ESTCP
Cost and Performance Report

(EW-201146)

Concentrating Photo-Voltaic System for DoD Rooftop Installations

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ESTCP

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

COST & PERFORMANCE REPORT
Project: EW-201146

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ACRONYMS AND ABBREVIATIONS

AC	alternating current
AFB	Air Force Base
ARB	Air Reserve Base
BLCC	building life cycle cost
CO_2	carbon dioxide
CPV	Concentrating Photo-Voltaic
CSI	California Solar Initiative
DAS	data acquisition system
DC	direct current
DLI FLC	Defense Language Institute Foreign Language School
DNI	direct normal irradiance
DoD	Department of Defense
eGRID	Emissions & Generation Resource Integrated Database
Electricore	Electricore, Inc.
EPA	U.S. Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
GHG	greenhouse gas
GHR	global horizontal radiation
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelized cost of energy
MCAGCC	Marine Corps Air-Ground Combat Center
MCAS	Marine Corps Air Station
MCLB	Marine Corps Logistics Base
MCRD	Marine Corps Recruit Depot
MW	megawatts
NAS	Naval Air Station
NAWS	Naval Air Weapons Station
NB	Naval Base
NCBC	Navy Construction Battalion Center
NIP	normal incidence pyroheliometer
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
NS	Naval Station
NWS	Naval Weapons Station

ACRONYMS AND ABBREVIATIONS (continued)

PDP	Performance Data Provider
PTC	performance test conditions
PV	photo voltaic
RDAT&E	research, development, test, acquisition and evaluation
SAI	Solar America Initiative
SAM	Solar Advisor Model
Suncore	Suncore Photovoltaic, Inc.
TJ	triple junction
TMY3	typical meteorological year 3
TOU	time of use
TRACEN	training center
UL	Underwriters Laboratories
USAF	U.S. Air Force
USCG	U.S. Coast Guard
V	volt
W	Watt

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EXECUTIVE SUMMARY

Electricore, Inc. (Electricore), in teaming with Suncore Photovoltaic, Inc. (Suncore) and Morrow Meadows, conducted a 15-month demonstration of a 50 kilowatt (kW) Concentrating Photo-Voltaic (CPV) Solar system at Naval Air Weapons Station (NAWS), China Lake, California. The installation was conducted over two phases allowing for 1 full year of seasonal data collection on both systems; the Suncore 25kW SE-500X system was demonstrated for the full 15 months and the Suncore 25kW Soliant 1000 system was demonstrated for 12 months.

OBJECTIVES OF THE DEMONSTRATION

The primary objective of this project was to demonstrate Suncore's high-performance and high-efficiency CPV solar panels through the installation and operation of both the Suncore 25kW SE-500X system and Suncore 25kW Soliant 1000 system at NAWS China Lake. In addition, the demonstration project was to help quantify the operational and cost benefits of the CPV technology for future application with Department of Defense (DoD) customers.

Key performance objectives for this project included annual energy production, greenhouse gas (GHG) emissions, system availability, and levelized cost of energy (LCOE). To date, the system has delivered 93,725 kilowatt-hours (kWh) of energy, which equates to a savings of more than 7,237 gallons of gasoline or 64 tons of carbon dioxide (CO_2).

TECHNOLOGY DESCRIPTION

Each SE-500X panel included six 22.5% efficient solar modules and each Soliant 1000 panel included eight 25.3% efficient solar modules. Both will produce electricity at parity with the statewide average retail grid price of electricity for commercial users. The system was engineered specifically for rooftops in hot, dry, sunny areas using high-efficiency cells and dual-axis TipTilt Tracking™. The selected demonstration site at NAWS China Lake was an ideal location to test and demonstrate this type of system, given the area's high Direct Normal Irradiance (DNI) and multiple sunny days. This technology can also be easily replicated at virtually all DoD installations and other government facilities in the Southwest United States, specifically the areas with similar climate profiles to NAWS China Lake.

During the course of this program, Suncore also developed an integrated racking product for the Soliant 1000 panels. The integrated rack is utilized for both transport of the panels as well as the system's installation.

For typical large commercial users, the Suncore product offering will result in a payback of less than 7 years; however, under this demonstration the payback profiles were not demonstrated. The solar manufacturer has outlined the required cost elements and typical payback values should the technology be installed at another site. Many military and DoD installations will have different cost/payback profiles since the DoD is not always eligible for most solar incentives or rebates as noted under this program.

DEMONSTRATION RESULTS

Throughout the demonstration, the Electricore Team, Environmental Security Technology Certification Program (ESTCP) and NAWS China Lake personnel were able to monitor the system performance via Deck's online interactive monitoring service. During the demonstration, the Team conducted a qualitative and quantitative analysis of the system, including customer feedback from NAWS China Lake personnel. In the report are the actual test results and solar data collected, including comments and interpretations of performance by Suncore engineers. Most performance objectives were met with the exception of Annual Energy and Payback, which are addressed in detail later in this document. The system also showed a 98% availability and had an estimated LCOE of $0.17/kWh.

Overall, the performance of the system was adequate for Phase 2, but less than expected for Phase 1. This can be attributed to the initial installation errors made by the solar installer and the use of the now discontinued SE-500X model CPV tracker unit in Phase 1. Installed costs (without the cost overrun) are consistent with similar sized commercial photo-voltaic (PV) systems, when compared to California solar statistics in 2010 when the project was initially proposed. Based on this information, the estimated projected cost of the CPV module/tracker for a turnkey system on a typical roof is $3-$4/Watt (W) for future installations.

The demonstration did not include any models or simulations. The program strictly collected the operational data of the installed system, relative to the actual conditions experienced at NAWS China Lake. All of the equipment purchased with government funding installed at the demonstration site will remain at the installation and ownership will be retained by the government.

IMPLEMENTATION ISSUES

The implementation issues experienced on this program can be directly tied to the selection of a facility/demonstration site. During the initial phase of the project, several preliminary sites proved unsuitable for the demonstration due to the lack of structural and electrical drawings available for each site. After settling on a demonstration site, the Team faced additional problems including asbestos in the silver roofing and silver roof mastic. These problems resulted in delays to the installation and demonstration timelines, as well as, additional cost to the program.

In early April 2014, the south array, SE-500X panels, were found in an idle state and not tracking the sun. These panels are powered by 24 volt (V)-direct current (DC) power supplies, and there is a known failure mechanism in which the separation of a 2-piece plastic electrical connector interrupts the 24V power for an entire string of panels. As of July 30, 2014, all connectors have been replaced and all 72 panels are correctly tracking the sun.

In addition, the solar manufacturer went through a change in ownership for the division producing the modules being used in this demonstration. Suncore has since closed its California manufacturing facilities and moved all production to their facility in China.

1.0 INTRODUCTION

Today, nearly all Department of Defense (DoD) installations rely on off-base commercial utilities for electric power generation. This increases their vulnerability to attack and also harms the environment when purchasing power from coal plants. The goal of this program was to strengthen national security through energy independence by using more renewable energy such as solar to reduce dependence on fossil fuels. Additionally, many DoD facilities, such as the Naval Air Weapons Station (NAWS) China Lake, pay increased "peak demand" electricity rates during the day. NAWS China Lake reports their peak time of use (TOU) energy rate to be as much as $.42 kilowatt-hour (kWh) peak between the hours of 12PM and 6PM during summer months. In addition, NAWS China Lake's is also charged a separate demand charge depending on time of day and time of year. This time period also correlates to the peak solar availability that the Suncore Photovoltaic, Inc. (Suncore) Concentrating Photo-Voltaic (CPV) solar system capitalized on. However, today's inefficient "flat panel" solar systems require a large area to generate significant energy and have a long economic payback period. These factors, combined with the artificially low cost of conventional generation and high capital cost of renewable energy, delay the broad adoption of solar technologies.

Electricore, Inc. (Electricore) conducted a 15-month demonstration of a 42 kilowatt (kW) alternating current (AC) system at NAWS China Lake. The Suncore 25kW SE-500X system was demonstrated for a full 15 months and the Suncore 25kW Soliant 1000 system was demonstrated for 12 months, enough time to collect seasonal data on both systems. The SE-500X was fully installed and operating starting January 1, 2013; the Soliant 1000 was fully installed and operating starting June 24, 2013.

The demonstration project helped quantify the operational and cost benefits of the technology for future application with DoD customers. The successful implementation of this technology yielded several specific and measurable benefits to the military, including offset energy demand from the grid, reduced energy costs, and decreased carbon emissions.

1.1 BACKGROUND

The 25kW SE-500X and 25kW Soliant 1000 commercially available rooftop CPV solar systems nearly doubles energy production compared to conventional flat panels. The system was engineered specifically for rooftops in hot, dry, sunny areas using high-efficiency cells and dual-axis TipTilt Tracking™. The Suncore product gives the lowest cost of energy by maximizing the energy output at price points in parity with the grid. Additional savings can come from significant reductions in installation costs. This demonstration project installed and demonstrated the Suncore CPV solar system at the NAWS China Lake and gathered performance and economic/cost data to accelerate market and end-user acceptance of this new technology.

Prior to the NAWS China Lake CPV installation, this DoD facility was using other traditional flat solar panels, which was used for comparative performance and economic analysis. In early 2012, NAWS China Lake also installed a new 118 acre solar farm adding 13.78 megawatts of solar photovoltaic (PV) power. This installation, considered the largest in the Navy, shows tangible progress toward national energy independence and reaching the Department of the Navy's energy goals.

1.2 OBJECTIVE OF THE DEMONSTRATION

The primary objective of this project was to demonstrate Suncore's high-performance and high-efficiency CPV solar panels through the installation and operation of both the Suncore 25kW SE-500X system and Suncore 25kW Soliant 1000 system at the NAWS China Lake. At the end of the demonstration, all equipment purchased with ESTCP funding that was installed at the demonstration site will remain at the installation and ownership will be retained by the government.

- ***Validate:*** This project installed and demonstrated the Suncore system at the NAWS China Lake, CA, and gathered performance and economic/cost data to accelerate market and end-user acceptance of this new technology.
- ***Findings and Guidelines:*** NAWS China Lake has other traditional flat solar panels installed, which were used for comparative performance and economic analysis.
- ***Technology Transfer:*** This successful demonstration helped provide operational and cost performance data of CPV solar panels on a targeted DoD installation. This technology was installed at an existing DoD building with minimum changes to existing infrastructure.
- ***Acceptance:*** This project demonstrated the advantages of Suncore's CPV systems in high direct normal irradiance (DNI) areas of the Southwest United States and provided DoD installations a cost effective, high-efficiency PV solution for multiple regions. Please see the list below for DoD Installations where this system would be most effective.

  California

  - Beale Air Force Base (AFB)
  - Camp Pendleton
  - Defense Language Institute Foreign Language School (DLI FLC) Presidio-Monterey
  - Defense Distribution Depot San Joaquin
  - Edwards AFB
  - Fort Irwin
  - Los Angeles AFB
  - Marine Corps Air-Ground Combat Center (MCAGCC) 29 Palms
  - Marine Corps Air Station (MCAS) Miramar
  - Marine Corps Logistics Base (MCLB) Barstow
  - Marine Corps Recruit Depot (MCRD) San Diego
  - March Air Reserve Base (ARB)
  - McClellan AFB
  - Naval Air Station (NAS) Lemoore
  - NAS North Island
  - NAS Pt. Mugu
  - Naval Base (NB) Point Loma
  - Navy Construction Battalion Center (NCBC) Port Hueneme
  - Naval Station (NS) San Diego

- Naval Weapons Station (NWS) China Lake
- Naval Post Graduate School
- Travis AFB
- U.S. Coast Guard (USCG) Training Center (TRACEN) Petaluma
- Vandenberg AFB

Nevada

- NAS Fallon
- Nellis AFB

Colorado

- Buckley AFB
- Fort Carson
- Petersen AFB
- Schriever AFB
- U.S. Air Force (USAF) Academy

Utah

- Dugway Proving Ground
- Hill AFB
- Tooele Army Depot

Arizona

- Davis-Monthan AFB
- Fort Huachuca
- Luke AFB
- MCAS Yuma
- Yuma Proving Ground

New Mexico

- Cannon AFB
- Holloman AFB
- Kirtland AFB
- White Sands Missile Range

Texas

- Dyess AFB
- Fort Bliss
- Goodfellow AFB
- Laughlin AFB

Overall, the goal of the demonstration is to have a cost and design guidance document to help DoD end users (all services) select CPV systems based on their individual site characteristics.

1.3 REGULATORY DRIVERS

Our successful implementation of this technology yielded several specific and measurable benefits to the military including: offset energy demand from the grid, on-site renewable energy generation, reduced energy cost, and decreased carbon emissions.

This project offset over 69,693 kWh of energy demand annually from the grid and contributed 42kW AC of on-site renewable energy generation. The project levelized cost of energy (LCOE) of $0.20/kWh is equivalent to the current off-peak energy costs and substantially less than the peak TOU energy rate of $0.42/kWh. Thus, when the system is used to offset energy demand during peak times, NAWS China Lake receives the benefit of reduced energy costs.

