Final Grant Report

Solaria CSI RD&D Project

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2 Acknowledgments

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Numerous hard working individuals and organizations contributed to the success of the Solaria and the CSI RD&D project including the development of Solaria's high performance technology. Through their contributions, the project was a true success.

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NOTE:
Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the CPUC, Itron, Inc., or the CSI RD&D Program.

3 Abstract

The California Public Utilities Commission (CPUC) created the California Solar Initiative (CSI) Research, Development, Demonstration, and Deployment (RD&D) Program, a grant program that aims to help achieve the goal of a vibrant and sustainable solar industry for California. Solaria, a California corporation, were awarded funding in September 2010 through the CSI RDD&D grant program [1]. The program focus is:

- Reducing technology costs and increasing system performance.
- Focusing on issues that directly benefit California.
- Filling knowledge gaps to enable wide-scale deployment of distributed solar.
- Supporting the integration of distributed power into the grid.

The following report covers in detail the Solaria CSI RD&D project characteristics for which two separate installations are operating and producing performance and reliability data in California. The systems consist of 240 kWp installed at the Alameda County, Santa Rita Jail located in Dublin, CA, and 110 kWp installed at the Solaria manufacturing facility located In Fremont, CA. This report describes project objectives, approaches and outcomes including performance and reliability data of Solaria's high performance technology across various tracking technologies.

As part of the agreement between Itron, on behalf of the CPUC and Solaria, ongoing quarterly reporting for system performance and production data can be found online, at the CSI website [1].

4 Executive Summary

This project was supported with assistance from the CSI RD&D Program. The purpose of this program is to help achieve the goal of creating a vibrant and sustainable solar industry. This program makes investments to fund solar research and demonstration projects that will measurably reduce the cost and accelerate the installation of solar and other distributed technologies, which could employ solar for generation, storage, or that could reduce the use of natural gas. This project's primary goal is to drive down the installed cost of solar.

Solaria, a California corporation, developed photovoltaic modules that use 50-67% less silicon than other standard silicon modules without compromises in performance or reliability. The Solaria module, made possible in part with support from NREL, is the first flat plate photovoltaic module to use optical concentration and the first low-concentration module to receive UL and IEC certification. Solaria's module is optimized for large-scale commercial and utility tracking applications and uses only UL-Listed, proven materials standard in the silicon photovoltaic industry, thereby eliminating risk associated with new and uncommon materials.

The goal of this Solaria CSI RD&D project was to perform detailed analysis and reporting on the performance of Solaria's low-concentrating photovoltaic installations that incorporate innovations to reduce costs, increase reliability, and improve system production and efficiency. Solaria used CSI RD&D funds to support the installation and ongoing operation of two separate photovoltaic test systems to demonstrate that the technology is financeable. The project provides performance and reliability data for Solaria's products on various tracking systems totaling 350 kWp DC on two installations of which 240 kWp is installed at Alameda County Santa Rita Jail located in Dublin, CA, and 110 kWp is installed at Solaria manufacturing facility located in Fremont, CA (see Table 1). These installations are long term demonstration systems. The power generated by the RD&D projects noted above will power the end-user at each site. Solaria will collect, analyze, and report on data and detailed system performance factors for these systems.

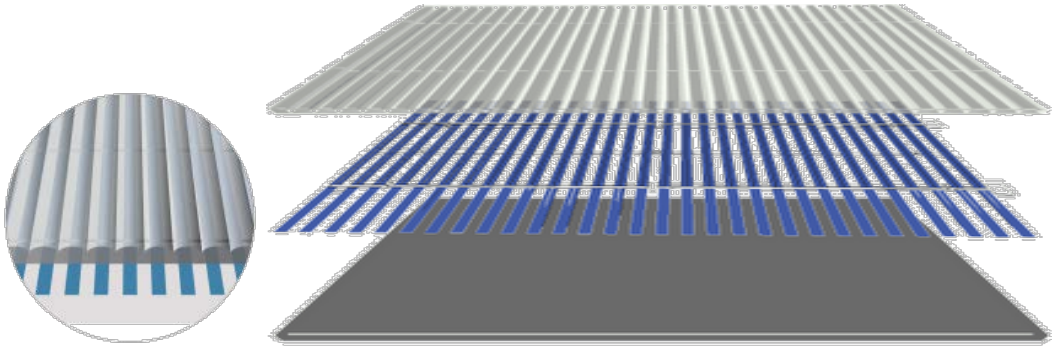
Table 1: System types and capacities

Solaria Demonstration Projects		
Location	**Size**	**Type**
Solaria Manufacturing Facility, Fremont, CA	58 kWp	Single Axis Horizontal Tracker
Solaria Manufacturing Facility, Fremont, CA	52 kWp	Azimuth Tracker
Alameda County Santa Rita Jail, Dublin, CA	220 kWp	Azimuth Tracker
Alameda County Santa Rita Jail, Dublin, CA	20 kWp	2-Axis Tracker

5 Introduction and objectives

The evolution of concentrator photovoltaic (CPV) technologies has a long history, from the first demonstration of CPV modules in the late 1970's to today's dozens of design concepts in various stages of development. However, Solaria has a low concentration design concept that fully leverages the materials, manufacturing processes, form factor, function, and field experience of the well-established crystalline silicon flat-plate PV industry. In particular, it is advantageous to build concentrators that are capable of using tracking systems designed for standard flat-plate modules rather than high accuracy tracker systems designed with the requirements of high concentrating ratio technologies (HCPV). The low concentrating ratio PV (LCPV) module design developed by Solaria has all the physical attributes of a conventional silicon module laminate, coupled with optical concentration by a patterned glass superstrate illustrated on Figure 1.

Figure 1: Illustration of low concentration concept using refraction from a patterned glass superstrate onto crystalline silicon cell strips connected in series and parallel underneath.



Due to the unique design and optical characteristics of these modules, it is necessary to fully understand their performance characteristics in order to accurately calculate expected energy production using currently available system performance models such as the one used by Sandia National Laboratories.

The primary objective of the Solaria CSI RD&D project is to perform detailed analysis and reporting on the performance of Solaria low concentrating photovoltaic systems that incorporate innovations to reduce costs, increase reliability, and improve system production and efficiency. By measuring actual system data across three different tracking system types and two sites, the results have led to a better understanding of the technology and its associated risks.

This report will show how the energy produced across all systems matches long-term forecasts, and expectations are then re-adjusted based on the actual irradiance observed on site during the period.

6 Project Approach

Solaria originally applied to the California Solar Initiative RD&D program to demonstrate and perform detailed analysis on a 350 kWp low concentration solar photovoltaic project using land provided by the California state fairgrounds. Because of the financial turmoil in California state government, that project was no longer feasible, Solaria informed both Itron and the CPUC on this development and received approval to move the project to two different locations.

The two separate systems then became Task 2 and Task 3 in the agreement between the Itron, on behalf of the CPUC and the Solaria Corporation.

6.1 Solaria Manufacturing System: Task 2

The purpose of this task was to install and monitor a 110 kWp photovoltaic tracking system at the Solaria manufacturing facility In Fremont, CA. The installation includes two different tracking technologies which will allow for the comparison of Solaria's high performance technology across a range of industry applications and offers higher granularity of the Solaria module performance characteristics. In addition, the installation of Solaria modules on various tracking system types has allowed for further cost and performance comparisons to validate the optimal tracker technology to use with Solaria modules.

The Solaria manufacturing system was constructed in the winter and spring of 2011 with 56 kWp arranged on a single axis horizontal tracking system and 52 kWp installed on azimuth tracker technology. The Solaria module is optimized for tracking systems, which typically offer the lowest price solar power by generating between 25-35% more energy than fixed tilt systems, while costing approximately 5% more to install. Performance data which validates the optimal tracking technology to use with the Solaria module can be found in section 7 of this report.

The Solaria manufacturing facility was the first ground mounted tracking system approved for construction in the City of Fremont in a residential location. Solaria and the City of Fremont worked together diligently to deliver the necessary permitting and system requirements to construct the system. Solaria partnered with industry leader, Array Con for foundation and welding services and Albion Power Company of San Francisco for tracker, module and electrical installation of the 110 kWp tracking system. Upon completion of the installation, Next Phase Solar and DK Solar works were both selected to perform system and data acquisition system commissioning respectively [2].

