ESTCP
Cost and Performance Report

(EW-201301)

Soitec 1MW Concentrated Photovoltaic (CPV) Demonstration Projects for On-Site Distributed Power Generation

March 2018

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The Project's objectives were to demonstrate to the Department of Defense (DoD) the reliability and cost-effectiveness of the CPV technology in a harsh desert climate with high Direct Normal Irradiance (DNI, which means direct sunlight) a majority of the year. Additionally, the solar forecasting system, a component of the Project, was intended to produce a direct, measurable benefit to the DoD by providing cost-effective ways to manage and distribute on-site solar generation, resulting in increased energy quality and security.

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ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
BOS	Balance of System
CPV	Concentrating Photovoltaic
CX	Concentrix®
DAM	Day-Ahead Market
DNI	Direct Normal Irradiance
DC	Direct Current
DoD	Department of Defense
EPC	Engineering, Procurement and Construction
ESTCP	Environmental Security Technology Certification Program
IRR	Internal Rate of Return
HASP	Hour-Ahead Scheduling Process
kW	Kilowatt
kWh	Kilowatt Hour
kWp	Kilowatt Peak
m	Meter(s)
MW	Megawatt
MWh	Megawatt Hour(s)
MV	Medium-Voltage
NAVFAC	Naval Facilities
NEM	Net Metering
NREL	National Renewable Energy Laboratory
O&M	Operations and Maintenance
PPA	Power Purchase Agreement
PV	Photovoltaic
RTD	Real-Time Dispatch
SCA	Solar Cell Assembly
SDG&E	San Diego Gas and Electric
STACE	Saint-Augustin Canada Electric Inc.

TCU	Tracker Control Unit
UCSD	University of California at San Diego

ACKNOWLEDGEMENTS

Soitec would like to acknowledge the following individuals and organizations that contributed to this demonstration and this report. Point of contact information is provided in Appendix A.

Fort Irwin Military Installation –Mr. Muhammed Bari, Mr. Christopher Sayer, Mr. Christopher Woodruff, Mr. William Schaefer

University of California San Diego (UCSD) – Mr. Carlos Coimbra, Mr. Hugo Pedro

National Renewable Energy Laboratories (NREL) – Ms. Sarah Kurtz, Mr. Matthew Muller, Mr. Chris Deline

Soitec Solar – Mr. Marc Jeanson, Mr. Clark Crawford

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EXECUTIVE SUMMARY

Soitec constructed a one (1) MW_{AC} power plant ("Project") at the U.S. Army's installation at Fort Irwin, California, to demonstrate the Concentrix® (CX) concentrating photovoltaic (CPV) technology and address the Environmental Security Technology Certification Program's (ESTCP's) objective of cost effective on-site distributed energy generation. The Project employed forty (40) Soitec CX-S530 CPV systems and included third party performance validation by the National Renewable Energy Laboratory (NREL) and solar forecasting development expertise by the University of California at San Diego (UCSD). The data collection and observation period ran from 28 July 2015 to 28 July 2017 (24 months).

CPV technology converts sunlight into electricity with state-of-the-art Fresnel silicone on glass lenses concentrating sunlight onto high performance multi-junction solar cells. The modules are mounted on dual axis trackers that follow the sun's trajectory throughout the day. Fresnel lenses concentrate the sun by a factor of approximately 500 onto a small solar cell, thereby reducing the size and amount of costly cell material required.

The Project's objectives were to demonstrate to the Department of Defense (DoD) the reliability and cost-effectiveness of the CPV technology in a harsh desert climate with high Direct Normal Irradiance (DNI, which means direct sunlight) a majority of the year. Additionally, the solar forecasting system, a component of the Project, was intended to produce a direct, measurable benefit to the DoD by providing cost-effective ways to manage and distribute on-site solar generation, resulting in increased energy quality and security.

Specific demonstration objectives and results are show in Table 1, below.