All on-site renewable energy generation from this project directly results in decreased carbon emissions, as the system produces no greenhouse gas (GHG) emissions. Over the course of the program, this resulted in an annual savings of 105,947 lbs/year of carbon dioxide (CO_2) emissions.

This project directly supported the DoD's goal of 25% renewable energy generation by 2025, as well as contributed to the Department of the Navy's Energy Program for Security and Independence. The U.S. Department of the Navy, which comprises more than 64 installations, was required to install advanced meters to measure electrical energy use by October 1, 2012, as directed by the U.S. Energy Policy Act of 2005. With this data, the government hopes to find ways to lower usage and costs. By 2020, the Department of the Navy has determined that 50% of total energy consumption will come from alternative sources.

2.0 TECHNOLOGY DESCRIPTION

The solar array is a dual-axis tracking, concentrating, PV panel developed by Suncore. During the first installation of 25kW, the SE-500X system supplied at least 500 times concentration of sunlight onto triple junction (TJ) cells, and the second installation of 25kW using the Soliant 1000 system supplied at least 1000 times concentration, to produce electricity in grid-tied systems on commercial or industrial rooftops. The shape is optimized for a typical rooftop installation of traditional flat solar panels; low-aspect ratio, close to the mounting surface and a size approximately the same as a flat solar panel. Based on proprietary product design and manufacturing, these Suncore panels deliver a LCOE much lower than traditional flat panel and are competitive with retail grid pricing.

The panels were mounted on the rooftop of the Anti-Radiation Guidance Lab (Building #31440) at NAWS China Lake using a pre-fabricated mounting structure designed and built by the contractor, Morrow-Meadows.

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

Each SE-500X panel includes six 22.5% efficient solar modules and each Soliant 1000 panel includes eight 25.3% efficient solar modules. Both will produce electricity at parity with the statewide average retail grid price of electricity for commercial users. The selected demonstration site at NAWS China Lake, CA, was an ideal location to test and demonstrate this type of system, given the area's high DNI and multiple sunny days.

- ***Panel and mechanical system:*** The panel assembly consists of a rigid main structure and two rotating elements to enable high tracking accuracy. One rotation articulates east-west direction while the other will follow north-south direction. The modules and the control system are attached to the panel assembly. Project spacing of 6 feet between the panels minimizes shading from adjacent strings.
- ***Module:*** The module assembly integrates and aligns receiver assemblies with the primary Fresnel lenses and associated wiring. The module assembly also provides a rugged electrical enclosure around the PV components. This component provides tolerance to shading through a proprietary series/parallel wiring scheme.
- ***Receiver Assembly:*** The receiver assembly is responsible for directing and homogenizing sunlight from the primary concentrating element onto the solar cell, converting the incident optical power into electrical power and dissipating the excess thermal power.

Figure 1 shows the schematic for a single Soliant 1000 string design including the eight modules. The SE-500X is very similar in construction, differing in the number of modules per string.

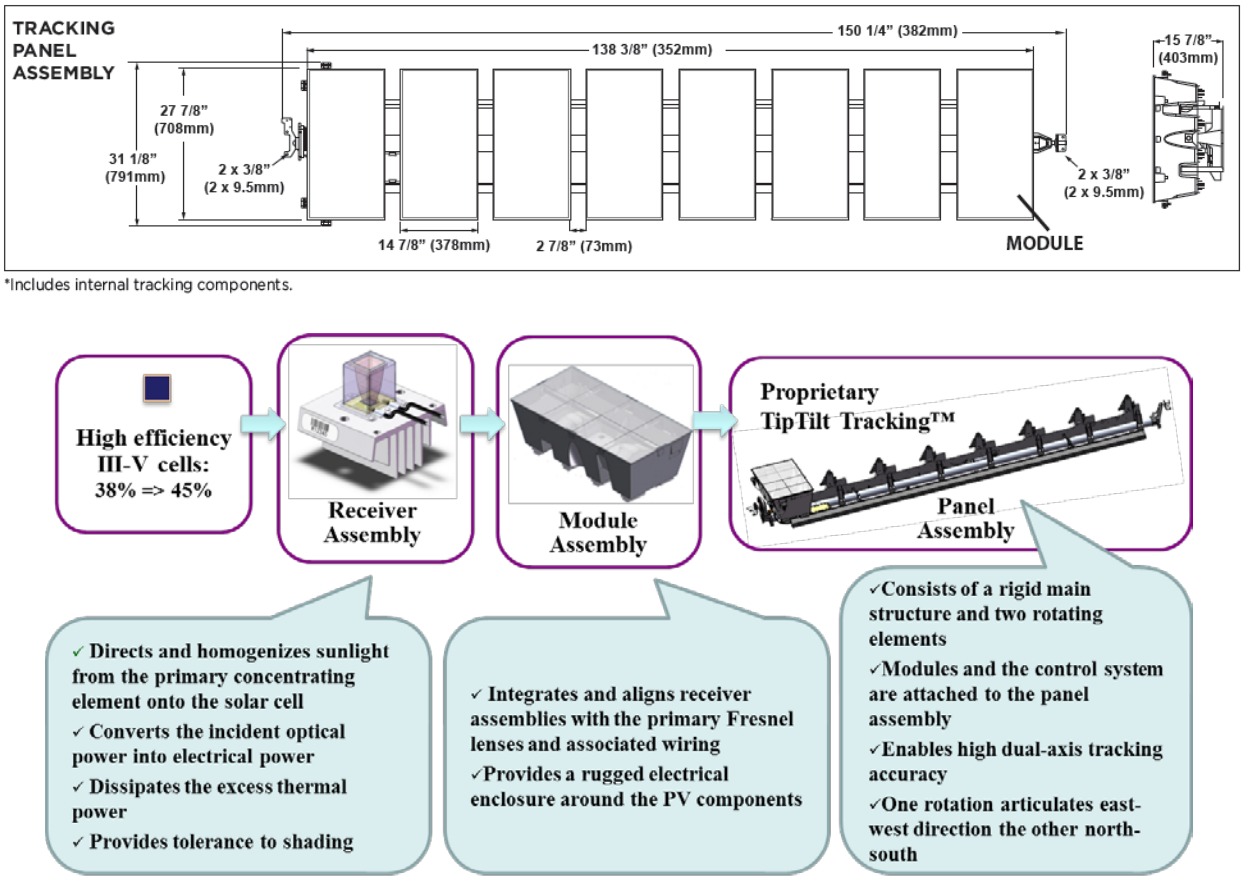


Figure 1. Soliant 1000 module and string.

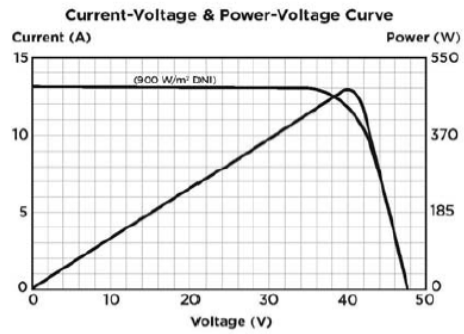
Figure 2 shows the tracking range of motion for the modules and string assembly throughout the day at a beta-test location.

Figure 2. Suncore tracking panel range of motion during the day.

Table 1 and Table 2 provide the electrical and mechanical specifications for Suncore's Soliant 1000 system.

Table 1. Soliant 1000 electrical data.

ELECTRICAL DATA - TRACKING PANEL			
P_{max} STC	504	W	(900 W/m^2 DNI)
P_{max} PTC	471	W	
V_{oc}	47.7	V	
I_{sc}	13.2	A	
V_{pmax}	39.8	V	
I_{pmax}	11.8	A	
Max V IEC, UL	1000, 600	V	
Series Fuse Rating	25	A	
NOCT	61	°C	(800w/m², 20°C, AM 1.5, WS = 1 m/s)
Temp. coeff. Power	-0.2	%/°C	
Temp. coeff I_{sc}	5	mA/°C	
Temp. coeff. V_{oc}	-9.2	mV/°C	module
Module Efficiency	25.3	%	(900 W/m^2 DNI)



Measured at performance test conditions (PTC). Irradiance of 900 W/m^2 DNI, Ambient Temp. 20°C, 4 m/s wind speed.

Table 2. Soliant 1000 mechanical data.

MECHANICAL DATA	
Cell Type	Triple-junction high-efficiency solar cells on Ge substrate
Panel Construction	Lens (silicone), composite housing, aluminum heat sink
Integrated Tracker	Coated steel and 304SS construction, TipTilt Tracking™ closed loop tracking, fits most PV mounting systems
Output Cables	80 inch (2m) length with locking connectors
Grounding	Integrated to mount, or optional factory-installed lug
Roof Load	5 lbs/ft^2 (0.0024 kg/cm^2) high density array, 2 lb/ft^2 (0.0009 kg/cm^2) low density array
Max Load	50 lbs/ft^2 (2394 Pa)
Wind Performance	130 mph (208 km/h) non-penetrating or penetrating
Operating and Storage Temp.	15°F to130°F (-9°C to 54°C)
Cells Per Module	8
Modules Per Panel	8
Cells Per Panel Assembly	64
Concentration Ratio	1000x
Weight	198 lbs (90 kg)
Dimension	(see diagram)
Area*	27.7 ft^2 (2.6 m^2)

*Includes internal tracking components.

The project built upon Suncore's prior offering of the SE-500X system by utilizing their next generation system, the Soliant 1000, through two development cycles. The 25kW of the SE-500X was delivered in the first installation stage and 25kW of the Soliant 1000 were delivered in the second stage. The Suncore solar system is a proprietary implementation that builds on the technology platform developed by Suncore under its Department of Energy Solar America Initiative (SAI) Technology Pathway Partnership award, and through ESTCP funding in this project. Suncore's Soliant 1000 system is currently commercially available for sale and Underwriters Laboratories (UL) Classified to IEC626108.

The SE-500X has been demonstrated as a proof of concept at multiple site locations. Real world performance data has been used to validate their system designs and models. Suncore has begun commercial installation for their products, including a project in Palm Springs, CA. The

installation featured Suncore's innovative rooftop-mounted high concentration solar panel, the SE-500X system that is located at a two-story office building located in Palm Springs, CA, whose tenancy is anchored by the General Services Administration. The 2kW rooftop concentrated solar system was projected to generate approximately 4,200 kWh of electricity annually. Based upon the success of this initial program, a larger 190kW rooftop system was installed at the property that will provide 90% of the buildings' electrical needs at a LCOE of 8-cents per kW, and a 5-year payback. This project payback is more favorable than the proposed NAWS China Lake project due to an increase in capital costs, availability of solar incentives and tax credits, and the system footprint. Each site's LCOE is dependent on a number of different inputs and assumed costs.

This technology can be replicated at virtually all DoD installations and other government facilities in the Southwest United States, specifically the areas highlighted in yellow and orange on the map in Figure 3 below, and in overseas installations and bases with similar climate profiles.

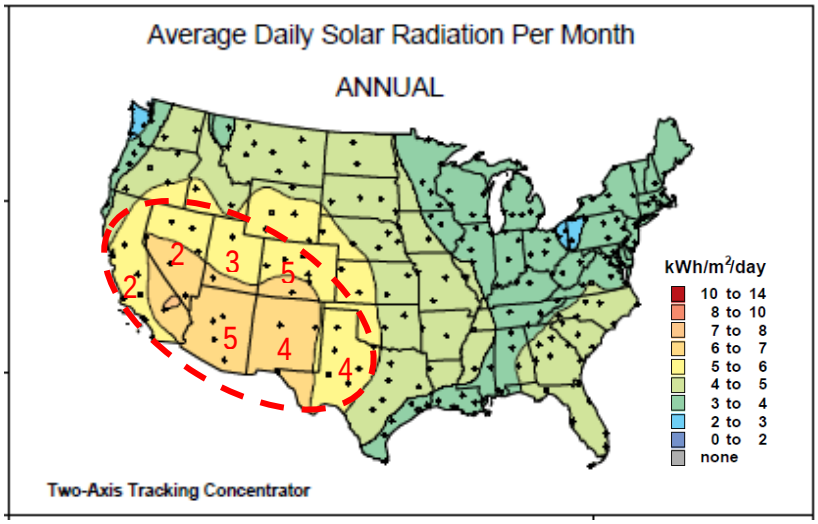


Figure 3. Map of the United States with areas of high DNI identified.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/METHODOLOGY

Performance Advantages: In 2010, testing showed the Suncore system will produce up to 37% more lifetime electricity over an equivalent investment in flat panel PV, with even lower LCOEs of approximately 10-25% (based on calculations using the Soliant 1000 product).

Cost Advantages: Suncore significantly improves the economics of solar energy by reducing technology costs and increasing system performance. The demonstration helped quantify the operational and cost benefits of the technology for future application with DoD customers. Estimates for cost and performance were:

- $4.00 per Watt delivered system costs (costs will improve as production volume increases);

- Approximately $0.15/kWh (based on National Renewable Energy Laboratory [NREL] Solar Advisor Model [SAM]); and
- 1.3 kWh per day per square meter.