Single Axis Horizontal Tracker

- 264 Solaria 220 W modules, for a total of 58 kWp
- Six Single Axis Horizontal Tracker rows
- Four Sunny Boy Inverters (10 kVA)
- Three Sunny Boy Inverters (5 kVA)

Azimuth Tracker

- 240 Solaria 220 W modules, for a total of 52 kWp
- 12 Azimuth Trackers
- 12 Sunny Boy Inverters (5 kVA)

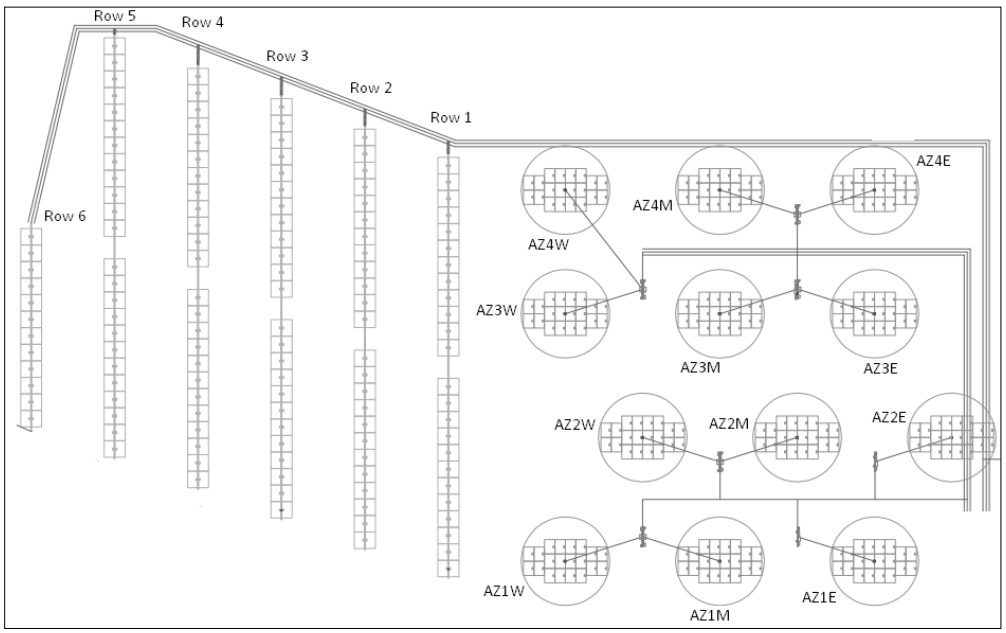
Data Acquisition System (DAS)

- Pyrheliometer
- Pyranometer (horizontal and in-plane)
- Multiple back-of-module temperature sensors
- Meteorological sensors

6.2 Fremont HQ System Layout and Equipment

Shown below is the layout of the Solaria HQ system. The total system size is 110 kWp_{dc} with the Horizontal Axis tracker system being 58.1 kWp_{dc} and the azimuth tracker system being 52.9 kWp_{dc}. As shown, the system comprises 6 rows of horizontal axis trackers and 12 azimuth trackers.

Figure 2: Solaria HQ horizontal and azimuth systems layout



The individual module types and inverter types used for each string are shown in the table below. Different generations of Solaria modules that include Solaria 210W, 220W, 230W, 260W, Framed and Frameless were used. The SMA 10kW and 5kW inverters have been used for small groups of two to four strings. The Solaria module characteristics are shown in Table 2 below.

Table 2: Modules and inverters used for Solaria HQ plant

System	Module	Inverter Brand	Inverter Model
Row 1	Solaria 220/210 Framed	SMA	SB10000TL-US
Row 2	Solaria 230 Frameless	SMA	SB5000US
Row 3	Solaria 230 Framed	SMA	SB10000TL-US
Row 4	Solaria 220/230 Frameless	SMA	SB10000TL-US
Row 5	Solaria 210/220/230 Frameless	SMA	SB10000TL-US
Row 6	Solaria 220/230 Frameless	SMA	SB5000US
AZ1W	Solaria 220 Frameless	SMA	SB5000US
AZ1M	Solaria 210 Frameless	SMA	SB5000US
AZ1E	Solaria 210/220 Frameless	SMA	SB5000US
AZ2W	Solaria 210 Frameless	SMA	SB5000US
AZ2M	Solaria 210 Frameless	SMA	SB5000US
AZ2E	Solaria 260 Frameless	SMA	SB5000US
AZ3W	Solaria 220 Frameless	SMA	SB5000US
AZ3M	Solaria 220 Frameless	SMA	SB5000US
AZ3E	Solaria 220 Frameless	SMA	SB5000US
AZ4W	Solaria 210/220 Frameless	SMA	SB5000US
AZ4M	Solaria 230 Frameless	SMA	SB5000US
AZ4E	Solaria 210 Frameless	SMA	SB5000US

Table 3: Module characteristics

Peak Power, Pmax (Watts)[1]	210	220	230	260
Open Circuit Voltage, Voc (V)	43.53	43.32	43.20	44.308
Short Circuit Current, Isc (A)	7.125	7.59	7.59	8.85
Voltage at Pmax (V)	37.69	35.01	34.13	35.45
Current at Pmax (A)	5.75	6.86	7.10	8.28
Max Series Fuse Rating (A)	15	15	15	15
Max System Voltage (V)	US600/IEC1000	US600/IEC1000	US600/IEC1000	US600/IEC1001

6.3 Alameda County, Santa Rita Jail System: Task 3

Task 3 involved the procurement, installation and interconnection of a 240 kWp tracker installation at the Alameda County Santa Rita Jail in Dublin, CA. The Santa Rita Jail (SRJ) installation demonstrates how Solaria modules perform on a 240 kWp commercial tracker installation. The system uses two different tracker technologies: 220 kWp are installed on azimuth tracking and 20 kWp on a two axis tracking installation.

[1] *The different module ratings are due to cell bins.*

Here again, the use of two tracking technologies allows for a side-by-side evaluation and helps build the case for Solaria modules across a variety of applications.

Solaria partnered with Alameda County to make this project come to life and demonstrate the benefit of renewable energy for local government. The county was a valuable partner based on their excellent track record of procuring, managing, constructing and operating multiple megawatts of solar photovoltaic systems in California. Alameda County has installed over 3 MWp worth of solar photovoltaic panels across multiple sites. A majority of the energy generated by the Solaria demonstration photovoltaic systems will support operations at Santa Rita Jail. Upon completion of the installation, Next Phase Solar and Groundwork Renewables were selected to perform system and data acquisition system commissioning respectively [3].

Azimuth Tracker

- 1,000 Solaria 220 W modules, for a total of 220 kWp
- 50 azimuth trackers
- Two Satcon 100 kVA Inverters

2-Axis Tracker

- 96 Solaria 220 W modules, for a total of 20 kWp
- Two dual axis tracker
- Two Fronius 10 kVA Inverters

Data Acquisition System (DAS)

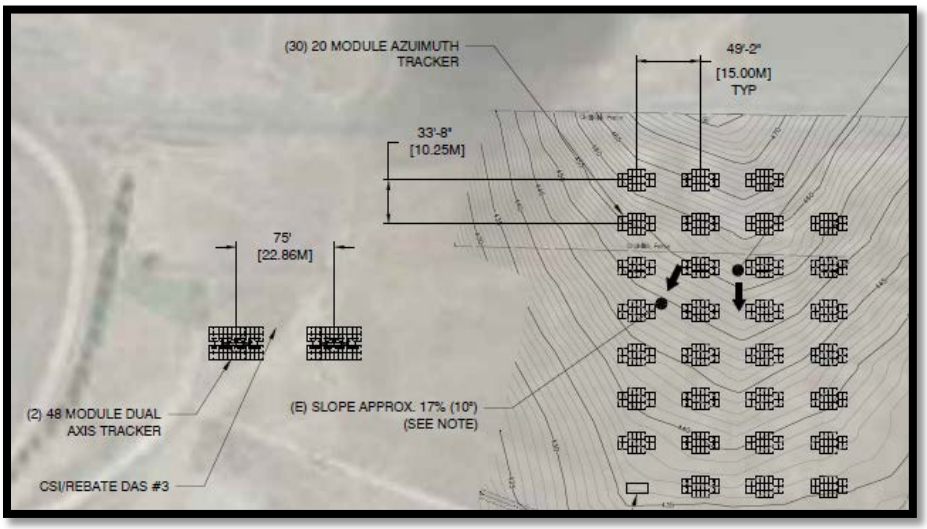
- Pyrheliometer
- Pyranometer (horizontal and in-plane)
- Multiple back-of-module temperature sensors
- Meteorological sensors

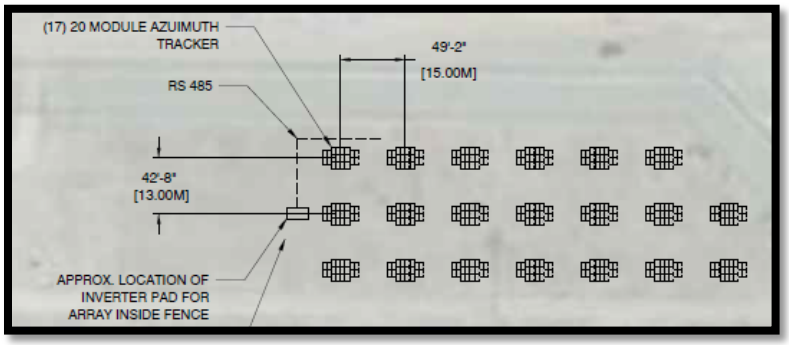
6.4 Santa Rita Jail System Layout and Equipment

Shown below is the layout of the Santa Rita Jail system. The total system size is 235.4 kWp_{dc} split into three distinct systems:

- the “hillside” system comprises 30 Azimuth trackers and has a capacity of 126.4 kWp_{dc}
- the “fenced” system comprises 20 Azimuth trackers and has a capacity of 87.9 kWp_{dc}
- the “dual axis” system comprises 20 Azimuth trackers and has a capacity of 21.1 kWp_{dc}

Figure 3: Santa Rita Jail systems layouts (top: dual axis, left, and hillside array, right; bottom: fenced array)





The individual module types and inverter types used for each string are shown in the table below. Different generations of Solaria modules that include Solaria 210W, 220W, 270W, Framed and Frameless have been used. The inverters used are two Satcon 100 kW for both azimuth systems and Fronius inverters for the dual axis system. Shown in the Table 5 are the Solaria module characteristics.

