR00000034087	8.658	44.528	73.878	284.802	18%	+/- 5
FR00000034089	8.648	44.833	76.130	295.160	18%	+/- 5
FR00000034090	8.658	44.961	74.755	291.017	18%	+/- 5
FR00000034092	8.667	44.909	76.005	295.834	18%	+/- 4
FR00000034093	8.691	45.028	74.784	292.677	18%	+/- 5
FR00000034094	8.656	45.061	75.457	294.306	18%	+/- 5
FR00000034096	8.627	44.779	75.560	291.893	18%	+/- 5
FR00000034098	8.661	44.033	73.715	281.115	18%	+/- 5
FR00000034097	8.498	44.253	72.079	271.061	17%	+/- 5

Figure 2.4: Production Run demonstrating a minimum of 4 degrees AOI after lamination

The representative El images show good alignment. PV cells used for these modules had some inherent defect and that can be seen as darker shades on the strips. However, the purpose of this production run was to measure alignment of the PV strips with respect to the glass lenses and the measured data clearly shows +/- 4 degrees AOI on all modules.

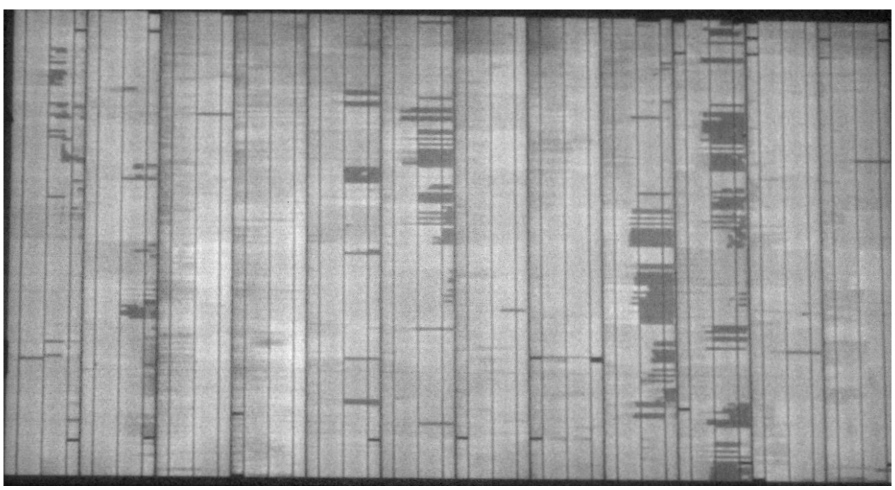


Figure 2.5: Representative EL image shows good alignment of PV to the lenses. The PV cell strips had some inherent defects which are evident from the darker regions in the picture. The number of broken tips have reduced significantly.

Yield was 100% with all 10 modules and the simplicity of the machine makes it available for 100% of the production time, excluding downtime for maintenance. This meets all requirements for our layup goal.

Task 3: Laser Scribe

The primary advantage of the laser scribe technology is a significant reduction in utility costs of blades and water usage associated with the more common mechanical scribing processes used to date. Prior to the start of Task 3, Solaria had developed a basic laser methodology for scribing PV wafers with matching or better throughput than the mechanical saw and with dramatically lower utility costs. However, the laser process can introduce defects at the scribe level that may result in broken edge strips after lamination which led quality and yield issues.

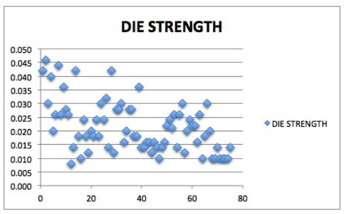
Figure 3.1: Laser scribing machine installed and under testing for compatibility with new singulator and stringer process

The primary focus of this task was to improve the die strength of PV at the singulated strip level. Additionally, the laser scribe process adoption for module manufacturing would have to be treated as comprehensive development that included stringing and layup improvements to determine the optimal die strength requirements.

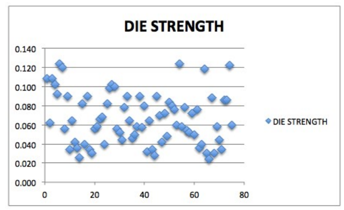
The process improvements of Tasks 1 and 2 led a reduced dependency on die strength requirements which shifted the focus of this task to process development rather than the more significant equipment upgrades that were originally predicted. Specifically, production EL images showed acceptable tip breakage requirements after lamination.