Performance Limitations: At this time, there are no widespread technological or other limitations to deployment within areas of high DNI. While Suncore CPV systems could be deployed elsewhere, the economic benefits will only be realized in the areas identified in Figure 3.

Cost Limitations: For typical large commercial users, the Suncore advantage will result in a payback of less than 7 years. Military and DoD installations will have different cost/payback profiles. DoD can't take advantage of most incentives or rebates, but at the same time, DoD is not paying directly the "cost of money" associated with borrowing to install capital equipment.

Social Acceptance: Through their lower cost per kWh of energy, the new Suncore product further overcomes a significant barrier to technology adoption and increases the total installed amount of PV at DoD locations. Currently there are no significant regulatory or legal barriers to widespread adoption of this technology.

The system is visible as Building #31440 does not have a parapet; however Suncore's compact and lightweight system is less than 2 feet tall. The aesthetic impact is minimal to the building; the Suncore system was designed to hide any hardware and blend into the roof line.

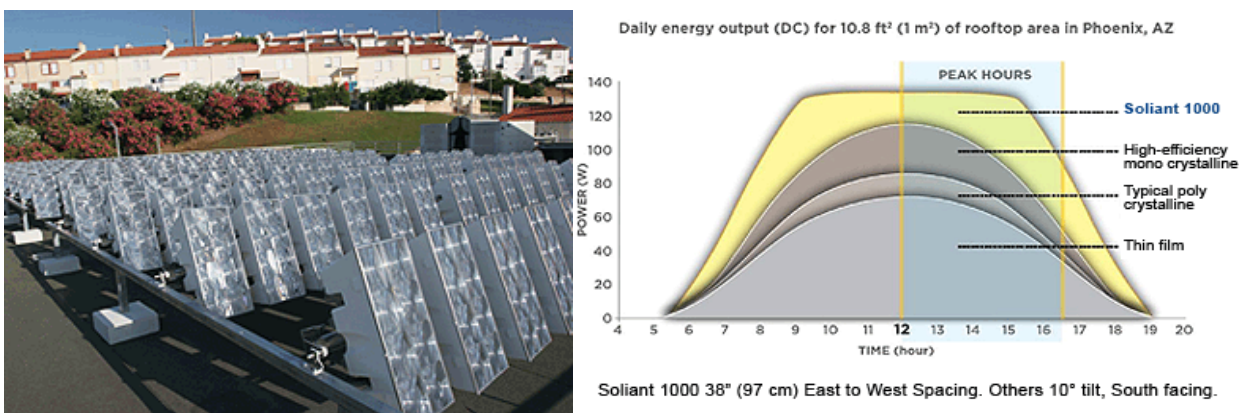


Figure 4. Installed Soliant 1000 System and peak performance curve versus currently commercial PV systems.

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3.0 PERFORMANCE OBJECTIVES

3.1 TECHNOLOGY PERFORMANCE OBJECTIVES

All of the technical performance objectives for this project are listed below. The installation provided assured access to reliable supplies of energy to meet NAWS China Lake's needs. Key measurements of the contribution of the new technology include:

- ***Energy Security:*** Reduced vulnerability to power grid disruptions (50kW of on-site power production) and increasing the use of year-round renewable energy generation at the selected building site.
- ***Cost Avoidance:*** As of March 26, 2014, the system has generated 76,526 kWh AC of energy, offsetting the purchase of energy from traditional utility grid sources. Each kWh produced renewable, avoids $0.16925 per kWh at off peak and $0.42 at peak prices.
- ***GHG Reduction:*** The solar system and balance of system components produce no GHG emissions. As of March 24, 2014, the system represented a savings of 56 tons of CO_2.

3.2 ECONOMIC PERFORMANCE OBJECTIVES

All of the economic performance objectives were met during this demonstration project. Key measurements of the contribution of the new technology include:

1. Successful installation and integration of Suncore's 25kW SE-500X system and 25kW Soliant 1000 system at the Anti-Radiation Guidance Lab, Building #31440 at NAWS China Lake, CA.
   a. The SE-500X was fully installed and operating starting January 1, 2013; the Soliant 1000 was fully installed and operating starting June 24, 2013.
   b. Actual Installation Nameplate is 48.312 kW direct current (DC)
      i. SE-500X = 24.12 kW DC
      ii. Soliant 1000 = 24.192 kW DC

   This was due to string sizing constraints with the six inverters. 50 kW DC can be thought of as a nominal number since the actual number has to be multiple of the actual string size and module nameplate rating.
2. A 15-month demonstration with greater than 98% availability of the system, i.e., very high system reliability.
   a. The system showed an annual availability of 97.8%
3. Data gathering, including KW, kWh, amps, and volts at the string level. Additional data measurements and tests will determine:
   a. Solar data including DNI, global horizontal radiation (GHR), humidity, ambient temperature, and wind speed is included in Appendix B and can be downloaded directly from the Deck Monitoring Site (http://live.deckmonitoring.com/?id=china_lake).

4. Gather quantitative and qualitative understanding of the maintenance implications for the system.
5. Comprehensive performance and economic analysis and comparison to other commercially available systems.

The Electricore Team collected data before and during system operation to evaluate the technical objectives of the project. A summary of the proposed performance objectives and the results are provided in Table 3. These objectives are based on a modeled solar resource of 8.5 kWh/m^2/day given by a statistical typical meteorological year 3 (TMY3) weather model year

Table 3. Performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Peak Power	kW AC	Power Measurements	≥ 50 kW AC delivered to site	42 kW AC delivered to site
Annual Energy	kWh	PV energy production measurements	> 100,000 kWh delivered to site	69,693 kWh delivered to site
GHG Emissions	lbs/yr CO_2 reduced	Inferred from annual energy production	> 117,000 lbs/yr CO_2	105,947 lbs/yr CO_2
System Availability	% of time available	Site operation data	> 98%	97.8%
Energy Generation Intensity	kWh/day/m^2	Energy production data and footprint for CPV system	> .0035 kWh/day/m^2	0.00349 kWh/day/m^2
Installed Cost	$	Hardware and labor expenses	≤ $7.00/W	$8.51/W ($7.02 without cost overrun)
LCOE	$/kWh	NREL SAM	≤ $0.15/kWh	$0.20/kWh ($0.17/kWh without cost overrun)
Payback	Years	NREL SAM & NIST BLCC	< 11 years	39 years (32 years without cost overrun)
Qualitative Performance Objectives				
System Maintenance	Type of maintenance and frequency	Records showing time and frequency for: • Lens washing • Inverter filter replacement • Tracking system maintenance • Any other maintenance (planned or unplanned)	Summary of maintenance during test period, including: • Description of maintenance activity • Indication if maintenance was planned or unplanned • Time (hrs) required for each maintenance activity • Maintenance frequency • Total maintenance time during test period	• Repairs were done to all connection points on the SE-500X panels. • Upon initial startup of the Soliant 1000 panels, excess noise due to equipment vibration was reported. The issue was quickly resolved by adjusting several of the equipment fasteners.

BLCC = Building Life Cycle Cost
Hrs = hours
lbs/yr = pounds per year
m^2 = meters squared
NIST = National Institute of Standards and Technology

Table 3. Performance objectives (continued).

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Qualitative Performance Objectives (continued)				
User Satisfaction	Feedback from NAWS China Lake personnel	Maintenance and management personnel interviews	Feedback showing level of satisfaction and areas for improvement.	Overall, NAWS China Lake personnel are satisfied with the installation and operation of the array.

Listed below is a summary of each performance objective listed in Table 3.

Peak Power

- *Purpose*: Peak power was measured quantitatively from the CPV system installed on Building #31440.
- *Metric*: Electricore used kW AC to measure power performance of the CPV installation.
- *Data*: The data required for calculations were direct peak power measurements in kW AC measured by the Deck data acquisition system.
- *Analytical Methodology*: Electricore used a graphical analysis to show actual peak power of the CPV system.
- *Success Criteria*: There was at minimum, 50kW AC delivered to the building site.

Annual Energy

- *Purpose*: Determined the estimated amount of kWh produced annually once full installation was reached, as well as provided quantitative data on the performance of high-efficiency PV solutions for DoD installations.
- *Metric*: Electricore used kWh to measure performance of the solar installation.
- *Data*: The data required for calculations was the PV energy production measurements tracked by the Deck data acquisition system.
- *Analytical Methodology*: Electricore used a graphical analysis to show the target energy production compared to baseline performance.
- *Success Criteria*: Minimum, 100,000 kWh delivered to the site.

GHG Emissions

- *Purpose*: Electricore did not monitor GHG emissions. No GHG is produced by the solar system or balance of plant components.
- *Metric*: Comparison of energy production and associated GHG emissions calculated using U.S. Environmental Protection Agency (EPA) Emissions & Generation Resource Integrated Database (eGRID) published values versus the zero emission energy production of the CPV system.
- *Data*: No data was collected in regards to direct GHG emissions.

- *Analytical Methodology*: N/A
- *Success Criteria*: Minimum, a 100,000 kWh annual energy produced on site. This directly correlated to a decrease in carbon emissions due to avoidance of power generation from conventional sources.

System Availability

- *Purpose*: Electricore monitor the percentage of time that the system is capable of meeting the load requirements.
- *Metric*: Electricore monitored the percentage of time the system is available.
- *Data*: The data required for this calculation was pulled from the site's operation data through the Deck monitoring system.
- *Analytical Methodology*: Electricore used a graphical analysis to show the percentage of system availability.
- *Success Criteria*: Minimum 98% system availability after installation is complete.

Energy Generation Intensity

- *Purpose*: Electricore monitor the percentage of time that the system is capable of meeting the load requirements.
- *Metric*: Electricore monitored energy production and use the CPV system footprint to conduct calculations.
- *Data*: The data required for this calculation was pulled from the site's operation data through the Deck monitoring system.
- *Analytical Methodology*: Electricore used a graphical analysis to show the percentage of system availability.
- *Success Criteria*: Greater than 1.3 kWh/day/m^2.

Installed Cost

- *Purpose*: Tracking the installation costs of the PV system helped quantify the cost benefits of the solar technology for future application with DoD customers. This technology can be replicated at virtually all DoD installations and other government facilities in the southwest United States.
- *Metric*: Electricore tracked the direct cost of installing the system at the selected facility.
- *Data*: Data collected included the direct hardware and labor cost for system installation.
- *Analytical Methodology*: Electricore provided a cost analysis and budget report that determines both the capital and operating costs of a PV system. Costs included the initial costs of designing and installing a PV system and maintaining and operating the PV system over its useful life.

- *Success Criteria*: Success was defined by a lower delivered system costs per Watt. For this project, the project team anticipated less than or equal to $7.00/W installed.

Levelized Cost of Electricity (LCOE)

- *Purpose*: Tracking the system economics helped quantify the operational and cost benefits of the solar technology for future application with DoD customers. This technology can be replicated at virtually all DoD installations and other government facilities in the southwest United States. Renewable energy provides a lower LCOE than conventional sources at peak demand and pricing parity during non-peak hours with the benefit of on-site renewable energy generation.
- *Metric*: Electricore tracked the LCOE using $/kWh.
- *Data*: Data collected included a combination of annual renewable energy production (kWh), technology capital and installation costs, and system performance.
- *Analytical Methodology*: Electricore used the NREL SAM model to provide a life cycle cost analysis and performance report that determines both the capital and operating costs of a PV system. Costs included the initial costs of designing and installing a PV system and maintaining and operating the PV system over its useful life.
- *Success Criteria*: The success criterion for this system was a reduced cost per kWh per day. Calculated LCOE is $0.15/kWh.

Payback

- *Purpose*: Tracking the economic payback period of the CPV system helped quantify the operational and cost benefits of the solar technology for future application with DoD customers. This technology can be replicated at virtually all DoD installations and other government facilities in the Southwest United States.
- *Metric*: Electricore tracked the number of years required for the return on investment to "repay" the sum of the original investment CPV investment.
- *Data*: Data collected included annual renewable energy production (kWh), Southern California Edison utility rates, technology costs, and system performance.
- *Analytical Methodology*: Electricore used the NREL SAM and NIST BLCC models to provide a life cycle cost analysis and performance report that determines both the capital and operating costs of a PV system. Costs included the initial costs of designing and installing a PV system and maintaining and operating the PV system over its useful life.
- *Success Criteria*: Success in this criteria results in payback period of less than 11 years.

System Maintenance

- *Purpose*: For the purpose of this demonstration, it was important to look at the maintenance requirements of the PV system, especially in relation to operating and performance costs.

- *Metric*: Electricore utilized routine maintenance and visual inspections to evaluate the PV system in regards to the baseline, as shown in Table 3.
- *Data*: Direct labor hours and cost for system maintenance and an on-site maintenance log.
- *Analytical Methodology*: Electricore reported any repairs or additional costs outside of the planned system maintenance.
- *Success Criteria*: There was minimal system maintenance, limited to the costs of regular upkeep.