Table ES1. Executive Summary of Performance Objectives and Results

Performance Objectives	Metric	Success Criteria	Met Objective?
1. Technology Installation Time	Number of days needed to install and commission the CPV systems.	Two systems per day	**YES**
2. Preventive Operations and Maintenance (O&M) Labor	Cumulative number of man-hours	$\leq$ one man-hour annually per CPV System	**NO**
3. Reactive O&M Labor	Cumulative number of man-hours	$\leq$ two man-hours annually per CPV System	**NO**
4. Energy Model Validation	Energy produced (MWh or kWh generated by the power plant and the CPV systems).	Within 2% of baseline model or expected value	**YES**
5. CPV Power Plant Availability	Energy produced (MWh or kWh) and system downtimes and failures.	Power plant availability is greater than 98%	**NO**
6. Long Term Performance Degradation	Energy produced (MWh or kWh generated by the power plant and the CPV systems)	Power output change after two years of operations is within measurement accuracy	**YES**

IMPLEMENTATION ISSUES

Soitec has found most end-user concerns with CPV revolved around the financeability of the CPV technology. These concerns are categorized as:

1) **Dual-axis drive.** The drive unit, though composed of a standard housing, slewing rings, worm gearing, reduction gearboxes and alternating current (AC) motors, was a source of end-user concern. Major worries were how the drive would handle the large tracker loads (especially during wind or seismic events), if the drive's precision would support the exact pointing requirements of the CPV tracker (especially over time as the gear teeth experienced wear), and the general lifecycle of the drive.

2) **Soitec's Long-Term Viability.** End users, developers and investors were concerned about what would happen if Soitec went bankrupt or abandoned its solar business.

3) **Equipment and Implementation Costs.** Equipment costs for this Project were over $1.20/watt. During the same time period, conventional PV module efficiency rose moderately and prices fell precipitously. Support technologies, such as 3rd party single-axis trackers and inverters have seen a shakeout in the industry, with quality rising and prices falling.

4) **Operations and Maintenance (O&M) Costs.** End-users were concerned at the lack of real O&M cost data, realizing that the CPV technology was unproven and could require intensive preventive and reactive maintenance over the life of the plant.

5) **Lack of Commercialization of CPV System Components.** At the time of construction of the DoD Fort Irwin project, the Soitec Bill of Materials were a combination of standard commercial off-the-shelf items, custom-built parts, or newly commercialized parts.

In 2015, Soitec announced its exit of the solar business and began the divestiture process. In late 2016, Soitec sold its CPV technology to Saint-Augustin Canada Electric Inc. (STACE), a world-class supplier of large electrical equipment in the power generation industry. With this acquisition, STACE became the technological leader of the CPV industry and stated it would continue to improve the technology and maintain the collaboration with the recognized Fraunhofer Institute for Solar Energy Systems ISE, based in Freiburg, Germany.

1.0 INTRODUCTION

1.1 BACKGROUND

Soitec constructed a one (1) MW_{AC} power plant (“Project”) at the U.S. Army’s installation at Fort Irwin, California, to demonstrate the Concentrix® (CX) concentrating photovoltaic (CPV) technology and address the Environmental Security Technology Certification Program’s (ESTCP’s) objective of cost effective on-site distributed energy generation. The Project employed forty (40) Soitec CX-S530 CPV systems, which represented the fifth generation of Soitec’s CPV technology and included third party performance validation by the National Renewable Energy Laboratory (NREL) and solar forecasting development expertise by the University of California at San Diego (UCSD). The demonstration period ran from 28 July 2015 to 28 July 2017 (24 months).

1.2 OBJECTIVES OF THE DEMONSTRATION

The Project’s objectives were to demonstrate to the Department of Defense (DoD) the reliability and cost-effectiveness of the CPV technology in a harsh desert climate with high Direct Normal Irradiance (DNI, which means direct sunlight) a majority of the year. Additionally, the solar forecasting system, a component of the Project, was intended to produce a direct, measurable benefit to the DoD by providing cost-effective ways to manage and distribute on-site solar generation, resulting in increased energy quality and security. Specific objectives and results are shown in Table 1.

Table 1. Performance Objectives and Results

Performance Objectives	Metric	Success Criteria	Met Objective?
1. Technology Installation Time	Number of days needed to install and commission the CPV systems.	Two systems per day	**YES**
2. Preventive Operations and Maintenance (O&M) Labor	Cumulative number of man-hours	$\leq$ one man-hour annually per CPV System	**NO**
3. Reactive O&M Labor	Cumulative number of man-hours	$\leq$ two man-hours annually per CPV System	**NO**
4. Energy Model Validation	Energy produced (MWh or kWh generated by the power plant and the CPV systems).	Within 2% of baseline model or expected value	**YES**
5. CPV Power Plant Availability	Energy produced (MWh or kWh) and system downtimes and failures.	Power plant availability is greater than 98%	**NO**
6. Long Term Performance Degradation	Energy produced (MWh or kWh generated by the power plant and the CPV systems)	Power output change after two years of operations is within measurement accuracy	**YES**