The work in Q214 was primarily focused on process optimization of the existing tool. DOE's were conducted to determine the effect of feed rate, pulse rate and uncut portion on the die strength of singulated strips and compare to control samples using saw scribing. Sample runs for the DOE are illustrated in the following measurements in 3 point die bend tests from the blue and the gray side of the strips. Every run was based on specific feed rate and pulse rate for the laser.

- RUN 1 (140 mm/s / 110 Khz)

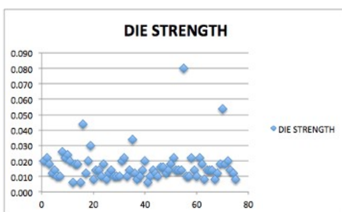


BLUE SIDE (Kg)	
AVE	0.021
MIN	0.008
MAX	0.046
STDEV	0.009

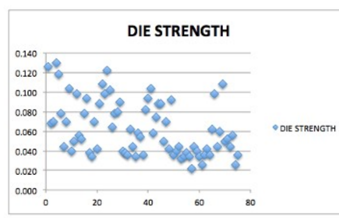


GRAY SIDE (Kg)	
AVE	0.066
MIN	0.024
MAX	0.124
STDEV	0.027

- RUN 2 (140 mm/s / 120 Khz)

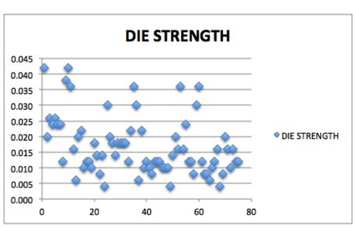


BLUE SIDE (Kg)	
AVE	0.016
MIN	0.006
MAX	0.080
STDEV	0.013

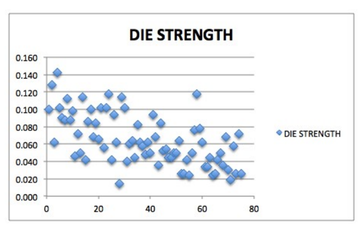


GRAY SIDE (Kg)	
AVE	0.063
MIN	0.022
MAX	0.130
STDEV	0.028

- RUN 3 (140 mm/s / 130 Khz)



BLUE SIDE (Kg)	
AVE	0.017
MIN	0.004
MAX	0.042
STDEV	0.009



GRAY SIDE (Kg)	
AVE	0.065
MIN	0.014
MAX	0.142
STDEV	0.030

RESULTS						
RUN	FEED RATE	PULSE RATE	RESPONSE			
			POWER	AVE.UNCUT PORTION	AVE. DIE STRENGTH(kg)	
	(mm/s)	(khz)	(watts)	(mm)	BLUE SIDE	GRAY SIDE
1	140	110	5.43	0.091	0.021	0.066
2	140	120	5.46	0.092	0.016	0.063
3	140	130	5.32	0.103	0.017	0.065
4	160	110	5.39	0.108	0.012	0.050
5	160	120	5.61	0.106	0.012	0.053
6	160	130	5.44	0.093	0.012	0.066
7	180	110	5.80	0.110	0.017	0.080
8	180	120	5.69	0.107	0.022	0.093
9	180	130	5.49	0.109	0.028	0.099
10 (Saw Scribe)	N/A	N/A	N/A	0.100	0.063	0.071

Table 3.1: 9 runs of laser scribe were compared with base line saw scribe process. Feed rate and pulse rate of the laser were the key variables. The maximum load in kg was recorded during 3 point bend test of the strips tested from blue side as well as the gray side.

SAW VS LASER COMPARISON				
	AVE DIE STRENGTH (kg)		PERCENTAGE	
RUN	Blue Side	Gray Side	BLUE	GRAY
1	0.021	0.066	33.8%	93.9%
2	0.016	0.063	26.0%	88.9%
3	0.017	0.065	26.6%	91.5%
4	0.012	0.050	19.4%	71.0%
5	0.012	0.053	19.0%	75.6%
6	0.012	0.066	19.1%	92.9%
7	0.017	0.080	34.6%	113.4%
8	0.022	0.093	34.6%	131.5%
9	0.028	0.099	44.7%	140.5%
10	0.063	0.071	100.0%	100.0%

Table 3.2: Maximum load until breakage was recorded in 3 point bend test was from blue side and gray side of the strips. Each data point represents an average of 10 tests. The right side of the table shows comparison in percent of max load with respect to the saw scribed samples (Run 10). Run 9 was the best scribe parameter obtained within the limits of the laser process and the machine capability.