Table 4: Modules and inverters used for Santa Rita Jail plant

System	Module	Inverter Manufacturer	Inverter Model
Hillside	Solaria 210	Satcon	Powergate Plus 100 kW
Fenced	Solaria 220 and 270 W	Satcon	Powergate Plus 100 kW
Dual Axis	Solaria 220	Fronius	IG+ 10 kW

Table 5: Module characteristics

Peak Power, Pmax (Watts)	210	220	260
Open Circuit Voltage, Voc (V)	43.53	43.32	44.18
Short Circuit Current, Isc (A)	7.125	7.59	8.04
Voltage at Pmax (V)	37.69	35.01	35.14
Current at Pmax (A)	5.75	6.86	7.69
Max Series Fuse Rating (A)	15	15	15
Max System Voltage (V)	US600/IEC1000	US600/IEC1000	US600/IEC1001

7 Project Outcomes

7.1 Performance

Both sites have a full set of weather and irradiance instruments installed as part of Task 4. In addition, each system has inverter independent data acquisition equipment for measuring for both DC and AC power and energy production. All instruments were calibrated prior to use and periodically re-calibrated throughout the project duration. The data is downloaded automatically to Solaria servers on a daily basis.

When the data was missing or when maintenance tasks were performed, the data for these days was discarded and the monthly values rescaled to show what the output would have been otherwise. This adjustment was only performed for months containing a representative number of days without errors or maintenance.

For example, in June 2012, for the horizontal system at Solaria headquarters, the tracker was stopped for two days to perform work on some of the modules. As a result, only the remaining 28 days are deemed representative and the measured irradiance and energy output during these days was considered and scaled:

Month	Days	Valid Days	Reference Yield	Final Yield	Adjusted Reference Yield	Adjusted Final Yield
June	30	28	300	226	321	242

Throughout this section, we will categorize different data as:

- Forecasted: based on models and assumptions known at the time of project planning, and uses a typical meteorological year from the TMY3 database [4] as model input
- Actual: based on measured observations
- Expected: based on measured observations, applied model inputs instead of the typical meteorological year

The particular quantities of interest are also defines as follows:

- Specific Yield: the amount of energy produced by unit of solar capacity installed. Typically in units of kWh/kW or kilowatt-hour of AC energy delivered per kilowatt of DC capacity installed. This is the most important metric for investors because it represents the return on investment or "bang" for the "buck" spent on a solar array.
- Performance Index: the ratio of the energy produced vs. what is expected according to models. This metric is particularly important for owners/operators because deviations from the 100% value indicate that the solar array is experiencing something that was not predicted by the model, such as a fault or degradation due to an unknown process.

7.1.1 Fremont HQ

7.1.1.1 Horizontal System

The following table summarizes the findings for this system:

Table 6: Summary data for the Fremont horizontal system

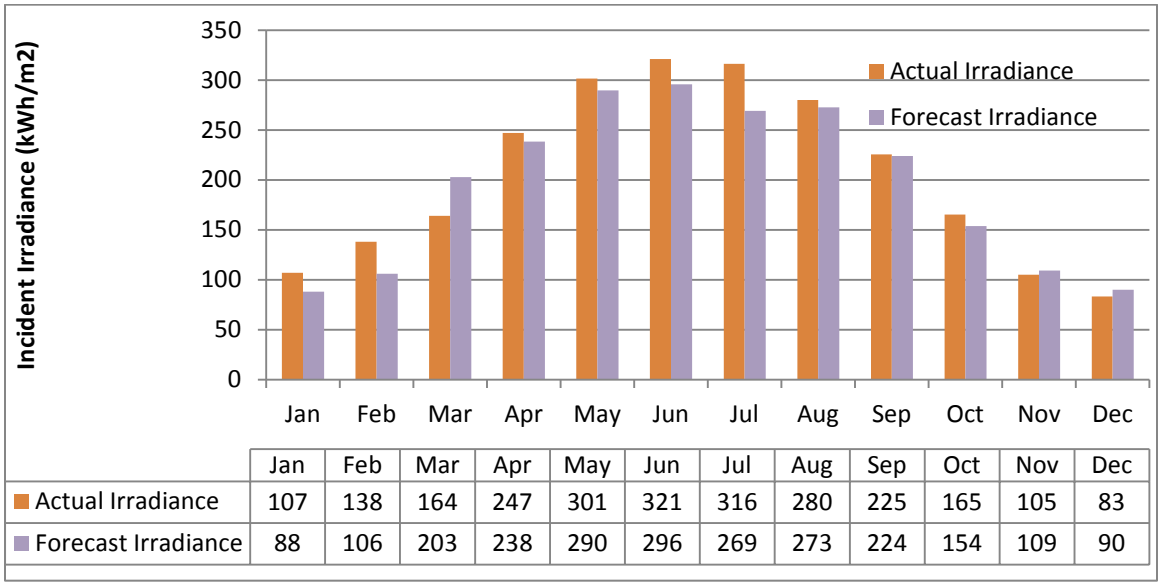
Data Point	Value
Annual Yield Forecast (kWh/kW)	**1851**
Annual Yield Observed (kWh/kW)	**1873**
Annual Yield Expected (kWh/kW)	**1944**

Performance Index	**96%**

The series of figures below illustrate details of the data in Table 6 above on a month by month basis. Figure 4 shows the forecasted, actual and expected specific yield,

Figure 5 shows how the irradiance compared vs. the typical year used for the forecast, and finally,

Figure 4: Typical vs. observed irradiance for the horizontal system in Fremont

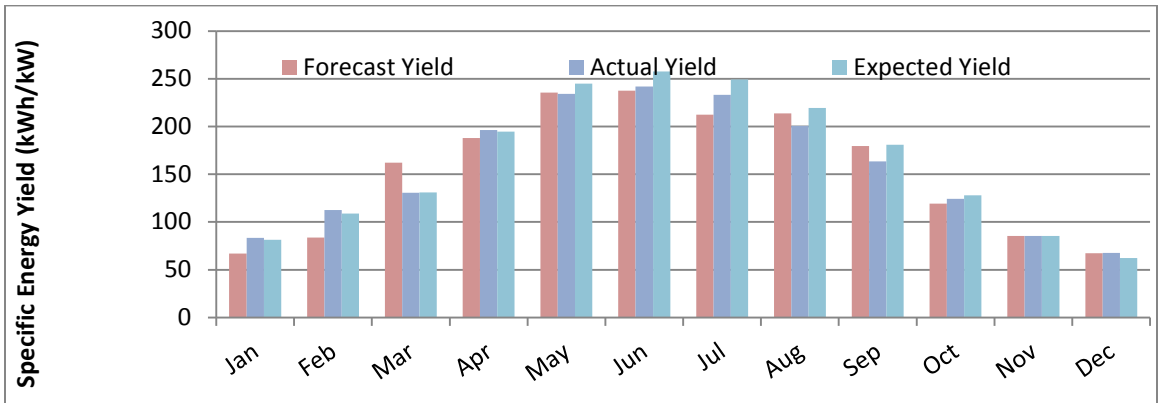


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual Irradiance	107	138	164	247	301	321	316	280	225	165	105	83
Forecast Irradiance	88	106	203	238	290	296	269	273	224	154	109	90

Figure 5 shows the performance index values.

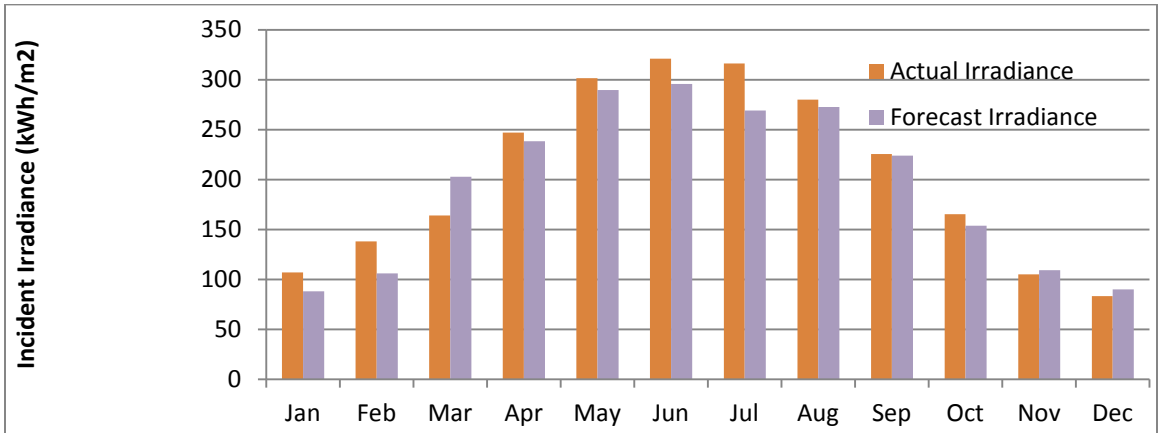
Note that the data from November was actually filled-in from forecasted values due to an outage of several weeks that rendered the very few operational days in November ill-suited to extrapolate a monthly performance number. The outage was due to a ground fault in a conduit that created system wide perturbations of the data acquisition system.