1.3 REGULATORY DRIVERS

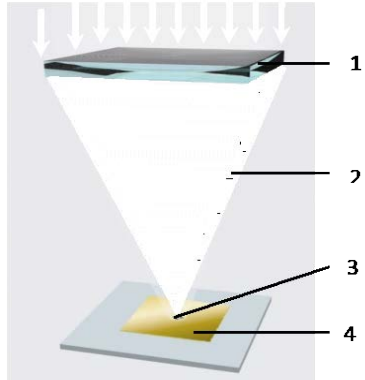
San Diego Gas and Electric (SDG&E), in its "Net Metering 2.0" model, recently shifted its peak hours from 11 AM – 6 PM to 4 PM – 9 PM[1]. This is a result of plentiful renewable power in the old peak hours. The new peak hours reflect the changing energy markets and capture a portion of daylight hours when conventional PV power production has decreased significantly or stopped completely during sunset hours. CPV more closely matches matching peak load demands than conventional PV. CPV ramps up early in the morning and, more importantly, produces more energy in typical peak demand periods when conventional PV ramps down production.

[1] Robert Walton. 2017. California regulators propose shifting peak period for SDG&E TOU rates. Utility Dive. Online.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

As shown on **Error! Reference source not found.**, Soitec's CX CPV technology converts sunlight into electricity with state-of-the-art Fresnel silicone on glass lenses, concentrating sunlight onto high performance multi-junction solar cells. The modules are mounted on dual axis trackers that follow the sun's trajectory throughout the day. Fresnel lenses concentrate the sun by a factor of approximately 500 onto a small solar cell, thereby reducing the size and amount of costly solar cell material required.



1. Silicone on glass Fresnel lens
2. Concentrated light
3. Multi-junction III-V solar cell
4. Heat spreader

Figure 1. Concentrator Photovoltaic Solar Cell Assembly (SCA)

The design and layout of the CPV system is displayed in Section 5.3. Prior to the field demonstration, the CX CPV (formerly termed FLATCON) technology had been developed by the Fraunhofer Institute for over 10 years and had been field tested since 2005, with commercial power plants in operation since 2008. Evolutionary improvements over time included increased concentration ratios, reduced cell material, less expensive materials, less redundancy, increased module efficiency/size, and increased tracker size to strike a balance between material requirements and installation cost.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.2.1 Advantages

CPV competes with conventional crystalline-silicon PV systems to produce energy from utility power plant installations. Due to the fact that CPV uses dual-axis tracking, the electricity produced by CPV technology is consistently high in high-DNI regions (>1800 kWh/m^2). CPV more closely matches peak load demands than conventional PV.

2.2.2 Limitations

As with any technology CPV has limitations and constraints, some of which have been addressed during this demonstration:

1. CPV experiences more significant energy fluctuations based on cloud cover vs. conventional PV.
2. High wind events limit energy production due to the wind stow function.
3. Excessive rocky soil or sloped sites may limit economical foundation options.
4. CPV capital expenditure and operational expenditure costs are higher than those of conventional photovoltaic solar technology. This is discussed in more detail in Section 7.
5. Many CPV providers have departed the business or have declared insolvency.

6. There is a current lack of government policy supporting CPV Technology.
7. There is difficulty overcoming the more established photovoltaic solar technology and industry.
8. There remains a lack of familiarity of financial institutions about CPV, resulting in limited financing options for CPV power plant projects.
9. Additional implementation challenges are discussed in Section 8.

3.0 PERFORMANCE OBJECTIVES

3.1 SUMMARY OF CPV SYSTEM PERFORMANCE OBJECTIVES

Performance objectives for the CPV technology's installation, O&M, energy production, availability and performance degradation are summarized in Table 2. Soitec has provided a broad overview of the test design and data analysis to provide insight into the methodology.