User Satisfaction

- *Purpose*: In this demonstration Electricore measured user satisfaction in order to understand whether customer expectations have been met or exceeded over the lifetime of the project. This also provided feedback for future DoD installations.
- *Metric*: Electricore measured customer satisfaction through interviews with maintenance and management personnel at the end of the program.
- *Data*: User comments on system performance.
- *Analytical Methodology*: Electricore reported the interview results of NAWS China Lake personnel.
- *Success Criteria*: Customer was satisfied with PV installation and system performance.

4.0 SITE DESCRIPTION

The Electricore team conducted multiple site visits to NAWS China Lake to discuss the demonstration and site selection of the Suncore CPV system. During these meetings and subsequent tours of the facilities, several sites for this demonstration were evaluated including Buildings # 98012, #02466, and #31440.

The final selected demonstration site for this project was the Anti-Radiation Guidance Lab, Building #31440, at NAWS China Lake. Alternative demonstration sites were identified and quantified for the purpose of having a backup in case there were complications with the primary building during the permitting process. The alternative buildings were eventually screened out due to a lack of availability in structural drawings and necessary site approvals/permits. Building #31440 has approximately 16,000 square feet of roof space and was structurally sound enough for the system.

After the site selection, Suncore and Morrow Meadows prepared a detailed installation plan, which was later approved by NAWS China Lake personnel.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The selected building represents a number of similar building sites found common in many DoD installations that could benefit from Suncore's solar technology. The Government facility is located in the southwest United States, specifically in an area that receives the appropriate high levels of solar radiation required to fully realize the benefits of the proposed Suncore PV Solar system.

Building #31440 was by far the largest building evaluated with more than 16,000 square feet of rooftop space for the PV system. Morrow Meadows, the selected solar installer, deemed the specified building as structurally sufficient for an installation. A structural analysis would need to be completed for the installation of any PV system; both the CPV system and a typical PV system have a distributed roof load of 2-6 lbs/square foot depending on spacing and layout and may be ballasted or attached. An analysis of the wind zone at the demonstration site was conducted to determine mounting hardware with specifications far in excess of the anticipated wind loading. Due to the perforated, block like, geometry of the CPV equipment, no additional external hardware, such as wind deflectors, was necessary. Typical tilted "flat plate" PV systems may require wind deflectors to reduce lift.

The roof of Building #31440 was in good shape and was recently sealed with a new white coating for protection. However, a report by NAWS China Lake environmental personnel identified that a small amount of asbestos does exist within the building's roof. A copy of the asbestos report was provided to Electricore.

See Figure 5 below for a satellite view of the demonstration site at NAWS China Lake.

Figure 5. Satellite view of demonstration site.

See Figure 6 below for an aerial view of Building #31440, Anti-Radiation Guidance Lab.

Figure 6. Anti-radiation guidance lab, Building #31440.

4.2 FACILITY/SITE CONDITIONS

NAWS China Lake is a 1.1 million acre military facility located in the Mojave Desert of California, approximately 150 miles northeast of Los Angeles. This site conducts state-of-the-art weapons research, development, test, acquisition and evaluation (RDAT&E) for weapon systems associated with air warfare, aircraft weapons integration, missiles and missile subsystems, and assigned airborne electronic warfare systems and related training within a safe and secure, and operationally diverse land range test environment.

Within the vicinity of the solar demonstration, both U.S. and Foreign military personnel use the airfield and range to conduct more than 1,000 test and evaluation operations each year. Throughout the demonstration there was no effect to the airfield or its operations.

All of the information created and used in the demonstration was provided remotely to Electricore using the Deck monitoring system. The Deck system was installed to communicate via a dedicated wireless data modem pre-installed within the Deck monitoring system. No security issues were experienced during the demonstration.

Currently, there are no regulations at the federal, state, or local level related to the project. In addition, there were no environmental permits required for the installation of the Suncore PV Solar System.

All site-related permits pertain to the actual construction and installation of the solar array at NAWS China Lake. Morrow Meadows also provided a strict fall protection plan during the installation phase of both the 25kW SE-500X system and the Soliant 1000 system. NAWS China Lake was responsible for obtaining the necessary electrical interconnection agreements with Southern California Edison as part of a larger agreement proposed.

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5.0 TEST DESIGN

The proposed project was to demonstrate the operational and cost benefits of Suncore's high-performance and high-efficiency CPV solar panels. Also, this project will help quantify the deployment the CPV solar panels on targeted DoD installations where this technology is most applicable.

Throughout the demonstration the Electricore Team, ESTCP and NAWS China Lake personnel were able to monitor the system performance via Deck's online interactive monitoring service. The Electricore team completed a 15-month demonstration of the Suncore CPV system. During the demonstration, the Team conducted a qualitative and quantitative analysis of the system, including customer feedback from NAWS China Lake personnel. Included in the report are also comments on the data collected and interpretations of performance by Suncore engineers. Below is an assessment of the system performance discussed in Section 5.6, as well as highlights from the test design before installation.

5.1 CONCEPTUAL TEST DESIGN

- ***Independent variables:*** These are the values being manipulated by nature.
  1. The presence or absence of a solar energy generation system.
  2. The physical size and peak power capacity of the CPV system, inverter, and the building.
- ***Dependent variable(s):***
  1. Energy generated by the CPV system.
- ***Controlled variable(s):***
  1. DNI solar resource measured in W/m^2 at the site location. Needed to evaluate CPV performance.
  2. GHR useful to compare traditional PV performance.
  3. Ambient temperature at the site.
  4. Average Wind speed.
- ***Hypothesis:*** The Suncore rooftop CPV system will deliver 50kW of rooftop renewable energy production offering use of energy by NAWS China Lake from the utility grid.
- ***Test Design:*** The CPV system will be grid connected, while the performance of the system, solar resource, and ambient weather conditions will constantly be measured by the Deck data acquisition system. Net metering will be at the discretion of the utility provider, Southern California Edison. The energy produced by the CPV system can be considered an avoided energy cost. A comparison of NAWS China Lake energy costs with and without the avoided energy costs will be made to determine the cost of energy offset by the CPV system.
- ***Test Phases:*** The testing phase consisted of installing the system and the data acquisition equipment. Pretest preparation involved finding a suitable location for the

wind and irradiance instrumentation to ensure accurate measurements of the resources. All sensors and instruments carried a factory calibration or underwent calibration before the testing phase. Once installed, the entire system was commissioned to ensure that all equipment was working properly. This included the back end portion of the data acquisition system to ensure that data was being recorded and displayed properly on the website interface for further analysis. Data from the performance of the CPV system was available in graphical and tabular form from the website tool.

5.2 BASELINE CHARACTERIZATION

- ***Reference Conditions:*** The Team collected the following energy related data to assess the performance objectives listed in Table 3 including; estimated historical energy consumption, CPV energy production, GHG emissions avoided, and CPV system footprint.
- ***Existing Baseline Data:*** Baseline cost and performance data was established using 2-3 years past energy costs. NAWS China Lake pays a single facility energy rate and then allocates costs to the base consumers based upon building meters or estimates. As the proposed CPV system is grid connected, any energy produced will offset the overall facility energy consumption.
- ***Baseline Estimation:*** In this demonstration, the baseline is no renewable energy generation or 100% generation from conventional sources.
- ***Data Collection Equipment:*** Data acquisition and system monitoring was conducted via a Deck Commercial Solar Monitoring Package, which monitored the system performance down to the individual solar string level. The Deck Commercial Solar Monitoring System included an Energy Meter with Split Core Current Transformers (Revenue Grade 50A - 2400A) and a Data Acquisition Server with RS 485/Ethernet Connectivity). Data collected included KW, kWh, amps, and volts (V) data points. All service and equipment is Performance Data Provider (PDP) approved in California.

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

- ***System Design:*** The system was comprised of four main components.
  1. The CPV panel includes a self-contained control system and tracker and is thought of as a single unit.
  2. The structural roof mounting system was made from standard construction materials such as steel, pipe, and aluminum that fixes to the roof to hold the CPV panel.
  3. The electrical distribution system included a network of DC circuits that collect energy from the CPV panels and route it to the inverter. The inverter delivered energy in the form of AC power to the building's distribution system and the grid.
  4. The monitoring system recorded how much energy is produced by the CPV array along with ambient weather conditions and solar resource.
- ***System Depiction:*** Section 2 discusses the Soliant 1000 detail and layout example.

- ***Components of the System:*** See System design information above.
- ***System Integration:*** This demonstration did not augment or replace any existing system. This was a new rooftop CPV installation; it will not affect any larger systems within the chosen facility.
- ***System Controls:*** An example of the Deck Monitoring Dashboard can be seen below in Figure 7.

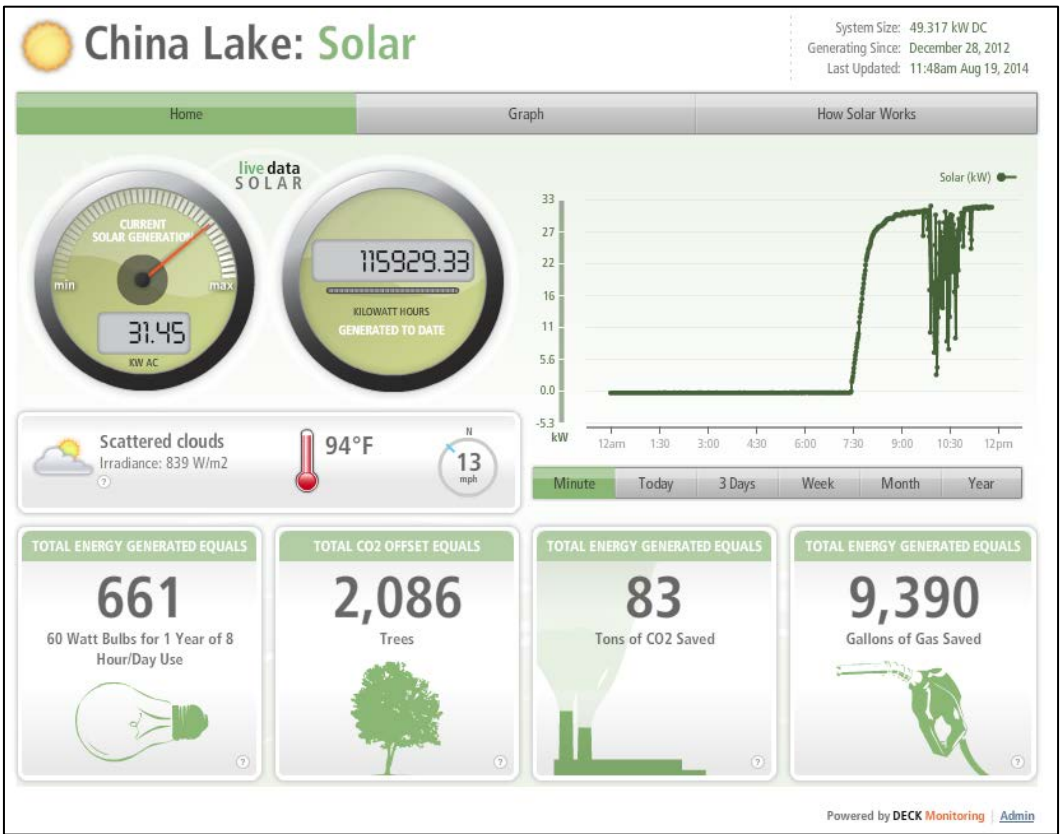

Figure 7. Deck monitoring dashboard.

5.4 OPERATIONAL TESTING

The installation of the Suncore CPV was installed in two phases, the first being the 25kW SE-500X system and the second being the Soliant 1000 system. The Suncore 25kW SE-500X system was demonstrated for the full 15 months and the Suncore 25kW Soliant 1000 system was demonstrated for 12 months, enough time to collect seasonal data on both systems. The SE-500X was fully installed and operating starting January 1, 2013; the Soliant 1000 was fully installed and operating starting June 24, 2013.

All solar data was captured via the Deck Monitoring System through all of the various modes of operation.

The demonstration did not include any models or simulations. The program strictly collected the operational data of the installed system, relative to the actual conditions experienced at NAWS China Lake.

A detailed schedule of activities was provided in the demonstration plan.

All of the equipment purchased with government funding installed at the demonstration site will remain at the installation and ownership will be retained by the government.

5.5 SAMPLING PROTOCOL

Hardware purchased from Deck monitoring was provided with factory calibration specific to each component. This included hardware for energy generation monitoring, voltage and current sensing, ambient temperature and humidity measurements, wind speed, and GHR. Additional hardware purchased by Suncore for CPV specific solar resource monitoring was also provided with a factory calibration. This included a Normal Incidence Pyroheliometer (NIP) for measuring DNI manufactured by Kipp and Zonen.

Random samples of raw data from the data logger's database were taken periodically to assess the quality of the data prior to any post processing performed by Deck Monitoring for web use. Blank fields were found in tables reported from the SMA inverters, which caused averaging errors in certain variables reported by the inverters on the Deck Monitoring website. However, these errors only affected the visual way the graphs were displayed for 15 minute averaging, and did not affect the computed sum of those variables in the final tables used for the data analysis. It should be noted that when viewing graphs or tables of data directly from the inverters on the Deck Monitoring website these errors can be seen as artificial zeroes in the graphs resulting in a downward spike especially when using the 15 minute average view option. These values are only blanks in the raw data table, not actual zeroes.