Figure 5: Forecast, actual, and expected specific energy yield for the horizontal system in Fremont



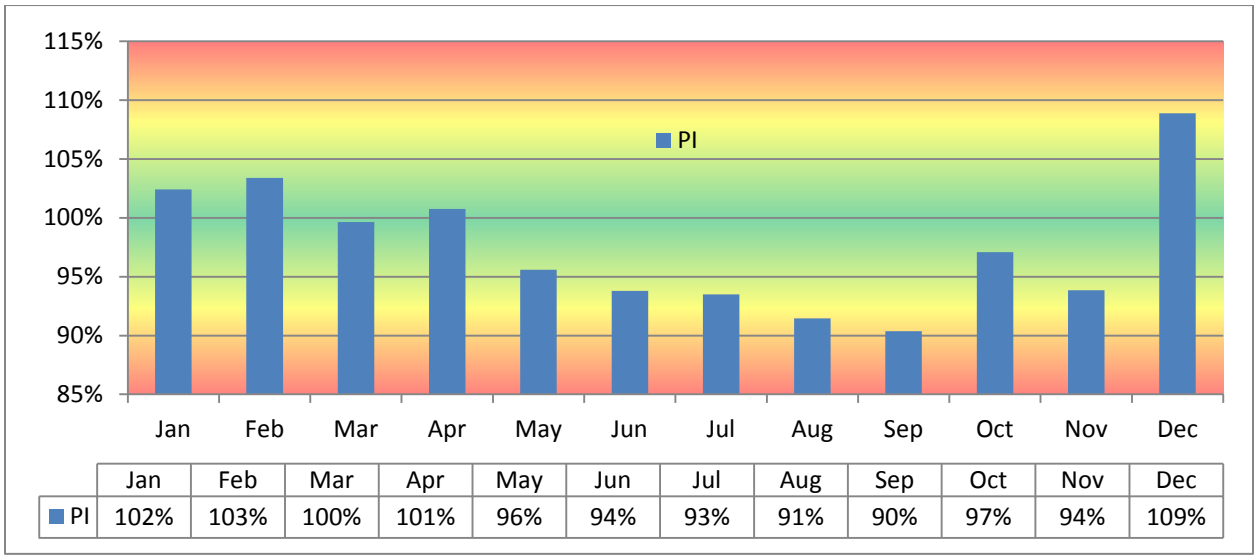
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Forecast Yield	67	84	162	188	236	238	212	214	180	119	85	67
Actual Yield	83	113	131	196	234	242	233	201	163	124	85	68
Expected Yield	81	109	131	195	245	258	249	220	181	128	85	62

Figure 6: Typical vs. observed irradiance for the horizontal system in Fremont



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual Irradiance	107	138	164	247	301	321	316	280	225	165	105	83
Forecast Irradiance	88	106	203	238	290	296	269	273	224	154	109	90

Figure 7: Performance index for the horizontal system in Fremont



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PI	102%	103%	100%	101%	96%	94%	93%	91%	90%	97%	94%	109%

It is worth noting for this system that while the performance seems to be predicted on an annual basis, there is a seasonal aspect to the Performance Index that is clearly visible. It is likely to be caused by soiling, which is assumed to be constant in the model when in reality, it increases over the summer and diminishes during the fall and winter rains, which wash the panels naturally.

7.1.1.2 Azimuth System

The following table summarizes the findings for this system:

Table 7: Summary data for the Fremont azimuth system

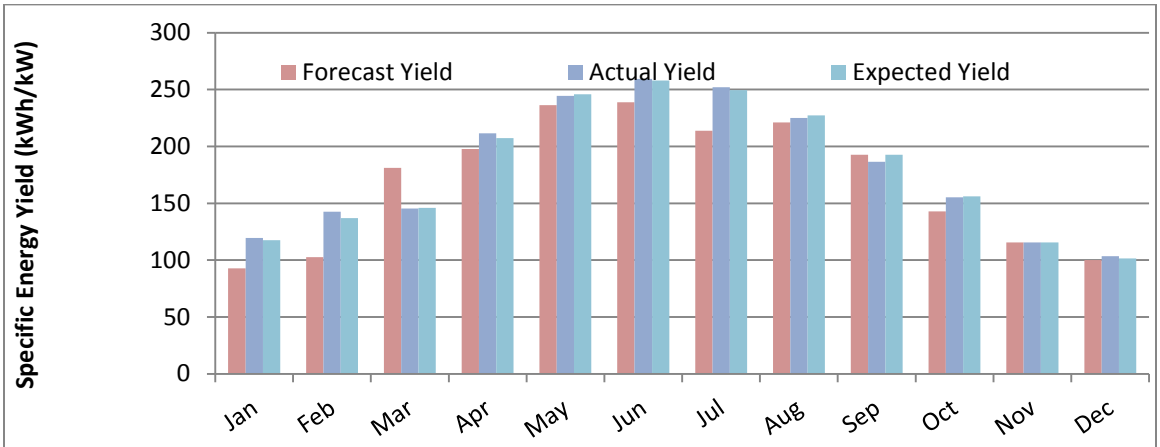
Data Point	Value
Annual Yield Forecast (kWh/kW)	**2035**
Annual Yield Observed (kWh/kW)	**2160**
Annual Yield Expected (kWh/kW)	**2154**

Performance Index	**100%**

The series of figures below show the data backing up the summary table above on a month by month basis. Figure 7 shows the forecasted, actual and expected specific yield, Figure 8 shows how the irradiance compared vs. the typical year used for the forecast, and finally, Figure 9 shows the performance index values.

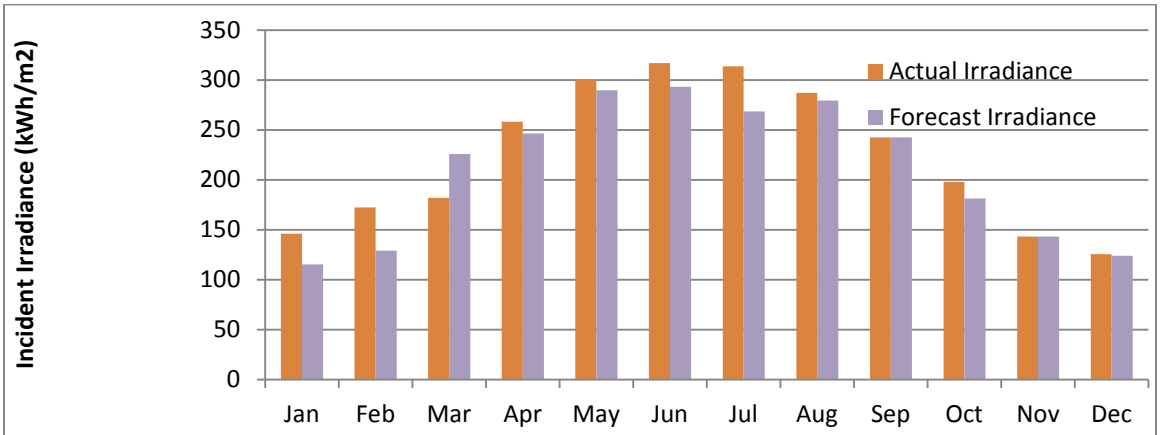
Here again, the values for November were filled in from the forecast due to the previously mentioned abnormally long outage.

Figure 8: Forecast, actual, and expected specific energy yield for the azimuth system in Fremont



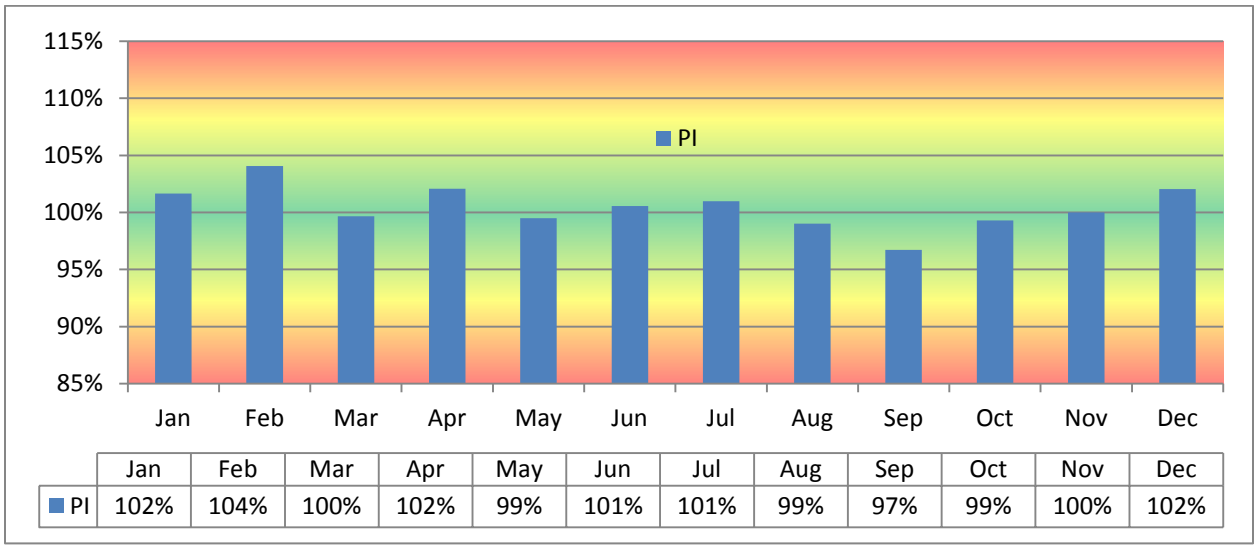
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Forecast Yield	93	103	181	198	236	239	214	221	193	143	115	100
Actual Yield	120	142	145	212	244	259	252	225	186	155	115	103
Expected Yield	118	137	146	207	246	258	250	227	193	156	115	101