Optimization was based on 9 runs of laser scribe. The primary variables were feed rate in (mm/s) and the laser pulse rate varying from 110 khz to 130 khz. The loading capability of the strips were measured using a 3 point bend test. 10 data points were collected for each run from the blue side and gray side bending test.

Impact of Die Strength was evident after lamination process. Reduced die strength and strip edge defects result in broken edge strips in laminated modules. Laser Optimization is targeted for reduction in the number of broken strips. Laser process also significantly reduces the cost of utility by eliminating water usage and water treatment.

Based on the comparative results of the 9 different runs within the range of feed rate and pulse rate of the laser, we have clearly seen that run 9 resulted in the best results for laser scribed strips. Saw base scribing was used as base line for comparison. Although the blue side loading capability of the strips are lower compared to saw process, the subsequent module assembly has already shown minimal tip breakage after lamination. The improved handling process for the strips and the touch-less induction soldering process for making strings in new stringer allows better quality modules with minimum strip breaks after lamination.

Based on the above results we found optimum parameters for laser scribe. The laser scribe process for module manufacturing is now treated as comprehensive development that includes new generation stringer, modified singulator and the semi-auto layup tool.

Based on the actual production run we have evaluated savings from the laser scribe process.

Laser Scribe		
	Proposed	Actual
UPH	3.6	3.8
Capacity (W)	8672400	9154200
Headcount	2	0.5
Capex (total)	$ 450,000.00	$ 420,000.00
Capex ($/Wp)	$ 0.0074	$ 0.0066
DL	$ 0.0303	$ 0.0076
$/Wp (Mfg)	$ 0.0377	$ 0.0141
Savings ($/Wp)		**$ 0.024**

Table X: Cost savings associated with optimized laser scribe process.

1 hr production run was performed to measure UPH of laser scribe from loading to unloading operation. UPH was 125 wafers/h (~3.8 modules/h) with optimized scribing parameters. Capex reduction will not be significant in the future however, the reliability of the tool allows only 0.5 headcount to run the machine including loading unloading process. Headcount savings result in ~$0.024 of additional savings on a $/Wp basis.

Task 4: PowerXT Stringer

The first task of BP2 was the PowerXT stringer. This stringer is the key to enabling the shingled cell module construction. No off-the-shelf tooling currently exists for this process and prototyping was done completely manually up until this time. The goal was to develop a 25MW tool that could make reliable shingled strings utilizing electrically conductive adhesive (ECA). This task was successful and resulted in the installation and qualification of the tool at our Fremont HQ facility.

Figure 4.1: Installation of 25MW PowerXT stringer at Solaria HQ

The results of the final qualification of this tool are presented in the following figures.

Quality Criteria Requirement						
Process	Quality Parameter	Acceptance Criteria for each Measured Strip	String Quantity	Measurement location	Total Sample Size	Measurement Tool
Stringing	Strip pitch	29.85 ± .125mm	10	17 pitches per string	170	200x Microscope
	String length	509 ± .50 mm		Each string	10	
	String camber	± .50 mm		Each string	10	

Figure 4.2: Quality criteria and monitoring for stringer qualification

The summary of results from the 8-hour qualification marathon are presented in Figure 4.3.

STRINGER 8 HOUR RUN		
YIELD	IN (String)	606
	REJECT	26
	OUT TOTAL	580
	YIELD	95.7%
UP TIME	TOTAL TIME (mins)	480.0
	UP TIME (mins)	304.0
	DOWN TIME(mins)	176.0
	UPTIME %	63.3%
ASSIST	TOTAL ASSIST	30
	ECA ASSIST	12
	OTHER ASSIST	18
UPH	UPH	184

Figure 4.3: Results of 8-hour marathon for POWERXT Stringer

We were able to achieve passing metrics for UPH and Yield but encountered issues with machine uptime. However, these uptime issues have been isolated and determined not to be directly tied to the functionality of the machine itself.