- ***Data Description:*** Data collected included kW, kWh, amps, volts, ambient weather conditions, and solar resource.
- ***Data Collector(s):*** All information was collected using a Deck Commercial Solar Monitoring System.
- ***Data Recording:*** The monitoring system recorded data at customizable intervals below 15 minutes. The 15 minute average was logged and uploaded to the server every 15 minutes unless otherwise specified.
- ***Data Storage and Backup:*** Data was uploaded from the data logger to the server and stored in highly redundant web servers managed by Deck Monitoring and Amazon.
- ***Data Collection Diagram:*** The Deck Monitoring System was located inside the building near the system inverter. Ambient weather and solar resource collection was through devices located outside on the roof attached to the CPV System.
- ***Non-standard Data:*** Data on lens soiling was collected through manual observation of the lens surface.
- ***Equipment Calibration:*** All monitoring equipment came with a current 1 year calibration from the manufacture.
- ***Quality Assurance Sampling:*** Sampling frequency is set at the device level to suit each instrument.

- ***Post-Processing Statistical Analysis:*** Data streams were compared through the web interface and automated alarms and filters were customized to flag certain data points, or alert the user if the values are outside of normal ranges.

5.6 SAMPLING RESULTS

Samples were collected by various instruments in the monitoring system. Each instrument was sampled locally by the data logger at 1 minute intervals. The data logger can be programmed to average multiple samples and report them to the Deck Monitoring server. However, Suncore chose to keep the 1 minute samples for the early stages of the project in order to troubleshoot any tracking specific performance issues where higher resolution temporal data is desirable. Raw data was archived in 1 minute intervals for this purpose. For energy generation reporting purposes data was downloaded in daily intervals to simplify visualization and analysis. The daily data table is included in Appendix B.

See Figure 8 for an example of 1 minute graphical data below.

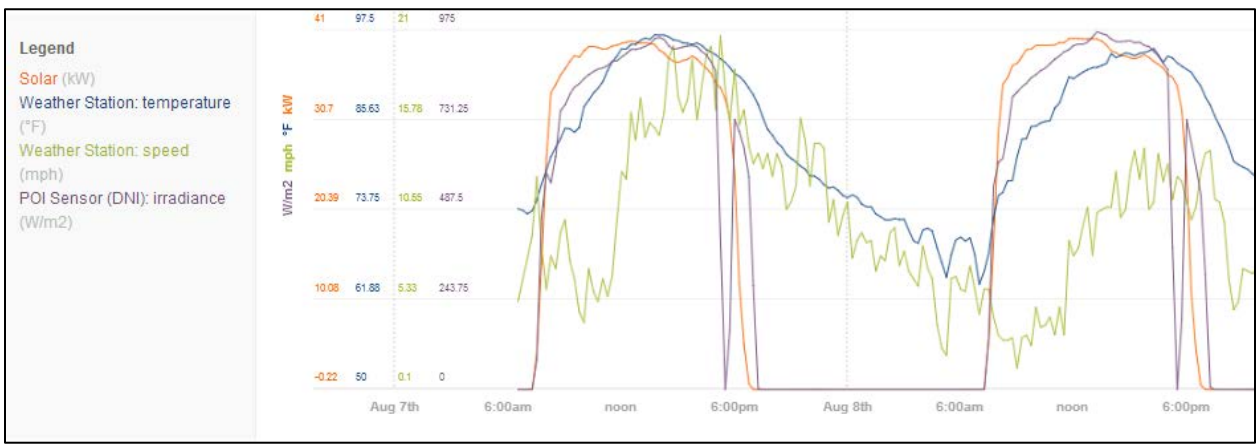

Figure 8. Annual performance plot per day.

An annual plot of each day illustrates how the system performed for the given solar resource.

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6.0 PERFORMANCE ASSESSMENT

For data analysis, daily data tables in the form of CSV files were downloaded from the Deck Monitoring website (http://live.deckmonitoring.com/?id=china_lake). These tables were imported into Excel for further processing to provide a summary to support the performance objectives. This table is provided in Appendix B.

Annual variables were calculated using data sums from a sample size of 365 days from 3/18/2013 to 3/19/2014. Availability was calculated on a daily basis rather than an hourly basis to simplify calculations. This was a conservative approach since the array may have been available for a partial day during a maintenance visit but were counted as unavailable for the entire day.

- ***Performance Objective Analysis Overview:*** The hourly energy production of the CPV system can be assessed by observing the average hourly energy production reported on the web interface. This can be used to calculate kWh/ft^2 or kWh/kW, and observe the benefit of producing energy late into the afternoon.
- ***Statistical Methodologies:*** A variety of general graphical and statistical tools are available through the Deck monitoring web interface and more specifically the "admin panel." Tabular data may also be downloaded to perform further analysis using statistical software.
- ***Graphical Methodologies:*** Same as statistical methodologies above.
- ***Modeling and Simulation:*** Suncore is constantly updating their own internal modeling capabilities to better predict the performance of their products. The current model used is the Sandia Photovoltaic Model (King model). The Sandia Model is currently the most accurate prediction tool available. The Sandia Model was used to predict energy production and used to reserve associated California Solar Incentives. No further analysis using the Sandia Model is included under the scope of this project.
- ***Sensitivity Analysis:*** Sensitivity to soiling may be observed between washing periods to determine the local soiling conditions and how they impact the energy production of the system. This may also be used to set a washing schedule.
- ***Anecdotal Perspectives:*** Monthly communication was initiated by Electricore with NAWS China Lake to collect anecdotal feedback from energy manager personnel and maintenance personnel.
- ***Industry Standards:*** Electricore models system performance using the industry standards developed by Sandia National Labs (Sandia PV Models). All equipment complies with UL standards of safety.
- ***Internal Validity:*** Limitations to the roofing structure and ability to support panels and certain spacing intervals could result in a less than optimized system in terms of kWh/ft^2. A planned action would be to evaluate the kWh/kW and provide calculations to show optimized kWh/ft^2. Outages in equipment like the combiner box or inverter that could interrupt the energy production were logged and noted in the dataset. For final

data analysis, hours when the data acquisition system is not functioning, or certain instruments are not reported and are removed from the final average.

- ***External Validity:*** Optimal production from a CPV system compared to a traditional PV system will be realized in locations that have a solar resource of 5.5 or greater DNI. Other prospective sites should be evaluated for this criterion first.

Table 4. System details and performance summary.

System Details	Total Nameplate	48.31	kW DC	The proposed goal was 50kW.
	SE-500X	24.12	kW DC	
	Soliant 1000	24.19	kW DC	
	Inverter	42	kW AC	
Target	Energy Production	100,000	kWh AC/year	This number was based on 50kW anticipated capacity.
	Annual Average per kW	2070	kWh AC/kW DC/year	Scaling the energy production to kW DC corrects for 48kW versus 50kW. It also adjusts for Phase 1 and Phase 2 capacities.
	Daily Average per kW	5.67	kWh AC/kW DC/day	
	Modeled Average Solar Resource (DNI)	8.50	kWh/m^2/day	Meteonorm file for China Lake, CA.
	Modeled Average Temperature	18.4	EC	
	kWh/DNI Ratio	0.67		Dividing out DNI allows us to compare years with different solar resource.
	Annual Availability	98%		
Actual Production	Life of the System	76,526	kWh AC	This is a combination of the first 24.12 kW and the total 48 kW at various stages.
	Past Year	69,613	kWh AC/year	Absolute number reflects 2 Phases; a combination of the first 24.12kW and the total 48kW at various stages
	kWh/kWdc/year Average	1698	kWh AC/kW DC/year	Scaled by kW, DC is a better number to compare to.
	kWh/kWdc/day Average	4.65	kWh AC/kW DC/day	Lower solar resource and shadowing on second array.
	Measured Average Solar Resource (DNI)	6.11	kWh/m^2/day	Taken from February 2013 to February2014. Note that the DNI is lower than the modeled year for the expected generation.
	Measured Average Temperature	18.8	EC	
	kWh/DNI Ratio	0.76		Dividing out actual DNI allows us to compare years with different solar resource.
	Performance over expectation taking measured solar resource into account	114%		*Based on locally measured values for DNI. (kWh/DNI ratio actual)/(kWh/DNI ratio target)
	Life of System Availability			
	Total Days	447		Number of days since system went live.
	Available	422		Offline for several days during the Phase 2 installation.
	Availability	94.4%		Phase 1 had more down time due to troubleshooting tracker field wiring issues.
	1 Year System Availability			
	Total Days	365		
	Available	357		7 days down for Phase 2 construction not counted as down time.
	Annual Availability	97.8%		• Most of this is still due to Phase 1 wiring issues. • 1 day due to the wind storm and installer damage on Phase 2. • 1 day due to troubleshooting the noise complaint on Phase 2.

* This could be due to both annual variation and sensor mounting limitations. Uncertainty of the DNI solar resource in the Meteonorm weather file is around 4%. Due to budget constraints, the NIP used to measure the CPV solar resource was mounted to one the Soliant closed loop CPV trackers. Some minor shading of the sensor may have occurred from fixed objects or neighboring CPV trackers during certain hours. The sensor was located to minimize this affect. The tracker has some minor range of motion limitations (<5 degrees above the horizon) and days when the tracker was offline will also affect the annual total.

Solar resource measurement for typical fixed PV modules requires only a stationary sensor (GHR). These two solar resources vary widely depending on location, climate, and air mass. The Meteonorm file for China Lake, CA, gives an average DNI of 8.50 kWh/m^2/day and an average GHR of 5.92 kWh/m^2/day.

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7.0 COST ASSESSMENT

The total installation cost of this project is $425,267.77 or $8.51/W. A breakdown of the associated costs can be seen below in Table 5.

Table 5. Total installation cost by subcontractor.

Cost Element	Morrow Meadows	Suncore Photovoltaic, Inc.	EAR Management	TOTAL
Solar Installation	$205,383.00	$0.00	$0.00	$205,383.00
Asbestos Remediation	$0.00	$0.00	$14,000.00	$14,000.00
Solar Equipment	$0.00	$205,884.77	$0.00	$205,884.77
TOTAL	**$205,383.00**	**$205,884.77**	**$14,000.00**	**$425,267.77**

The total installation cost was inclusive of an additional $60,136.00 for cost overruns experienced by the solar installer, Morrow Meadows and $14,000.00 for asbestos remediation. The additional time, labor, equipment, and material associated with the project changes were based on the site changes and not originally identified in the project's scope of work or budget.

The installation costs of this project without the additional expenses incurred by the project site changes was $351,131.77 or $7.02/W.

The cost of the demonstration project, which was originally bid in 2010, compared favorably with already mature traditional rooftop systems at that time using polycrystalline PV modules. According to the California Solar Initiative (CSI) in 2010, the average cost of a commercial 40 kW DC system was around $6.16/W DC, and ranged from $4/W DC to $8/W DC as shown below in Figure 13. It should also be noted that the cost of the CPV system is represented by only one sample. With the added benefit of tracking and a temperature coefficient, the CPV system can outperform traditional systems especially in hot desert climates.

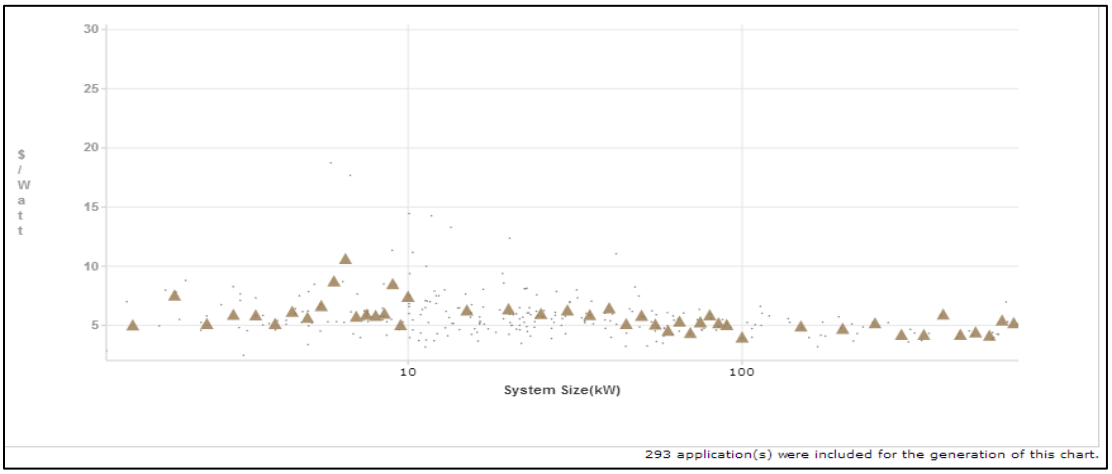

Figure 9. System size versus $/watt from CSI.

Using PVWatts, an online generic production estimator for polycrystalline PV modules, we can simply model a traditional rooftop PV system (fixed mount) located in China Lake, CA, using the same site orientation and system losses, and compare results to the installed CPV system.