Figure 9: Typical vs. observed irradiance for the azimuth system in Fremont



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual Irradiance	146	172	182	258	301	317	314	287	243	198	143	126
Forecast Irradiance	115	129	226	246	290	293	269	279	243	181	143	124

Figure 10: Performance Index for the azimuth system in Fremont



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PI	102%	104%	100%	102%	99%	101%	101%	99%	97%	99%	100%	102%

7.1.2 Santa Rita Jail

7.1.2.1 Azimuth System

The following table summarizes the findings for this system:

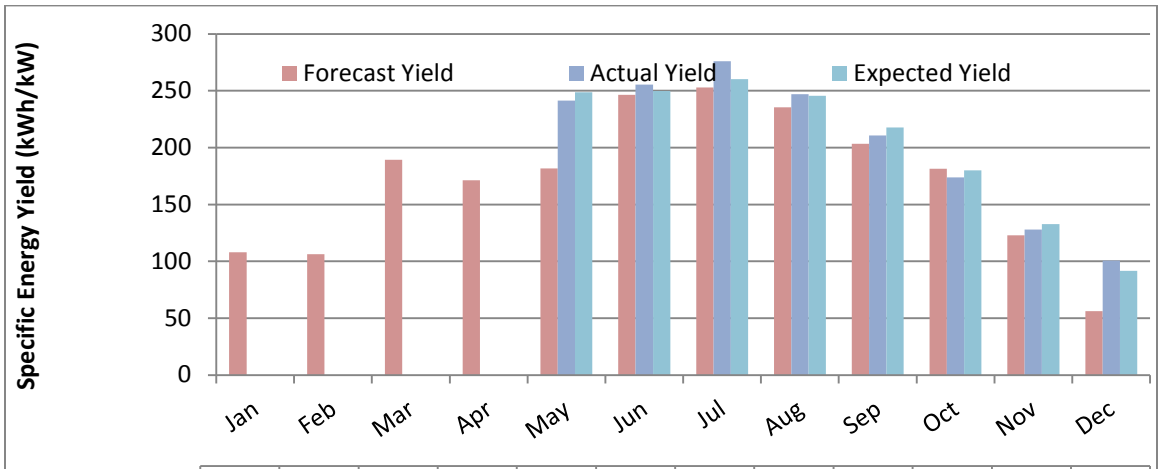
Table 8: Summary data for the Santa Rita Jail azimuth system

Data Point	Value
Annual Yield Forecast (kWh/kW)	**2055**
Annual Yield Observed (kWh/kW)	**1633**
Annual Yield Expected (kWh/kW)	**1626**

Performance Index	**100%**

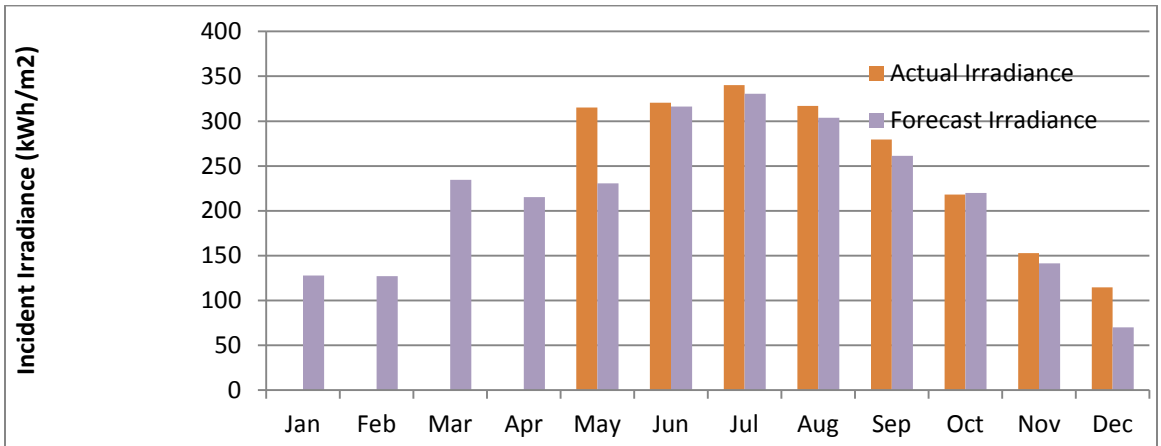
The series of figures below show the data backing up the summary table above on a month by month basis. Figure 10 shows the forecasted, actual, and expected specific yield, Figure 11 shows how the irradiance compared vs. the typical year used for the forecast, and finally, Figure 12 shows the performance index values. The system was not online until May so no actual or expected performance is available for January through April.

Figure 11: Forecast, actual, and expected specific energy yield for the azimuth system at the Santa Rita Jail



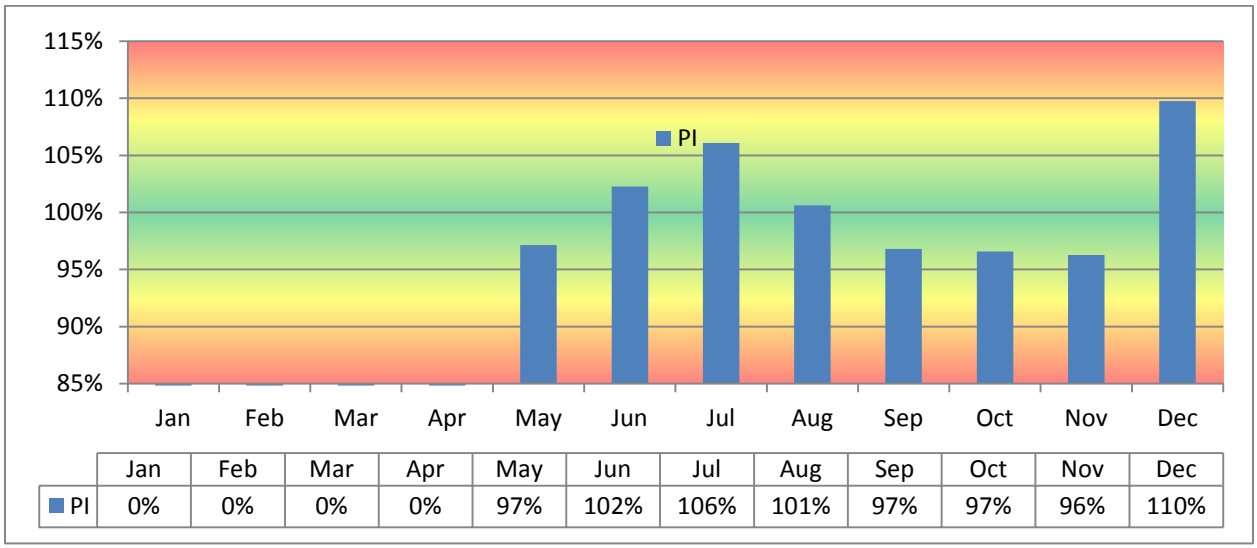
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Forecast Yield	108	106	189	171	182	246	253	235	203	182	123	56
Actual Yield	0	0	0	0	241	255	276	247	211	174	128	101
Expected Yield	0	0	0	0	249	250	260	246	218	180	133	92

Figure 12: Typical vs. observed irradiance for the azimuth system at the Santa Rita Jail



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual Irradiance	0	0	0	0	315	321	340	317	280	218	153	115
Forecast Irradiance	128	127	235	215	231	316	331	304	261	220	141	70

Figure 13: Performance Index for the azimuth system at the Santa Rita Jail



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PI	0%	0%	0%	0%	97%	102%	106%	101%	97%	97%	96%	110%

7.1.2.2 Dual Axis System

The following table summarizes the findings for this system:

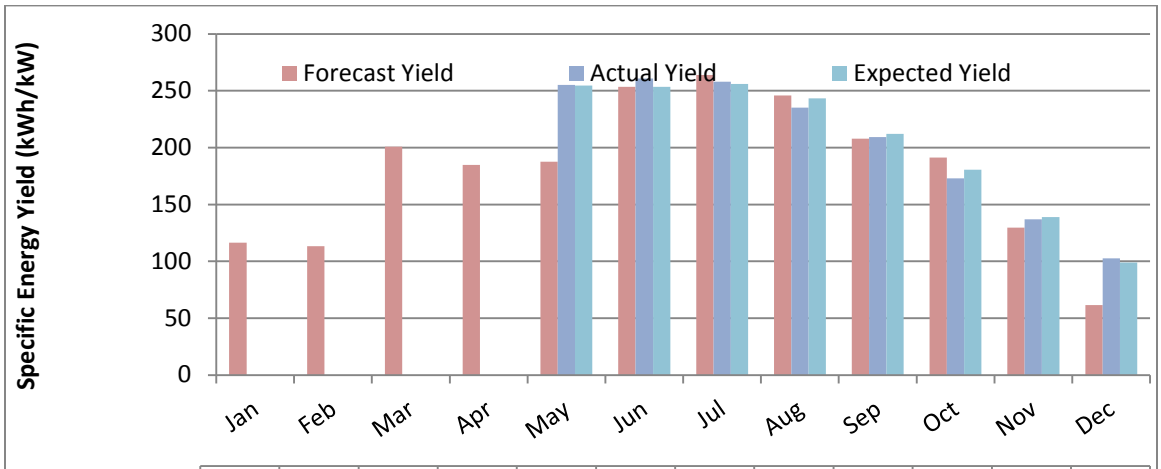
Table 9: Summary data for the Santa Rita Jail dual axis system

Data Point	Value
Annual Yield Forecast (kWh/kW)	**2157**
Annual Yield Observed (kWh/kW)	**1631**
Annual Yield Expected (kWh/kW)	**1637**

Performance Index	**100%**

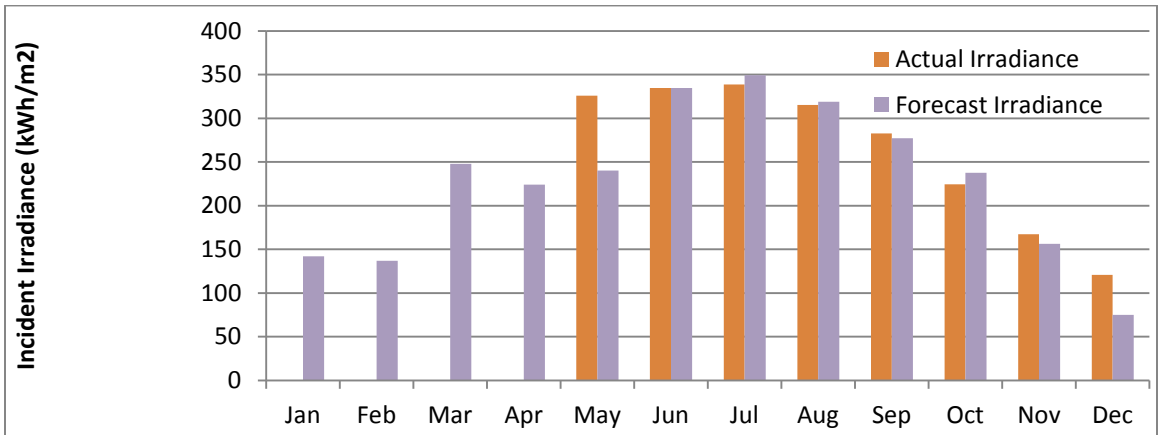
The series of figures below show the data backing up the summary table above on a month by month basis. Figure 13 shows the forecasted, actual, and expected specific yield, Figure 14 shows how the irradiance compared vs. the typical year used for the forecast, and finally, Figure 15 shows the performance index values.

Figure 14: Forecast, actual, and expected specific energy yield for the dual axis system at the Santa Rita Jail



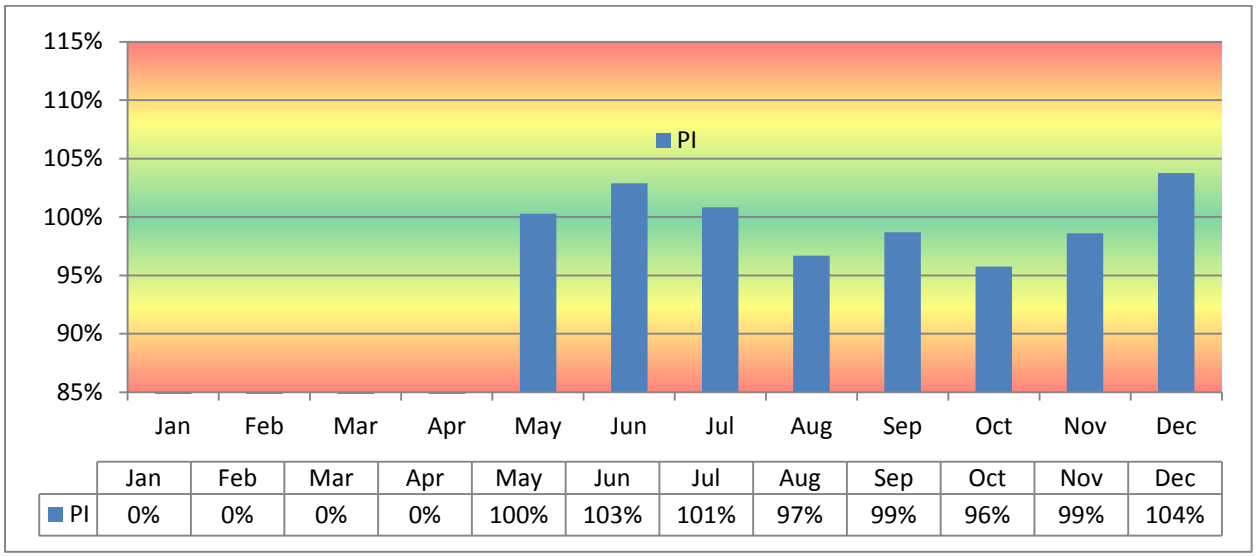
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Forecast Yield	116	113	201	185	188	254	264	246	208	191	130	62
Actual Yield	0	0	0	0	255	261	258	235	209	173	137	103
Expected Yield	0	0	0	0	255	253	256	243	212	181	139	99

Figure 15: Typical vs. observed irradiance for the dual axis system at the Santa Rita Jail



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual Irradiance	0	0	0	0	326	335	339	315	283	224	167	121
Forecast Irradiance	142	137	248	224	240	335	349	319	277	238	156	75

Figure 16: Performance Index for the dual axis system at the Santa Rita Jail

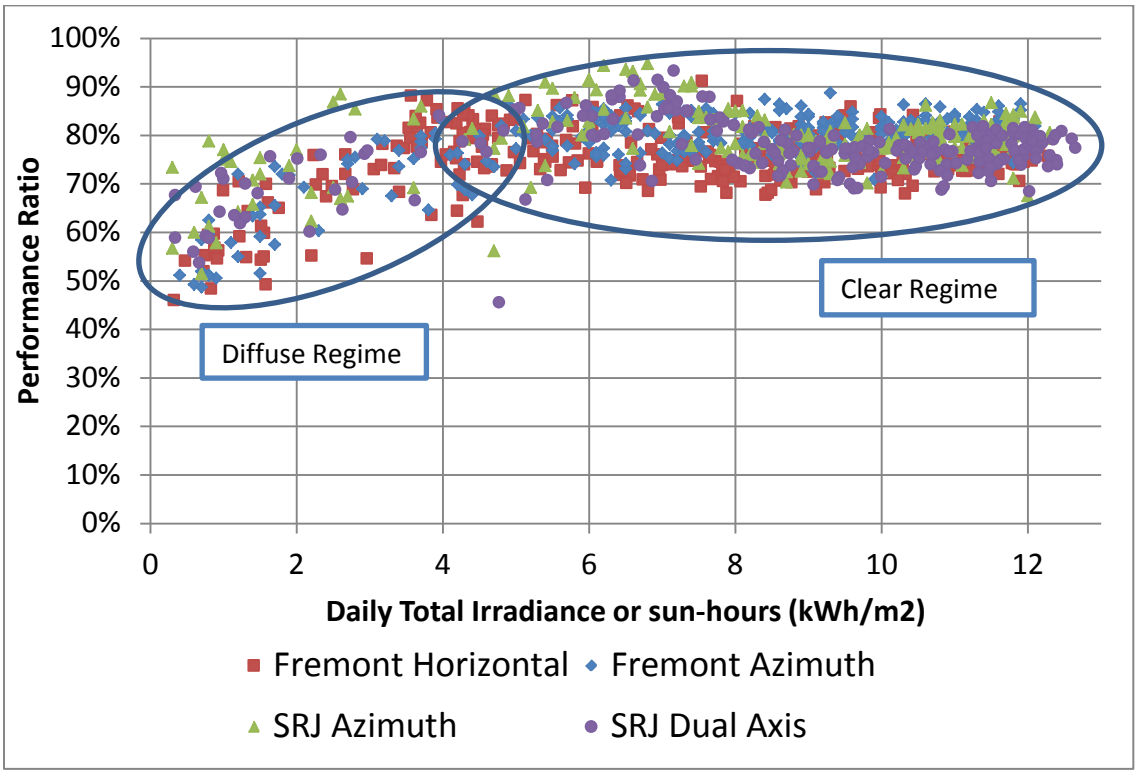


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PI	0%	0%	0%	0%	100%	103%	101%	97%	99%	96%	99%	104%

7.2 Module Diffuse Light Performance

Since performance ratio is a metric that is normalized for the amount of incident sunlight or irradiance, we can look across different sites to see if particular trends exist in the data. In particular, it is interesting for the Solaria technology to look at performance ratio as a function of irradiance. In Figure 16, we look at the daily performance ratio as a function of the total amount of irradiance received that very same day. On a day with little sun, meaning that the sky is likely to be cloudy or even overcast, this total is in the 0 to 4 kWh/m2 range. On a clear day, it can vary from 5 to 12 kWh/m2, depending on the season.