STRINGER		
ASSIST	**COUNT**	**Time (min)**
OFF-LOADER SENSOR ERROR	1	1.5
PLC SOFTWARE BUG	1	2.0
OFF-LOADER CYLINDER POSITION	2	2.0
CYLINDER COLLAPSOR STUCK	4	3.9
STRIP LOADER VACUME ERROR	5	1.1
BELT CALIBRATION	5	9.8
DISPENSE NOOZLE CLOGING	12	156.2
TOTAL	30	176.4

Figure 4.4: Results of 8-hour marathon for POWERXT Stringer

As shown in Figure 4.7, the primary contributor to uptime loss was clogging of the ECA. This was determined to be a specific batch issue from the ECA supplier. A more minor issue was realted to the conveyer belt and easily remedied with a replacement part. The belt was made with multiple joints, in this case welds. Each joint contributed to a small indexing error that caused the need to recalbrate it a few times during the run. Root cause has positively been verified by the belt manufacturer and a new belt is beign fabricated. With these two corrective actions Solaria expects the stringer to operate as expected.

In conclusion, the Stringer shows that it is capable of producing Solaria strings at the required UPH, Yield, and Uptime based on following metrics:

- 2 Operators
- UPH demonstrated at 184 strings/hour which is above target of 176 strings/hour
- Yield at 95.7%, above target of 95%
- Uptime: 96.75% when ECA and Belt issues are removed - above target

Task 5: PowerXT Scriber/Singulator

The scriber/singulator is the tool that creates the strips used for the PowerXT product. It is based on the laser technology developed for LCPV in BP1 but reconfigured to handed the higher throughput and larger strip sizes needed for the PowerXT strings. No off-the-shelf tooling currently exists for this process and prototyping for PowerXT was done by reprogramming the LCPV laser scriber developed in BP1. The LCPV tool was not configured to do this cost-effectively for PowerXT production. The goal was to develop a 25MW tool that could make high quality strips. This task was successful and resulted in the installation and qualification of the tool at our Fremont HQ facility.

Figure 5.1: Installation of 25MW PowerXT stringer at Solaria HQ

The results of the final qualification of this tool are presented in the following figures.

Quality Criteria Requirement						
Process	Quality Parameter	Acceptance Criteria for each Measured Strip	Cell Quantity	Measurement location	Total Sample Size	Measurement Tool
Scribe/Singulate	Kerf Width	<25um	16	1 cell/4 scribe/3 point	192	200x Microscope
	First Cut Position*	0.25 ± .050 mm		1 cell/3 points (1st cut position)	48	
	Scribe Depth	40%-60% of cell thickness		1 cell/4 scribe/3 points	192	
	PV Strip Width (Rec)	31.35 ± .025 mm		1 cell/3 strips/2 points	96	
	PV Strip Width (Chamf)	31.35 ± .125 mm		1 cell/2 strips/2 points	64	
	Yield	No chip, no protrusion		all strips	all	Visual

Figure 5.2: Installation of 25MW POWERXT stringer at Solaria HQ

The summary of results from the 8-hour qualification marathon are presented in Figure 4.3. The corresponding data on strip quality metrics is shown in Figure 5.4.

SCRIBER/SINGULATOR 8 HOUR RUN		
MATERIAL	CELL	Shinshung
QTY	IN (Cell)	4593
	IN (Strip)	22965
	REJECT FROM MAG	131
	REJECT FROM TRAY	49
	OUT TOTAL	22785
	YIELD	99.2%
UP TIME	TOTAL TIME (mins)	480.0
	UP TIME (mins)	459.0
	DOWN TIME(mins)	21.0
	UPTIME %	95.6%
MTBA	ASSIST COUNT	35
	MTBA (min)	14
UPH	UPH	631
LASER PARAMETERS		
MODE		SCAN
DIRECTION		BI
# OF PASSES		20, 22
Power Watt		24.1
Line Speed (mm/sec)		4,216
PRT (Khz)		365