A traditional PV system in this location would produce an estimated 3.82 kWh AC/kW DC/day average based on a statistical Meteonorm year. A CPV system using a similar performance model and the same Meteonorm file would produce around 5.06 kWh AC/kW DC/day taking into account that PVWatts only applies to generic PV. The actual annual results for this project indicate that the 4.2 kWh AC/kW DC/day produced is average. This could be due to nearby shading not accounted for in the original model or a deviation of the annual solar resource from the Meteonorm solar resource. The availability of Phase 1 panels was also lower due to installer error and connector/wire harness reliability. Phase 1 represented a "beta" stage CPV product intended to test certain components and assumptions for field reliability. Phase 2 represented the final product with improvements resulting in higher overall reliability in this demonstration product.

7.1 COST MODEL

Please see the cost model below for the installation of the Suncore CPV system, including all of the required cost elements should the technology be installed at another site.

Table 6. Cost model for energy efficiency technology.

Cost Element	Billed	$/Wdc	$/Wdc (43% efficiency)	$/Wdc (typical)	Notes
Mobilization	$2,500	$0.05	$0.05	$0.01	Remote crew required jobsite trailer and several trucks
PV Racking & materials	$37,818	$0.78	$0.78	$0.25	Improvement with integrated racking
Inverters	$19,400	$0.40	$0.40	$0.34	$0.40 is a high retail mark-up from Solar Installer
Balance of System	$12,400	$0.26	$0.26		
DAS	$10,625	$0.22	$0.22		
Other Equipment	$5,500	$0.11	$0.11		
PV Racking Labor	$14,500	$0.30	$0.30	$0.08	***Integrated racking proved a huge savings on this
PV Module Cost	$200,000	$4.12	$3.83	$1.87	Averaged between $1.75 and $2.00 for typical
PV Module Install	$8,500	$0.18	$0.18	$0.13	***Electrical work still needed for modules
DAS Install	$3,200	$0.07	$0.07		
Balance of System Labor	$7,280	$0.15	$0.15		
Direct Job Expenses	$16,124	$0.33	$0.33	$0.01	Remote crew travel, hotel, meals, safety equipment
Management Costs	$6,200	$0.13	$0.13		
Demobilization	$1,200	$0.02	$0.02	$0.02	
Total	**$345,247**	**$7.12***	**$6.83****	**$2.71**	

* The $7.12 estimate is based on the original bid for labor and balance of system provided by the installer assuming a typical rooftop, standard inverter configuration and the geometry of the SE-500X model. "Typical" values for materials are sourced from current commercial distributor pricing, whereas labor is calculated based on observed jobsite man-hours to complete a task. In addition, the added costs of travel, hotel, meals, etc. experienced by the solar installer required for a remote crew are not typical of an installation.

** 40% efficient cells are available today from at least four vendors. Future, higher efficiency cells (43%) would lower the cost of the CPV module and tracker on the $/W scale. This would then affect the LCOE by lowering the turnkey price of the system. For example, a 500W module using 40% efficient cells would then become a 537W module using 43% efficient cells. If both modules were sold for the same price, the 537W modules would see an approximate 7% reduction in $/W.

*** Calculated from measured man-hours using the Soliant 1000 and integrated racking for an entire project of similar size.

DAS = Data Acquisition System

The potential generation capacity/energy savings, if this program was scaled assuming a 500kW system, would be 1,000,000kWh or $130,000 per year.

Future cost reductions can be seen at both the CPV unit level and the system level.

At the CPV module level, cost reduction is driven by improved cell efficiency, lower cost of optical materials, and a learning curve. As the industry progresses down the learning curve, design improvements and shared materials among manufacturers will further lower the material and labor cost.

As detailed in Section 2, improved module efficiency can be observed between the two CPV unit models demonstrated during this project. This is mainly due to improved cell efficiency from around 38% to 40 % over the course of the products development. Today's CPV cell efficiencies have been documented at 43.5%.

At the system level, lowering the installation labor and racking materials costs are the key paths to lowering the system level costs. As installers become familiar with the equipment, the installed labor will also decrease. Installation improvements to the SE-500X, resulting in the Soliant 1000 that were demonstrated in this project include:

1. 33% more modules per tracker resulting in fewer trackers to ship, handle, and install;
2. 50% fewer rail fasteners required, only 2 bolts per 500 W tracker;
3. Self-capturing mounting bracket meaning the tracker can be attached to the rail by one person;
4. Integrated racking meaning the tracker and roof racking are pre-assembled at the factory eliminating the associated material and labor costs associated with 3rd party racking; and
5. 3-Pack lifting, which allows three trackers with integrated racking to be lifted directly from a trailer and placed on the roof.

Improvements not demonstrated included the following:

1. 6-pack lifting and placement;
2. Integrated racking used to support the system on the roof (3rd party rack was already installed for Phase 2 of this installation); and
3. Roof transport cart allowing a single person to transport and install a tracker (two people were previously required for this task on the roof).

7.2 COST DRIVERS

The successful implementation of this technology yields several specific and measurable benefits to the military including: offset energy demand from the grid, on-site renewable energy generation, reduced energy cost, and decreased carbon emissions.

Deployment of Suncore's CPV technology offsets energy demand from the grid and also contributes to a facility's on-site renewable energy generation capabilities. Specific to the areas of the southwest United States identified in Figure 1 above, the demonstrated CPV system provides DoD installations a cost effective, high-efficiency PV solution. The projected LCOE of an installed system is equivalent to current off peak energy costs and substantially less than the peak TOU energy rates experienced by DoD facilities throughout the southwest.

All on-site renewable energy generation from this project directly results in decreased carbon emissions, as the system produces no GHG emissions.

In addition, Electricore was notified that NAWS China Lake was not eligible for any additional solar incentives and could not complete the CSI application with Southern California Edison. NAWS China Lake already has approximately 1.3 megawatts (MW) of solar systems in place and was completing a new power purchase agreement project of 11+ MW PV solar, reaching their incentive limits.

7.3 COST ANALYSIS AND COMPARISON

Table 7 presents projected estimates and actual test results for the technology installed at NAWS China Lake. The cost analysis below assumes DoD would not be entitled to any incentives or tax breaks associated with installing a CPV system. In addition, the Team assumed a 0.7% per year degradation and 98% availability. The analysis below covers 1 full year of system operation.

Table 7. Cost analysis.

Performance Objective	Metric	Data Requirements	Success Criteria	Test Result	Comment
Quantitative Performance Objectives					
Peak Power	kW AC	Power Measurements	≥ 50 kW AC delivered to site	42 kW AC delivered to site	Fewer trackers were installed than originally planned
Annual Energy	kWh	PV energy production measurements	> 100,000 kWh delivered to site	69,693 kWh delivered to site	Annual energy was lower due to reduced name plate and solar resource
Specific Energy	kWh AC/ kW DC	Calculated	2070	1698	
Annual Solar resource	$kWh/m^2/day$	Statistical TMY3 year	8.50 $kWh/m^2/day$ modeled	6.11 $kWh/m^2/day$ measured on site	Measured solar resource was lower than model
GHG Emissions	lbs/yr CO_2 reduced	Inferred from annual energy production	> 117,000 lbs/yr CO_2	81,541 lbs/yr CO_2	
System Availability	% of time available	Site operation data	> 98%	97.8%	
Energy Generation Intensity	$kWh/day/m^2$	Energy production data and footprint for CPV system	> .0035 $kWh/day/m^2$	0.00349 $kWh/day/m^2$	System was installed at 72" rather than 80" spacing to suit building dimensions

Table 7. Cost analysis (continued).

Performance Objective	Metric	Data Requirements	Success Criteria	Test Result	Comment
Installed Cost	$	Hardware and labor expenses	≤ $7.00/W	$8.51/W	Cost overrun experienced by site changes
LCOE	$/kWh	NREL SAM	≤ $0.15/kWh	$0.20/kWh ($0.17/kWh without cost overrun)	Using simple LCOE for 25 years since there are no incentives
Payback	Years	NREL SAM & NIST BLCC *	< 11 years	39 years (32 years without cost overrun)	Jobsite factors out of our control and an expensive installer drove this price up.

One of the most significant changes during the installation phase of this program was the introduction of a new "integrated racking" system for the Soliant 1000 product. The integrated racking system was developed to both lower the installation cost of the Soliant 1000 tracker and eliminate the need for a separate transport cradle.

Under the first installation phase of 25kW of SE-500X panels, the team used a transport cradle that was originally designed to be collapsible on site, returnable, and re-usable. Working prototypes that were made by hand in small volume proved to be a success; the trackers could be safely lifted to the roofs and off loaded with the transport cradle. The cost of the transport cradle was approximately $0.22/W and was designed to be reused at least 50 times. The material cost of the transport cradle amortized over the useful life of the part was then assumed to be in the 0.03 to 0.04 $/W range.

During the product development process of the Soliant 1000, this concept was abandoned due to the added jobsite labor, fuel, and logistics costs required to return the transport cradle to the factory. The integrated racking product was then developed to solve two problems; the transportation cradle and the roof mounting system. The design approach for the integrated racking was to develop a single product that could be used for both purposes. No materials would need to be returned to the factory and no shipping waste materials would be generated/left at the jobsite.

In this process, the tracker and integrated racking remain attached and no additional disassembly or assembly is required. The solar installer would then transport each tracker/racking unit to the desired location on the roof. Only the addition of a roof pad or footing would be required at the proper location to protect the roof from the base of the integrated racking system. The high volume cost of this system was 0.12 to 0.15 $/W and the prototype integrated racking used for this ESTCP demonstration system was around 0.25 $/W. The most drastic savings can be seen in the transportation jobsite labor cost savings.

Under the second installation phase of 25kW of Soliant 1000 panels, the team used the new integrated racking product to transport and carry the trackers directly to the rooftop from a flatbed trailer. However, because the original steel mounting system was already in place from

Phase 1 installation, the integrated racking could not be used to support the system on the roof. For this project, the trackers were removed from the integrated racking system after they were taken to the roof top. They were then placed on the existing steel structure.

Steel versus Integrated Racking Comparison:

- Steel
  - Material cost $0.78/W;
  - Labor costs $0.30 /W; and
  - Tracker labor costs using steel structure $0.18 $/W (lifting and moving trackers were not efficient for this mounting system).
- Integrated Racking
  - Material $0.25/W (in prototype form, $0.15 is production in volume target);
  - Labor $0.08 /W (much less assembly required, handling lifting greatly reduced); and
  - Tracker labor costs using $0.13/W (due to not having to attach trackers in a typical case, electrical work still needed).

8.0 IMPLEMENTATION ISSUES

The bulk of the implementation issues the Electricore Team faced directly related to the facility/demonstration site itself. During the initial phase of the project, several preliminary site selections proved unsuitable for the demonstration due to the lack of structural and electrical drawings for each site. After settling on a demonstration site, the Team also faced a host of additional problems including a request for roof sealant, asbestos in the silver roofing and silver roof mastic, and redesigning the CPV racking structure. These problems resulted in delays to the installation and demonstration timelines, as well as, additional cost to the program.

In addition, the solar manufacturer went through a change in ownership for the division producing the modules being used in this demonstration. The company's offices, staff and manufacturing center was relocated to Irwindale, CA. The change in ownership and location resulted in a delay in the shipment of the Soliant 1000 panels.

As of April 2014, Suncore has closed their California manufacturing facility. For questions or concerns, please contact Jim Foresi for further details (Jim.Foresi@suncoreus.com, phone: 505-323-3429).

On July 28-30, 2014, Suncore representatives visited the facility to conduct repair activities to several system components. The site pyrheliometer was not reporting DNI data to the online DECK monitoring software, but it was immediately noticed that the sensor interface cable was disconnected. How it became unconnected is unknown, but it is a secure threaded connector appropriate for the environment, and the risk of reoccurrence is low.

The north array of Suncore Soliant 1000 panels was operating well, but some small improvements were made to the wire management to secure loose PV and DC supply power cables. All panels are operational, no components were replaced, and no further repairs were required.

A larger number of the south array of SE – 500x panels were found in an idle state and not tracking the sun. These panels are powered by 24V-DC power supplies, and there is a known failure mechanism in which the separation of a 2-piece plastic electrical connector interrupts the 24V power for an entire string of panels. A project had been started in April 2014 to remove these faulty connectors on each panel and replace them with hardwire butt splice connectors encapsulated in two layers of heat shrink insulation to create a more robust connection assembly, but 33 panels still needed to have this connector replacement on the time of the visit. As of July 30, 2014, all connectors have been replaced and all 72 panels are correctly tracking the sun.

The inverters were inspected and a problem was discovered with one of the six, which was reporting a consistent error: "I-max Disturbance." It was determined by SMA that the inverter is faulty and will be replaced under warranty. This faulty inverter will be exchanged for a replacement device at no charge, and the remainder of the warranty eligibility will be transferred to the replacement device.