Figure 17: Performance ratio of the four systems as a function of daily total irradiance



- Clear regime: in the higher range of irradiance totals, we can see that the performance ratio is consistently in the 70 to 85% range, with a slight downward trend due to the fact that the higher irradiance days tend to be longer days of summer with higher temperatures, which reduce the efficiencies of photovoltaic technologies, and therefore, lower the performance ratio.
- Diffuse regime: in the lower range of irradiance totals, we can see that the performance ratio is significantly lower with values ranging from 45 to 70%. This comes in large part from the fact that the Solaria technology being used is a concentrator and, hence, the light coming from various directions cannot be as well utilized as that coming straight from the sun on a clear day. In fact, Solaria modules typically capture only about two thirds of the incident diffuse light.

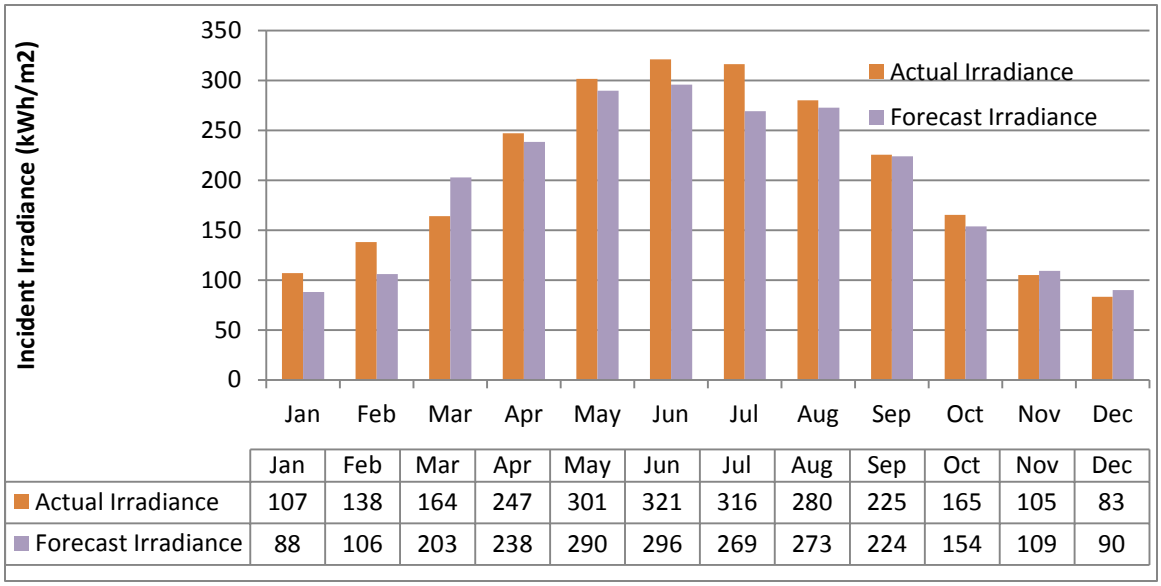
7.3 Module Degradation

Module degradation data is required by the financial community and customers to assess the long term cash flows associated with a solar project.

In accordance with our expectation, no degradation noticeable with our testing instruments was observed within the first year of operation; the models used to calculate expected power assume a degradation rate of 0.5% decrease in total produced energy every year. Given the lack of significant Performance Index trending

in Figure 6, Figure 9, Figure 12, and Figure 15, and the fact that annual Performance Indexes are generally equal or close to 100%, we can infer that, at this time, the degradation assumptions are well suited to reflect the performance of a Solaria system.

Figure 18: Typical vs. observed irradiance for the horizontal system in Fremont



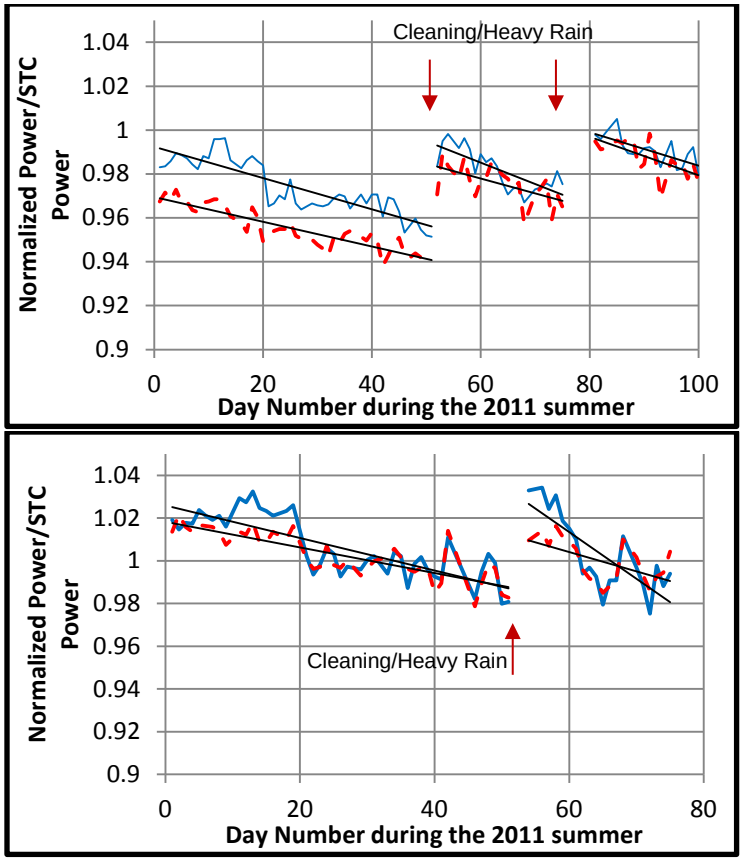
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual Irradiance	107	138	164	247	301	321	316	280	225	165	105	83
Forecast Irradiance	88	106	203	238	290	296	269	273	224	154	109	90

7.4 Soiling Studies

In order to determine whether the patterned glass impacts the rate at which Solaria modules accumulate soiling, we closely examined the performance of four side-by-side azimuth and horizontal tracking systems with both Solaria and standard flat-plate crystalline modules.

Performance measurements of each of the four systems were recorded throughout California's dry summer season in 2011 and the rates of performance degradation due to soiling for each system were compared. All four systems were treated in the same manner with identical maintenance and cleaning schedules. Figure 17 below shows how the normalized power at the module level decreased during successive time periods, interrupted by heavy rain or scheduled cleaning. The normalization was done using measured array performance translated to 1 kW/m2 irradiance and temperature correction, and then limited the conditions to the middle of the day and no shading. The initial difference between Solaria and standard modules on the azimuth tracker was due to a difference in their initial soiling conditions.

Figure 19: Top: normalized module power output curve as a function of day number during the summer of 2011 vertical-axis azimuthal tracker. Solaria is the solid blue line, the reference module is the dashed red line. Bottom: normalized power on horizontal axis tracker



The results are summarized in Table 10 and indicate that soiling rates for Solaria modules and standard flat-plate are in the same range, and that they are consistent across the two different tracking technologies.

Table 10: Soiling rates per day observed for Solaria and reference modules during the summer of 2011 for two types of tracker

	Azimuth Tracker		Horizontal Tracker	
	Solaria	Ref.	Solaria	Ref.
Period 1	-0.07% +/-0.01%	-0.06% +/-0.01%	-0.08% +/-0.02%	-0.06% +/-0.01%
Period 2	-0.1% +/-0.04%	-0.07% +/-0.04%	-0.14% +/-0.09%	-0.04% +/-0.06%
Period 3	-0.07% +/-0.04%	-0.09% +/-0.05%	N/A	N/A

For the first period (July 19, 2011 to September 7, 2011), soiling rates were in the 0.06 %/day to 0.08 %/day range as determined by a linear regression. It is worth mentioning that these values are in accordance with the previously reported value of 0.1%/day for rural/suburban areas of Northern California [5].

7.5 Financial Performance

7.5.1 Bankability

One key aspect of the financial performance of an energy technology is the ability to reliably predict the energy produced over time, and therefore, reliably predict the cash flow of a project using this technology.

As was demonstrated in the previous parts of this report, the energy production of both test sites in Fremont and at the Santa Rita Jail was reliably predicted with Performance Indexes close to 100% with the exception of the horizontal tracker in Fremont. These predictions were normalized for the actual conditions occurring at the site so one implicit assumption is that the average year used for the initial forecast is a good reflection of the average weather at the site. If this assumption is valid, over the duration of the project (typically 20 years), the project will end up producing an amount of energy very close to what was estimated originally, within a few percentage points.