Figure 5.3: Installation of 25MW POWERXT stringer at Solaria HQ

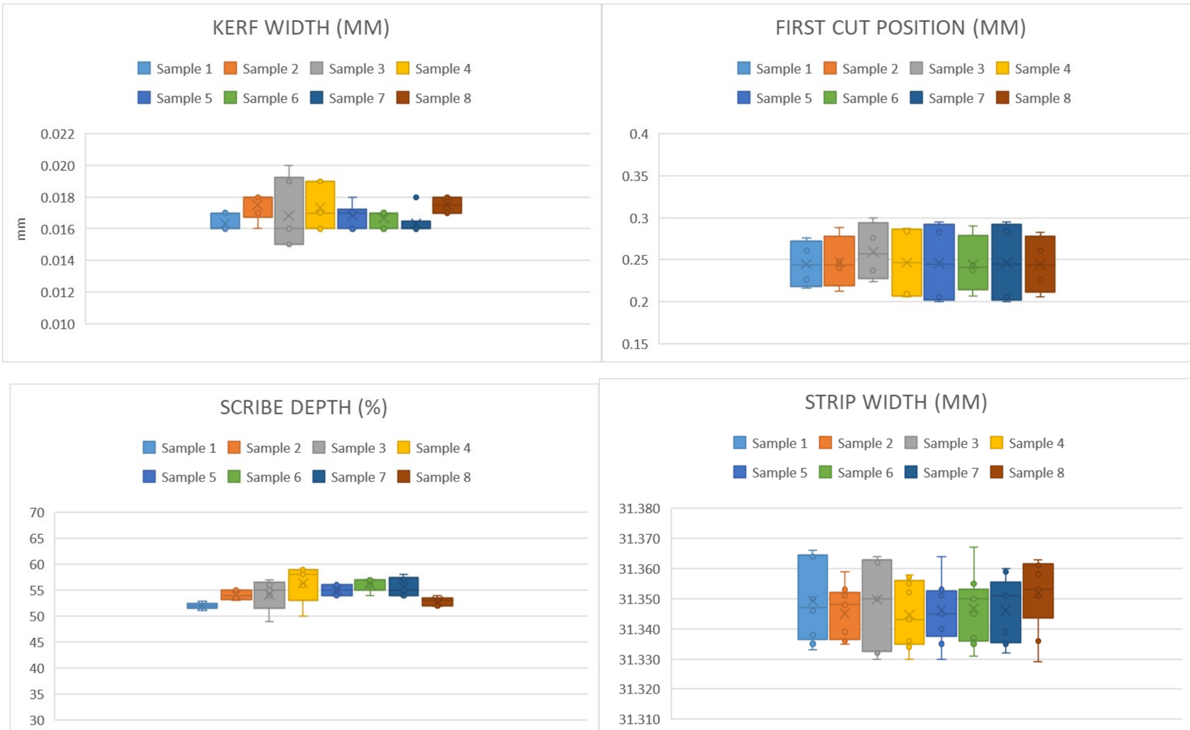


Figure 5.4: Strip quality metrics gathered from 8-hour marathon run

In conclusion, the Scriber/Singulator shows that it is capable of producing Solaria strips at the required UPH, Yield, and Uptime based on following metrics:

- 1 Operator which above target of 2 operators
- UPH demonstrated at 631 cells/hour which is above target of 600 strings/hour
- Yield at 99.2%, above target of 95%
- Uptime: 95.6% , above target of 95%

<u>Significant Accomplishments and Conclusions</u>:

Solaria considers this project and associated funding from DOE as very successful based on the following key accomplishments:

1. Sucessful launch of BIPV "PowerVision" product which leverages US-based manufacturing technology developed for LCPV in BP1
2. Successful installation of US-based 25MW manufacturing equipment for "PowerXT" product line based on successful BP2 project metrics
3. Distribution partnerships for "PowerXT" product with capacity sold out for 2017
4. Licensing partners established for the BIPV "PowerVision product" with 100% US-made strings

1. BIPV Manufacturing Capability and Product Development

At the end of Budget Period 1 LCPV remained a viable technology in many markets and the prospects for it to advance solar ubiquity globally were strong. However, from a manufacturing cost reduction perspective there are only small, incremental gains to be made. The scalability of LCPV is largely focused on utility BOS product development (i.e. Trackers) and market development.

It should also be mentioned that Solaria also has strong market signals that support BIPV opportunities. The equipment developed in budget period supports this technology very well. We see a strong BIPV presence in the coming years and to that end consider the technology developed in budget period 1 to be very successful and in line with SunShot goals. However, the POWERXT technology represents a lower risk, and more leveraging technology that will get us to SunShot goals faster than any other core technology offering. Solaria may consider other funding opportunities to support BIPV which grows the US solar market, job creation and the ubiquity of solar technology to aggressively meet SunShot goals. However, it is expected that BIPV needs more funding in the areas of product and technology development other than strictly manufacturing which is the focus of this particular funding round.