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9.0 REFERENCES

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APPENDIX A

POINTS OF CONTACT

Point of Contact	Organization	Phone E-Mail	Role In Project
Ms. Deborah Jelen	Electricore, Inc.	(661) 607-0260 jelen@electricore.org	Program Manager
Mr. Doug Podzemny	Suncore Photovoltaics, Inc.	(505) 221-4374 doug.podzemny@suncoreus.com	Solar Provider
Mr. Bob Elson	Morrow Meadows	(909) 594-4161 belson@morrow-meadows.com	Solar Installer
Mr. Harini Goneguntla	EAR Management	(951) 324-8060 hgoneguntla@earmanagement.com	Asbestos Remediation
Dr. Stephen Fallis	NAWS China Lake	(760) 939-2601 stephen.Fallis@navy.mil	DoD Service Liaison
Mr. Sean Halpin	NAWS China Lake	(760) 939-0651 Sean.Halpin@navy.mil	China Lake Energy Manager
Mr. Mark Williams	NAWS China Lake	(760) 939-1251 mark.a.williams20.ctr@navy.mil	China Lake Resource Efficiency Manager

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APPENDIX B

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
12/28/2012	33	126	24.12	1.4	1	
12/29/2012	11	49	24.12	0.4	1	
12/30/2012	11	23	24.12	0.5	1	
12/31/2012	61	152	24.12	2.5	1	
1/1/2013	30	96	24.12	1.3	1	
1/2/2013	77	125	24.12	3.2	1	
1/3/2013	65	172	24.12	2.7	1	
1/4/2013	62	172	24.12	2.6	1	
1/5/2013	53	146	24.12	2.2	1	
1/6/2013	48	102	24.12	2.0	1	
1/7/2013	59	166	24.12	2.5	1	
1/8/2013	63	178	24.12	2.6	1	
1/9/2013	32	119	24.12	1.3	1	
1/10/2013	75	206	24.12	3.1	1	
1/11/2013	72	202	24.12	3.0	1	
1/12/2013	50	202	24.12	2.1	1	
1/13/2013	8	52	24.12	0.3	1	
1/14/2013	72	197	24.12	3.0	1	
1/15/2013	79	228	24.12	3.3	1	
1/16/2013	86	213	24.12	3.6	1	
1/17/2013	67	86	24.12	2.8	1	
1/18/2013	73	206	24.12	3.0	1	
1/19/2013	88	221	24.12	3.6	1	
1/20/2013	89	228	24.12	3.7	1	
1/21/2013	23	236	24.12	1.0	1	
1/22/2013	79	100	24.12	3.3	1	
1/23/2013	-5	0	24.12		0	start-up troubleshooting
1/24/2013	-5	0	24.12		0	start-up troubleshooting
1/25/2013	-5	0	24.12		0	start-up troubleshooting
1/26/2013	51	133	24.12	2.1	1	
1/27/2013	129	302	24.12	5.4	1	
1/28/2013	113	290	24.12	4.7	1	
1/29/2013	80	235	24.12	3.3	1	
1/30/2013	106	270	24.12	4.4	1	
1/31/2013	129	299	24.12	5.4	1	
2/1/2013	110	267	24.12	4.6	1	
2/2/2013	0	13	24.12		0	Generation offline
2/3/2013	133	306	24.12	5.5	1	
2/4/2013	139	323	24.12	5.7	1	
2/5/2013	110	265	24.12	4.6	1	
2/6/2013	127	310	24.12	5.3	1	
2/7/2013	136	322	24.12	5.6	1	
2/8/2013	79	191	24.12	3.3	1	
2/9/2013	135	314	24.12	5.6	1	
2/10/2013	122	276	24.12	5.1	1	

APPENDIX B (continued)

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
2/11/2013	146	336	24.12	6.0	1	
2/12/2013	140	321	24.12	5.8	1	
2/13/2013	150	326	24.12	6.2	1	
2/14/2013	152	329	24.12	6.3	1	
2/15/2013	153	335	24.12	6.4	1	
2/16/2013	79	168	24.12	3.3	1	
2/17/2013	151	335	24.12	6.3	1	
2/18/2013	148	316	24.12	6.1	1	
2/19/2013	38	85	24.12	1.6	1	
2/20/2013	106	239	24.12	4.4	1	
2/21/2013	95	139	24.12	3.9	1	
2/22/2013	140	196	24.12	5.8	1	
2/23/2013	152	310	24.12	6.3	1	
2/24/2013	154	334	24.12	6.4	1	
2/25/2013	132	196	24.12	5.5	1	
2/26/2013	109	68	24.12	4.5	1	
2/27/2013	103	5	24.12	4.3	1	
2/28/2013	87	7	24.12	3.6	1	
3/1/2013	75	9	24.12	3.1	1	
3/2/2013	58	0	24.12	2.4	1	
3/3/2013	59	45	24.12	2.4	1	
3/4/2013	58	11	24.12	2.4	1	
3/5/2013	54	0	24.12		0	Low voltage tracker wiring issue from installer
3/6/2013	32	0	24.12		0	Low voltage tracker wiring issue from installer
3/7/2013	4	0	24.12		0	Low voltage tracker wiring issue from installer
3/8/2013	-5	0	24.12		0	Low voltage tracker wiring issue from installer
3/9/2013	43	0	24.12		0	Low voltage tracker wiring issue from installer
3/10/2013	60	0	24.12		0	Low voltage tracker wiring issue from installer
3/11/2013	116	189	24.12	4.8	1	
3/12/2013	178	364	24.12	7.4	1	
3/13/2013	178	366	24.12	7.4	1	
3/14/2013	145	299	24.12	6.0	1	
3/15/2013	143	282	24.12	5.9	1	
3/16/2013	171	345	24.12	7.1	1	
3/17/2013	159	322	24.12	6.6	1	
3/18/2013	116	233	24.12	4.8	1	
3/19/2013	172	338	24.12	7.1	1	
3/20/2013	-2	10	24.12		0	System offline
3/21/2013	184	368	24.12	7.6	1	
3/22/2013	140	329	24.12	5.8	1	

APPENDIX B (continued)

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
3/23/2013	157	321	24.12	6.5	1	
3/24/2013	178	355	24.12	7.4	1	
3/25/2013	33	71	24.12	1.4	1	
3/26/2013	129	253	24.12	5.3	1	
3/27/2013	147	284	24.12	6.1	1	
3/28/2013	106	201	24.12	4.4	1	
3/29/2013	180	367	24.12	7.5	1	
3/30/2013	158	304	24.12	6.6	1	
3/31/2013	169	334	24.12	7.0	1	
4/1/2013	191	388	24.12	7.9	1	
4/2/2013	178	351	24.12	7.4	1	
4/3/2013	181	360	24.12	7.5	1	
4/4/2013	131	246	24.12	5.4	1	
4/5/2013	128	263	24.12	5.3	1	
4/6/2013	112	215	24.12	4.6	1	
4/7/2013	75	159	24.12	3.1	1	
4/8/2013	103	184	24.12	4.3	1	
4/9/2013	195	387	24.12	8.1	1	
4/10/2013	199	398	24.12	8.2	1	
4/11/2013	183	352	24.12	7.6	1	
4/12/2013	187	370	24.12	7.8	1	
4/13/2013	132	258	24.12	5.5	1	
4/14/2013	185	380	24.12	7.7	1	
4/15/2013	133	401	24.12	5.5	1	
4/16/2013	53	178	24.12	2.2	1	
4/17/2013	138	409	24.12	5.7	1	
4/18/2013	136	406	24.12	5.6	1	
4/19/2013	121	358	24.12	5.0	1	
4/20/2013	127	380	24.12	5.3	1	
4/21/2013	128	383	24.12	5.3	1	
4/22/2013	123	373	24.12	5.1	1	
4/23/2013	122	359	24.12	5.1	1	
4/24/2013	94	281	24.12	3.9	1	
4/25/2013	124	369	24.12	5.1	1	
4/26/2013	126	377	24.12	5.2	1	
4/27/2013	123	372	24.12	5.1	1	
4/28/2013	122	370	24.12	5.1	1	
4/29/2013	124	374	24.12	5.1	1	
4/30/2013	112	333	24.12	4.7	1	
5/1/2013	130	389	24.12	5.4	1	
5/2/2013	136	413	24.12	5.6	1	
5/3/2013	133	411	24.12	5.5	1	
5/4/2013	104	323	24.12	4.3	1	
5/5/2013	7	37	24.12	0.3	1	
5/6/2013	60	192	24.12	2.5	1	
5/7/2013	91	273	24.12	3.8	1	

APPENDIX B (continued)

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
5/8/2013	88	269	24.12	3.7	1	
5/9/2013	17	87	24.12	0.7	1	
5/10/2013	120	363	24.12	5.0	1	
5/11/2013	129	389	24.12	5.3	1	
5/12/2013	130	393	24.12	5.4	1	
5/13/2013	16	74	24.12	0.7	1	
5/14/2013	-2	0	24.12		0	System offline
5/15/2013	115	221	24.12	4.8	1	
5/16/2013	86	163	24.12	3.6	1	
5/17/2013	194	350	24.12	8.0	1	
5/18/2013	200	367	24.12	8.3	1	
5/19/2013	203	383	24.12	8.4	1	
5/20/2013	206	390	24.12	8.5	1	
5/21/2013	90	175	24.12	3.7	1	
5/22/2013	203	386	24.12	8.4	1	
5/23/2013	207	392	24.12	8.6	1	
5/24/2013	197	375	24.12	8.2	1	
5/25/2013	164	359	24.12	6.8	1	
5/26/2013	196	362	24.12	8.1	1	
5/27/2013	146	278	24.12	6.0	1	
5/28/2013	144	318	24.12	6.0	1	
5/29/2013	171	371	24.12	7.1	1	
5/30/2013	171	338	24.12	7.1	1	
5/31/2013	194	375	24.12	8.1	1	
6/1/2013	148	321	24.12	6.1	1	
6/2/2013	69	187	24.12	2.9	1	
6/3/2013	166	327	24.12	6.9	1	
6/4/2013	171	345	24.12	7.1	1	
6/5/2013	182	343	24.12	7.5	1	
6/6/2013	190	354	24.12	7.9	1	
6/7/2013	161	355	24.12	6.7	1	
6/8/2013	162	364	24.12	6.7	1	
6/9/2013	125	266	24.12	5.2	1	
6/10/2013	179	371	24.12	7.4	1	
6/11/2013	158	334	24.12	6.5	1	
6/12/2013	157	317	24.12	6.5	1	
6/13/2013	177	392	24.12	7.3	1	
6/14/2013	176	391	24.12	7.3	1	
6/15/2013	167	382	24.12	6.9	1	
6/16/2013	165	375	24.12	6.9	1	
6/17/2013	-5	0	24.12		0	Construction of phase 2 - not counted for availability
6/18/2013	71	309	24.12		0	Construction of phase 2 - not counted for availability
6/19/2013	72	383	24.12		0	Construction of phase 2 - not counted for availability

APPENDIX B (continued)

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
6/20/2013	61	380	24.12		0	Construction of phase 2 - not counted for availability
6/21/2013	0	363	24.12		0	Construction of phase 2 - not counted for availability
6/22/2013	0	372	24.12		0	Construction of phase 2 - not counted for availability
6/23/2013	0	208	24.12		0	Construction of phase 2 - not counted for availability
6/24/2013	206	204	48.31	4.3	1	
6/25/2013	378	369	48.31	7.8	1	
6/26/2013	367	369	48.31	7.6	1	
6/27/2013	368	367	48.31	7.6	1	
6/28/2013	326	333	48.31	6.8	1	
6/29/2013	292	291	48.31	6.0	1	
6/30/2013	258	261	48.31	5.3	1	
7/1/2013	192	202	48.31	4.0	1	
7/2/2013	-2	0	48.31		0	High wind storm, Grid knocked out
7/3/2013	235	0	48.31	4.9	1	
7/4/2013	260	0	48.31	5.4	1	
7/5/2013	234	0	48.31	4.9	1	
7/6/2013	326	0	48.31	6.7	1	
7/7/2013	317	0	48.31	6.6	1	
7/8/2013	363	0	48.31	7.5	1	
7/9/2013	354	367	48.31	7.3	1	
7/10/2013	19	28	48.31	0.4	1	
7/11/2013	-4	0	48.31		0	System offline
7/12/2013	230	236	48.31	4.8	1	
7/13/2013	360	368	48.31	7.4	1	
7/14/2013	257	258	48.31	5.3	1	
7/15/2013	355	351	48.31	7.3	1	
7/16/2013	360	366	48.31	7.4	1	
7/17/2013	369	380	48.31	7.6	1	
7/18/2013	314	320	48.31	6.5	1	
7/19/2013	262	269	48.31	5.4	1	
7/20/2013	221	217	48.31	4.6	1	
7/21/2013	119	118	48.31	2.5	1	
7/22/2013	127	127	48.31	2.6	1	
7/23/2013	302	298	48.31	6.2	1	
7/24/2013	326	308	48.31	6.7	1	
7/25/2013	330	322	48.31	6.8	1	
7/26/2013	19	27	48.31	0.4	1	
7/27/2013	171	180	48.31	3.5	1	
7/28/2013	185	188	48.31	3.8	1	
7/29/2013	359	364	48.31	7.4	1	
7/30/2013	268	364	48.31	5.5	1	