In probabilistic terms, this not only means that the 50% probability (P50) case is valid, meaning that the forecast is a good approximation of the average production, but also that the 90% probability (P90) case is not significantly lower than the P50 case: this means that the energy production level that will be achieved 90% of the time (or of the project years) will be very close to the average (P50) case. The variability (or volatility) is minimized, and it also contributes to the bankability of the technology.

7.5.2 Installation Costs

The installation costs for the Solaria HQ 110kWp tracker and Santa Rita Jail 235 kWp tracker installation were very different. The Solaria HQ tracker installation was Solaria's first installation and fell in line with an RD&D project and did not represent the costs for a typical commercial installation. The Santa Rita Jail tracker installation with Alameda County was a larger installation and was more representative of typical costs for installing a 235 KWp small commercial tracker project. For this reason, the focus will be on the material procurement costs for a highly competitive bid process for the installation of the Santa Rita Jail tracker and the minimal costs of ongoing operation and maintenance for this project.

The following is a summary breakdown of the costs and scope for the Santa Rita Jail Tracker installation:

	Summary Alameda County Santa Rita Jail Tracker Installation Costs			
#	Description	Amount		Sales Tax for Alameda County Included
1	PV Costs	$	349,414	Includes Alameda County 8.25% Sales tax
2	Tracker Material Costs	$	228,189	Includes Alameda County 8.25% Sales tax
3	Balance of System Labor & Material Costs	$	628,135	Includes Alameda County 8.25% Sales tax
	Total Costs	**$**	**1,205,738**	
4	Maintenance Costs	$	1,500	Annual site inspections

- (1096) Solaria low concentration photovoltaic modules
- (50) Ideematec Azimuth Trackers
- (2) MecaSolar 2-Axis Trackers
- Performance Monitoring Equipment
- Alameda County 8.25% sales Tax on all materials
- Payment and performance bond
- Design for construction approvals
- Mobilization, management and general conditions
- Site preparation
- Azimuth tracker installation
- Mecasolar tracker installation
- Inverter Materials and electrical installation
- Monitoring equipment installation
- Ongoing operation and maintenance

Santa Rita Jail Tracker Procurement and Installation

Step 1: Solaria worked with Alameda County to develop the construction design drawings and scope of work for competitively bidding the Santa Rita Jail project with multiple contractors.

Step 2: Solaria with Alameda County qualified and invited approximately seven local Bay Area EPC contractors to bid on the installation. A bid walk was scheduled with the contractors at the construction site where the bid form, construction drawings and scope of work were distributed to the contractors for review and comment. The contractors were able to walk the site and obtain additional clarifications on the installation scope. The site walk was hosted by Alameda County and the Santa Rita Jail. A bid due-date was set.

Step 3: Alameda County and Solaria received and evaluated contractor bids based on cost and experience prior to contractor award.

Step 5: After the contractor was awarded the project, a contract was executed between the contractor and Alameda County.

Step 6: After the contract was executed, Alameda County executed a Notice to Proceed as standard practice that gives direction to the contractor that they can begin work per the contract terms. The installation and commissioning of the trackers with Solaria modules had minimal field changes with minimal change orders. The following was one of the construction lessons learned that led to change orders:

It was discovered that the incorrect communication wire for remote access was specified by Solaria so the communication wire had to be re-pulled and additional costs of about $4,000 in material costs were covered by Solaria and the labor to re-pull was performed by Alameda County.

7.5.3 Incentive Payments

Table 11 below shows how the energy production to date lines up with the estimated production from the California Solar Initiative (CSI) calculator. To date, energy production has exceeded the CSI model by close to 19%.

Table 11: California Solar Initiative expected generation vs. actual

SRJ Solar Tracker Generation								
2012/2013 Actual Generation				Expected Generation (CSI Calculator)				
Month	Total Generated (kWh)	CSI Payment #	% of Expected	Fence-220W	Fence-265W	Hill-210W	MecaSolar	Total
May	57,431	Payment #1	117.7%	12,509	6,452	25,313	4,521	48,795
June	57,658	Payment #1	120.3%	12,260	6,357	24,810	4,491	47,918
Jul	61,177	Payment #2	119.8%	13,069	6,794	26,447	4,748	51,058
Aug	58,105	Payment #3	122.5%	12,170	6,322	24,627	4,327	47,446
Sept	48,992	Payment #4	115.3%	10,916	5,672	22,090	3,828	42,506
Oct	40,476	Payment #5	109.8%	9,458	4,898	19,139	3,378	36,873
Nov	29,641	Payment #6	112.1%	6,770	3,482	13,700	2,499	26,451
Dec	23,285	Payment #7	100.7%	5,911	3,022	11,961	2,239	23,133
Jan	32,024	Payment #8	138.8%	5,905	3,028	11,950	2,188	23,071
Feb	39,071	Payment #9	138.3%	7,252	3,725	14,676	2,603	28,256
Mar	43,907	Payment #10	117.7%	9,590	4,928	19,408	3,363	37,289
Apr	50,545		115.7%	11,227	5,792	22,720	3,953	43,692
Total	542,310		118.8%	117,037	60,472	236,841	42,138	456,488

8 Conclusions

Thanks to the support of the CSI RD&D Program, two complete test sites were built using Solaria module technology. Solaria's analysis over the course of 2012 produced extremely valuable insights.

First, it was shown how the energy produced across all systems matches long-term forecasts, which establishes Solaria as a reliable and bankable provider of solar modules. In both sites, on two different tracker types, the yearly Performance Index was calculated to be equal or close to 100%; in other words, Solaria's models are a good reflection of the performance of Solaria's technology and can be used to reliably forecast performance. For the solar project investment community, this means that an investment in Solaria technologies produces known and calculated returns that can be relied upon. Fortunately, this particular aspect was put in practice with the financing of several tens of megawatts of Solaria modules installed around the world in 2012. An example is the flagship project at the White Sands Missile Range, which was built for the Army [6].

Two particular aspects of the Solaria technology were also described in depth: the response to diffuse light and to soiling. These are two of the chief concerns expressed by Solaria's customers when evaluating a concentrator technology with a patterned glass superstrate. On the first particular aspect, we showed that the technology works best in high irradiance environments by design, but still performs in cloudy or overcast environments when a high concentration ratio technology would simply shut down. Generally, the more the weather resembles dry, desert-like conditions that are ideal for large solar deployment, the more the performance will match that of standard crystalline modules. Regarding soiling, despite a different aspect of the glass superstrate when compared to other solar modules, it was proven that soiling doesn't affect the Solaria module in any manner that would be quantifiably different from standard modules, as far as power output is concerned. As a result, standard yearly soiling loss factors as would typically be applied to other technologies also apply here.

A common buzz word of the solar industry is "bankability" or the ability of a technology to deliver on its promises. Through this research project, Solaria was able to demonstrate that actual energy production from their technology closely aligned with modeled results. In very concrete terms, an investor of a project using Solaria technology should feel confident that the expected returns of the project will be met.

Finally, being almost a perfect substitute for standard modules, from a form and function standpoint, Solaria module systems do not show any particular increase in the installation costs structure. The Santa Rita Jail project approaches a size at which some

economies of scale kick in. At $637,000 for equipment, this translates into $2.55/W installed for the modules and associated trackers. For labor, the total was $2.17/W. This is reasonable for a system this size and cost models indicate that these numbers can be further reduced for multi-megawatts installations.

As a result of the data collected over the duration of this research project from the two test sites, Solaria has been able to initiate new projects on almost every continent, including systems in the following countries: USA, Chile, France, Italy, India, China, Qatar, etc. Specific systems and sizes include:

- 1 MW in Atwater, CA
- 4 MW in Las Cruces, NM
- 1 MW in Inner Mongolia, China
- Multiple 1 and 2 MW plants in southern Italy

In conclusion, thanks to this experience and to the conclusions contained in this report, Solaria is now in an excellent competitive position to grow as a company and participate to California's efforts to become an international hub for the solar industry.

9 Public Benefits to California

The primary obstacle preventing successful, wide-scale deployment of the Solaria technology and low concentration photovoltaic in general is that investors and financial institutions only fund projects that use solar technology with a proven performance history. It is difficult to develop the long term reliability data required to finance solar projects without deploying projects large enough to provide that data, which requires funding. Prior to the CSI RD&D project, Solaria has conducted extensive small-scale field testing on both single axis horizontal and dual axis trackers, but this in-house verification effort and small scale data collection was not sufficient to support the project financing necessary to take the Solaria module to the commercial and utility-scale markets.

The CSI RD&D project created the opportunity to perform detailed analysis and reporting on the performance of reference concentrating photovoltaic systems that incorporate innovations to reduce costs, increase reliability, and improve system production and efficiency. By measuring actual system performance on multiple tracking system types, the published research data and results have led to a better understanding of the technology and project risks, and ultimately increased market penetration of solar photovoltaic installations in California.

Figure 20: Project featuring Solaria modules for the City of Atwater, CA

10 References

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