In the current PV module market module efficiency has proven to be a highly leveraging force to deploying more PV while reducing associated BOS and soft costs. To address this market demand Solaria shifted the Budget Period 2 focus another form of module technology that also leverages its proprietary knowledge of dicing, singulation and stringing. Solaria has prototyped and tested modules using a novel, high-density stringing process that dramatically lowers series resistance and increases absolute module efficiency by up to 2%. By shifting focus of the DOE EERE funding to this technology Solaria is now well positioned to diversify its technology offering to meet the market demands for both high-efficiency and BIPV modules.

2. High-density (PowerXT) Module Manufacturing Capability and Product Development

Solaria was very successful at meeting the specific technical targets and the associated cost reductions goals of Budget Period 1 (BP1). In fact, the total cost reduction goals for the whole contract were met from just the work in BP1 (See Table 1) which was done significantly under budget. Given this success and the current market conditions described above it is proposed that remaining BP2 work focus on the PowerXT technology which will further diversify Solaria's ability to scale solar technology. The PowerXT technology proposition is highly dependent on specialized dicing and stringing technologies which are a core-competency Solaria' and the LCPV focused work done in BP1 can be applied to the advancement of PowerXT. The Budget period 2 tasks and milestones need to be adjusted to align with this accordingly. Solaria's goal is to build and demonstrate 25MW of unique module manufacturing technology in the US that demonstrates the cost advantage and scalability of the PowerXT approach relative to conventional c-Si PV module construction and manufacturing. Capex and throughput targets will be set to ensure total module cost at system level will be at least $0.05/Wp lower than convention c-Si PV modules. Although Solaria plans to procure new tools to optimize around the PowerXT module the equipment portion of the budget will be only be on the unique automation aspects rather than the total tool cost as many of the core processes have already been successfully developed in BP1 and will remain the same for BP2 (i.e. dicing, singulation, and induction soldering). Solaria is opting to procure new tools rather than modify existing ones so it can continue to support both product lines and retain maximum product flexibility moving forward. However, we will not apply the total 25 MW equipment cost to the budget.

Inventions, Patents, Publications, and Other Results:

No patents or inventions were submitted under this award. Solaria maintains its manufacturing process and technology as proprietary and confidential information. Product-based utility and design patents were applied for and in some cases granted but these were not under the purview of the award contract as they are associated with the product design and not the specific manufacturing technology required to make those products.

Solaria had press coverage regarding the US manufacturing expansion of its PowerXT and PowerVision products which utilize manufacturing technology developed under this award. Other press coverage shows the success of the products which utilize this same manufacturing technology. The most significant of which are as follows:

- https://www.solarpowerworldonline.com/2017/07/u-s-solar-panel-manufacturing-not-dead/
- https://www.greentechmedia.com/industry/read/soligent-solaria-partner-to-deliver-quality-efficiency-modules-to-5000-sola
- https://pv-magazine-usa.com/2017/06/27/solaria-ramps-power-xt-production-line-to-more-than-40-mw-per-year/
- Solaria Opens Expanded Silicon Valley Manufacturing Line to Ramp Up Production of its High Efficiency, Sleek PowerXT Solar Modules
- http://solarindustrymag.com/solaria-expands-manufacturing-line-powerxt-solar-modules
- https://www.greentechmedia.com/industry/read/solaria-provides-customized-architectural-solar-solution-for-new-cornell-te

Path Forward/Commercialization Plan:

Solaria's has successfully deployed two products and the associated US-based manufacturing capability to support these products. In this sense, the products have already been successfully commercialized. Over the next two years Solaria intends to grow and develop these products with their associated manufacturing technology to lead in two distinct sectors of the US PV market:

1. BIPV

Solaria's innovative BIPV module design leverages the cell dicing and stringing technology developed and commercialized for their LCPV module. Advantages of this technology are that it utilizes a Bill of Materials (BOM) that is virtually identical to standard double-layer building glass but with the addition of C-Si PV cells. The design enables a BIPV laminate to be easily integrated into standard Insulated Glass Units (IGU's) typical in new building construction (**Figure 1** and **Figure 2** above). This allows Solaria to leverage the current industry supply chain of low-cost, high-volume materials while retaining best in class reliability and construction methodology. However, the current equipment set at Solaria was optimized for the LCPV product which inherently use a single strip width and spacing. The Solaria BIPV solution is specifically valuable to architects and builders due to its accommodation of a wide variety of strip size, strip spacing, string length and string layout. These adjustable parameters allow architects and builder the ability to optimize for building glass features such as: light transmission, heat gain, power density all of which can vary greatly not only throughout the market but even on specific buildings (**Figure 6**). This will be the focus of further BIPV product and manufacturing technology development over the course of the next 24 months.