APPENDIX B (continued)

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
7/31/2013	380	374	48.31	7.9	1	
8/1/2013	383	380	48.31	7.9	1	
8/2/2013	216	215	48.31	4.5	1	
8/3/2013	354	352	48.31	7.3	1	
8/4/2013	363	357	48.31	7.5	1	
8/5/2013	388	384	48.31	8.0	1	
8/6/2013	355	349	48.31	7.4	1	
8/7/2013	387	378	48.31	8.0	1	
8/8/2013	393	386	48.31	8.1	1	
8/9/2013	393	385	48.31	8.1	1	
8/10/2013	381	368	48.31	7.9	1	
8/11/2013	383	372	48.31	7.9	1	
8/12/2013	384	378	48.31	8.0	1	
8/13/2013	384	386	48.31	7.9	1	
8/14/2013	384	384	48.31	8.0	1	
8/15/2013	378	363	48.31	7.8	1	
8/16/2013	375	358	48.31	7.8	1	
8/17/2013	378	366	48.31	7.8	1	
8/18/2013	257	237	48.31	5.3	1	
8/19/2013	215	214	48.31	4.5	1	
8/20/2013	338	341	48.31	7.0	1	
8/21/2013	338	331	48.31	7.0	1	
8/22/2013	356	350	48.31	7.4	1	
8/23/2013	372	376	48.31	7.7	1	
8/24/2013	372	380	48.31	7.7	1	
8/25/2013	368	368	48.31	7.6	1	
8/26/2013	193	193	48.31	4.0	1	
8/27/2013	146	150	48.31	3.0	1	
8/28/2013	355	331	48.31	7.4	1	
8/29/2013	358	342	48.31	7.4	1	
8/30/2013	195	176	48.31	4.0	1	
8/31/2013	278	268	48.31	5.8	1	
9/1/2013	285	275	48.31	5.9	1	
9/2/2013	290	265	48.31	6.0	1	
9/3/2013	313	298	48.31	6.5	1	
9/4/2013	338	329	48.31	7.0	1	
9/5/2013	356	337	48.31	7.4	1	
9/6/2013	356	340	48.31	7.4	1	
9/7/2013	362	347	48.31	7.5	1	
9/8/2013	263	244	48.31	5.4	1	
9/9/2013	304	284	48.31	6.3	1	
9/10/2013	237	217	48.31	4.9	1	
9/11/2013	149	154	48.31	3.1	1	
9/12/2013	293	275	48.31	6.1	1	
9/13/2013	311	288	48.31	6.4	1	
9/14/2013	314	299	48.31	6.5	1	

APPENDIX B (continued)

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
9/15/2013	336	316	48.31	6.9	1	
9/16/2013	350	335	48.31	7.2	1	
9/17/2013	359	346	48.31	7.4	1	
9/18/2013	336	314	48.31	7.0	1	
9/19/2013	339	324	48.31	7.0	1	
9/20/2013	338	321	48.31	7.0	1	
9/21/2013	344	321	48.31	7.1	1	
9/22/2013	353	339	48.31	7.3	1	
9/23/2013	351	339	48.31	7.3	1	
9/24/2013	343	335	48.31	7.1	1	
9/25/2013	341	330	48.31	7.1	1	
9/26/2013	261	278	48.31	5.4	1	
9/27/2013	289	338	48.31	6.0	1	
9/28/2013	282	337	48.31	5.8	1	
9/29/2013	318	333	48.31	6.6	1	
9/30/2013	307	329	48.31	6.3	1	
10/1/2013	297	305	48.31	6.1	1	
10/2/2013	306	293	48.31	6.3	1	
10/3/2013	315	309	48.31	6.5	1	
10/4/2013	293	320	48.31	6.1	1	
10/5/2013	294	326	48.31	6.1	1	
10/6/2013	292	330	48.31	6.0	1	
10/7/2013	113	165	48.31	2.3	1	
10/8/2013	230	305	48.31	4.8	1	
10/9/2013	59	90	48.31	1.2	1	
10/10/2013	223	291	48.31	4.6	1	
10/11/2013	219	289	48.31	4.5	1	
10/12/2013	221	295	48.31	4.6	1	
10/13/2013	205	268	48.31	4.3	1	
10/14/2013	220	295	48.31	4.5	1	
10/15/2013	221	298	48.31	4.6	1	
10/16/2013	221	303	48.31	4.6	1	
10/17/2013	215	295	48.31	4.4	1	
10/18/2013	217	300	48.31	4.5	1	
10/19/2013	216	302	48.31	4.5	1	
10/20/2013	213	299	48.31	4.4	1	
10/21/2013	210	293	48.31	4.3	1	
10/22/2013	205	274	48.31	4.2	1	
10/23/2013	156	222	48.31	3.2	1	
10/24/2013	209	285	48.31	4.3	1	
10/25/2013	201	278	48.31	4.2	1	
10/26/2013	200	278	48.31	4.1	1	
10/27/2013	199	274	48.31	4.1	1	
10/28/2013	143	194	48.31	3.0	1	
10/29/2013	179	237	48.31	3.7	1	
10/30/2013	194	275	48.31	4.0	1	

APPENDIX B (continued)

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
10/31/2013	198	274	48.31	4.1	1	
11/1/2013	193	274	48.31	4.0	1	
11/2/2013	186	261	48.31	3.8	1	
11/3/2013	178	255	48.31	3.7	1	
11/4/2013	148	216	48.31	3.1	1	
11/5/2013	183	266	48.31	3.8	1	
11/6/2013	173	244	48.31	3.6	1	
11/7/2013	122	175	48.31	2.5	1	
11/8/2013	179	259	48.31	3.7	1	
11/9/2013	113	178	48.31	2.3	1	
11/10/2013	172	254	48.31	3.6	1	
11/11/2013	167	249	48.31	3.4	1	
11/12/2013	-5	2	48.31		0	System offline
11/13/2013	167	250	48.31	3.5	1	
11/14/2013	167	246	48.31	3.4	1	
11/15/2013	142	241	48.31	2.9	1	
11/16/2013	97	180	48.31	2.0	1	
11/17/2013	129	221	48.31	2.7	1	
11/18/2013	58	118	48.31	1.2	1	
11/19/2013	38	84	48.31	0.8	1	
11/20/2013	119	211	48.31	2.5	1	
11/21/2013	37	73	48.31	0.8	1	
11/22/2013	-5	0	48.31		0	maintenance - power supply upgrade, general system check
11/23/2013	-5	0	48.31		0	maintenance - power supply upgrade, general system check
11/24/2013	124	241	48.31	2.6	1	
11/25/2013	166	241	48.31	3.4	1	
11/26/2013	101	135	48.31	2.1	1	
11/27/2013	103	128	48.31	2.1	1	
11/28/2013	24	40	48.31	0.5	1	
11/29/2013	11	26	48.31	0.2	1	
11/30/2013	180	240	48.31	3.7	1	
12/1/2013	181	248	48.31	3.7	1	
12/2/2013	160	227	48.31	3.3	1	
12/3/2013	137	172	48.31	2.8	1	
12/4/2013	174	244	48.31	3.6	1	
12/5/2013	169	247	48.31	3.5	1	
12/6/2013	151	209	48.31	3.1	1	
12/7/2013	107	175	48.31	2.2	1	
12/8/2013	112	165	48.31	2.3	1	
12/9/2013	152	252	48.31	3.1	1	
12/10/2013	154	248	48.31	3.2	1	
12/11/2013	145	246	48.31	3.0	1	

APPENDIX B (continued)

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
12/12/2013	137	240	48.31	2.8	1	
12/13/2013	135	244	48.31	2.8	1	
12/14/2013	141	243	48.31	2.9	1	
12/15/2013	136	230	48.31	2.8	1	
12/16/2013	95	161	48.31	2.0	1	
12/17/2013	55	100	48.31	1.1	1	
12/18/2013	-2	12	48.31		0	System offline
12/19/2013	66	105	48.31	1.4	1	
12/20/2013	135	233	48.31	2.8	1	
12/21/2013	135	232	48.31	2.8	1	
12/22/2013	137	231	48.31	2.8	1	
12/23/2013	138	232	48.31	2.9	1	
12/24/2013	132	225	48.31	2.7	1	
12/25/2013	138	241	48.31	2.9	1	
12/26/2013	140	245	48.31	2.9	1	
12/27/2013	119	210	48.31	2.5	1	
12/28/2013	137	237	48.31	2.8	1	
12/29/2013	138	237	48.31	2.8	1	
12/30/2013	127	220	48.31	2.6	1	
12/31/2013	70	108	48.31	1.5	1	
1/1/2014	136	226	48.31	2.8	1	
1/2/2014	141	231	48.31	2.9	1	
1/3/2014	90	141	48.31	1.9	1	
1/4/2014	138	229	48.31	2.9	1	
1/5/2014	146	247	48.31	3.0	1	
1/6/2014	101	163	48.31	2.1	1	
1/7/2014	16	29	48.31	0.3	1	
1/8/2014	134	224	48.31	2.8	1	
1/9/2014	49	93	48.31	1.0	1	
1/10/2014	133	218	48.31	2.7	1	
1/11/2014	83	117	48.31	1.7	1	
1/12/2014	111	174	48.31	2.3	1	
1/13/2014	150	248	48.31	3.1	1	
1/14/2014	152	250	48.31	3.1	1	
1/15/2014	152	250	48.31	3.1	1	
1/16/2014	158	257	48.31	3.3	1	
1/17/2014	156	259	48.31	3.2	1	
1/18/2014	160	258	48.31	3.3	1	
1/19/2014	134	211	48.31	2.8	1	
1/20/2014	157	252	48.31	3.2	1	
1/21/2014	22	44	48.31	0.5	1	
1/22/2014	121	213	48.31	2.5	1	
1/23/2014	117	171	48.31	2.4	1	
1/24/2014	44	82	48.31	0.9	1	
1/25/2014	163	244	48.31	3.4	1	
1/26/2014	5	15	48.31	0.1	1	

APPENDIX B (continued)

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
1/27/2014	132	193	48.31	2.7	1	
1/28/2014	132	195	48.31	2.7	1	
1/29/2014	95	144	48.31	2.0	1	
1/30/2014	49	69	48.31	1.0	1	
1/31/2014	203	220	48.31	4.2	1	
2/1/2014	252	277	48.31	5.2	1	
2/2/2014	51	65	48.31	1.0	1	
2/3/2014	246	259	48.31	5.1	1	
2/4/2014	154	153	48.31	3.2	1	
2/5/2014	231	249	48.31	4.8	1	
2/6/2014	78	78	48.31	1.6	1	
2/7/2014	146	17	48.31	3.0	1	
2/8/2014	178	29	48.31	3.7	1	
2/9/2014	244	24	48.31	5.1	1	
2/10/2014	261	24	48.31	5.4	1	
2/11/2014	239	15	48.31	4.9	1	
2/12/2014	106	14	48.31	2.2	1	
2/13/2014	261	17	48.31	5.4	1	
2/14/2014	221	20	48.31	4.6	1	
2/15/2014	27	23	48.31	0.6	1	
2/16/2014	258	27	48.31	5.3	1	
2/17/2014	224	18	48.31	4.6	1	
2/18/2014	98	17	48.31	2.0	1	
2/19/2014	269	20	48.31	5.6	1	
2/20/2014	142	15	48.31	2.9	1	
2/21/2014	283	16	48.31	5.9	1	
2/22/2014	287	16	48.31	5.9	1	
2/23/2014	279	17	48.31	5.8	1	
2/24/2014	282	17	48.31	5.8	1	
2/25/2014	286	18	48.31	5.9	1	
2/26/2014	95	17	48.31	2.0	1	
2/27/2014	268	28	48.31	5.5	1	
2/28/2014	7	4	48.31	0.1	1	
3/1/2014	12	11	48.31	0.2	1	
3/2/2014	63	12	48.31	1.3	1	
3/3/2014	131	16	48.31	2.7	1	
3/4/2014	74	19	48.31	1.5	1	
3/5/2014	233	21	48.31	4.8	1	
3/6/2014	254	28	48.31	5.3	1	
3/7/2014	286	23	48.31	5.9	1	
3/8/2014	331	19	48.31	6.9	1	
3/9/2014	178	22	48.31	3.7	1	
3/10/2014	244	24	48.31	5.1	1	
3/11/2014	183	19	48.31	3.8	1	
3/12/2014	325	19	48.31	6.7	1	
3/13/2014	180	18	48.31	3.7	1	

APPENDIX B (continued)

SOLAR DATA TABLE

Time	Generation	DNI	Nameplate	kWh AC/ kW DC	Availability	Comment
3/14/2014	328	19	48.31	6.8	1	
3/15/2014	318	21	48.31	6.6	1	
3/16/2014	331	22	48.31	6.8	1	
3/17/2014	73	38	48.31	1.5	1	
3/18/2014	339	19	48.31	7.0	1	
3/19/2014	195	3	48.31	4.0	1	

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ESTCP Office
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605

(571) 372-6565 (Phone)

E-mail: estcp@estcp.org
www.serdp-estcp.org