The Solaria BIPV solution is based on the same dicing and stringing methodology developed for the first successful LCPV concentration technology that has better reliability than standard c-Si modules. This further differentiates Solaria and has much lower market risk than other more disruptive BIPV technologies such as organics. The unique, redundant interconnection technique of the cell strips results in much lower dependence on solder joint reliability than standard c-Si modules (**Figure 3** above**).** The parallel connections allow for lower stress on each joint and make the cells less susceptible to performance degradation due to cracks which cannot propagate beyond a single strip.

Additionally, curtain walls and IGUs typically employ a much thicker glass-glass structure which is much more impact resistant the standard c-Si modules (**Figure 2** above). This results in a more robust design that is less susceptible to hail impact, wind loading or other extreme weather conditions. These design features improve the long term reliability of the product and further improve on crystalline module bankability relative to standard c-Si module and other concentration technologies. Thus, Solaria offers an innovative approach with low-risk technology that is uniquely positioned to address the rapidly expanding c-Si BIPV market opportunity. Addressing market needs for a complete low-cost and reliable BIPV solution will help achieve SunShot goals of attaining commercially viable solar ubiquity in the US by 2020.

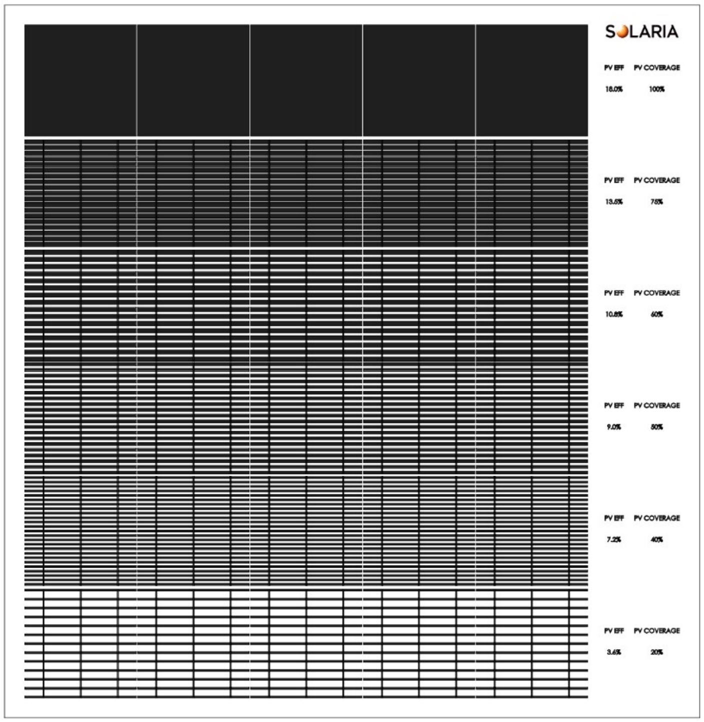


Figure 6: Examples of Solaria PV coverage options compared to standard multi c-Si cells (at top)

2. High-efficiency, premium aesthetic PV Modules

Solaria's PowerXT product offering the "PowerXT", has already gained significant market traction. It is a premium, high-efficiency product with US-based production capability backed by larger scale off-shore manufacturing. Our target in the next 24 months is to grow our global capacity to at least 500MW. Our target market and product focus will continue to be the US residential market where high-efficiency and superior aesthetics command a price premium. Solaria will endeavor to keep operating costs low by leveraging manufacturing partners in both the US and overseas. Even at the current scale we have a profitable cost model where market pricing can support positive and stable margins.

Additional R&D will focus on how to expand manufacturing as fast as possible while remaining economically viable. Solaria will continue to innovate on product design and manufacturing techniques such that our solution will remain the gold standard for shingle module technology.

Figure 2: Photo of US-made Solaria PowerXT high-efficiency (PowerXT) module

To diversify risk Solaria will keep manufacturing footprints in both US and Asia. Even with successful US-based manufacturing technology and innovations Solaria continues to achieve the lowest product manufacturing costs by using overseas contract manufacturing. However, we have identified key market segments in the premium roofing industry where US-made products are strongly favored or required by leading companies. These markets will be served with our smaller US-based capacity while large scale distribution of lower-cost product will be supported by overseas manufacturing, currently in S. Korea.