Table 2. Performance Objectives Summary Table

Performance Objectives	Metric	Data Requirements	Success Criteria	Results
1. Technology Installation Time	Number of days needed to install and commission the CPV systems.	Time studies of the installation from construction start to commissioning completion.	$\geq$ Two systems per day.	**MET OBJECTIVE** 2.9 systems per day
2. Preventive O&M Labor	Cumulative number of man-hours needed to perform annual preventive maintenance.	Maintenance logbook of the different maintenance activities.	$\leq$ one man-hours per CPV System annually.	**DID NOT MEET OBJECTIVE** 154 hours, which is 1.93 man-hour per CPV system annually.
3. Reactive O&M Labor	Cumulative number of man-hours needed to perform annual reactive maintenance.	Event and maintenance logbook of the different activities required to repair equipment in the field.	$\leq$ two man-hours per CPV system annually.	**DID NOT MEET OBJECTIVE** 393 hours, which is 4.92 man-hours per CPV system annually.
4. Energy Model Validation	Energy produced (MWh or kWh).	Meter readings of energy produced by installation and CPV systems.	Within 2% of baseline model or expected value	**MET OBJECTIVE** 99% (within 1% of expected)
5. CPV Power Plant Availability	Energy produced (MWh or kWh) and system downtimes and failures.	Meter readings of energy and status of main power plant equipment	Power plant availability is greater than 98%	**DID NOT MEET OBJECTIVE** CPV System 96.3%. Power Plant availability 95.6%.
6. Long Term Performance Degradation	Energy produced (MWh or kWh)	Meter readings of energy produced by CPV systems.	Power output change after 24 month operation is within measurement accuracy	**MET OBJECTIVE** Improved 1.6% (within %5 measurement accuracy)

Note: No Solar Forecasting performance objective is included in Table 2, however, a Performance Objective for Solar Forecasting is discussed below in Paragraph 3.2.

3.2 SOLAR FORECASTING PERFORMANCE OBJECTIVE

Purpose: With future incorporation of the CPV power plant and the Solar Forecasting System into an on-base grid management system, optimal plant operation (storage dispatch, curtailment, demand response, etc.) could be further achieved and potentially enable the effective capture of demand related savings.

Metric: The metric used for this assessment was the forecasting skill(s) developed by the UCSD team. When the variable *s* is equal to the number one (1) this means that the solar irradiance or solar power output is perfectly forecasted. When *s* is equal to zero (0) the forecast error is as large as the variability.

The metric *s* is defined as the ratio:

$$s = \frac{V - U}{V} = 1 - \left(\frac{U}{V}\right)$$

where uncertainty *U* is defined as the standard deviation of a model's forecast error divided by the estimated clear sky solar irradiance I_{clr} over a subset time window of N_w data points. The solar irradiance variability *V* is represented by the standard deviation of the step-changes of the ratio of the measured solar irradiance to that of I_{clr}.

Data: The quality and accuracy of the forecast provided by UCSD was monitored and documented using DNI and CPV tracker power data from the Project.

Success Criteria: The forecasting component of this project was to be considered a success if the target values in Table 3 were achieved.

Table 3. Forecast Performance of Current Techniques versus Target Values at the End of the Project by Time Horizon

Horizon	**< 1 hr (RTD[1])**	**1 hr (HASP[2])**	**1-6 hrs**	**24-36 hrs (DAM[3])**	**>36 hrs**
Averaging period	1 min	5 min	15 min	1 h	1 d
Current *s*	0.12-0.32	0.15-0.29	0.08-0.14	0.08-0.39	0.19
Target *s*	0.25-0.45	0.40	0.30	0.30	0.40

Result: Results are shown below in Table 4. For shorter time horizons the targeted forecasting skills were not fully achieved. However the obtained values are in agreement with the best performing forecasting models published in current literature[2]. For the forecast time window 1-6 hours, the Result s (DNI) of 0.25 to 0.39 (average of 0.32) exceeded the Target s of 0.30, meaning the average accuracy of the DNI forecast exceeded the target. With respect to longer horizons the demonstration exceeded the targets. More detail on the results can be found in Section 6.6.

[2] J. Antonanzas, N. Osorio, R. Escobar, R. Urraca, F. J. Martinez-de Pison, and F. Antonanzas-Torres. 2016. Review of Photovoltaic Power Forecasting. Solar Energy. 136:78–111.

Table 4. Forecast performance result values at the end of the project

Horizon	< 1 hr (RTD)	1 hr (HASP)	1-6 hrs	24-36 hrs (DAM)	>36 hrs
Averaging period	1 min	5 min	15 min	1 h	1 d
Result *s (DNI)*	0.24-0.32	0.24-0.32	0.25-0.39	0.34	0.41
Success Criteria Met?	No	No	Yes	Yes	Yes

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4.0 SITE DESCRIPTION

4.1 FACILITY / SITE LOCATION AND OPERATIONS

After evaluating DoD installations that meet the project criteria of a minimum average daily DNI of 6.0 kWh/m^2, Soitec located the solar power plant at the Fort Irwin Military Installation in San Bernardino County, California. Soitec used approximately 6 acres of land of the Fort Irwin National Training Center, CA (Department of Army). Fort Irwin is located roughly halfway between Las Vegas, NV and Los Angeles, CA. The project site is located on Goldstone Road, approximately 1 mile from the center of the Fort Irwin cantonment area.

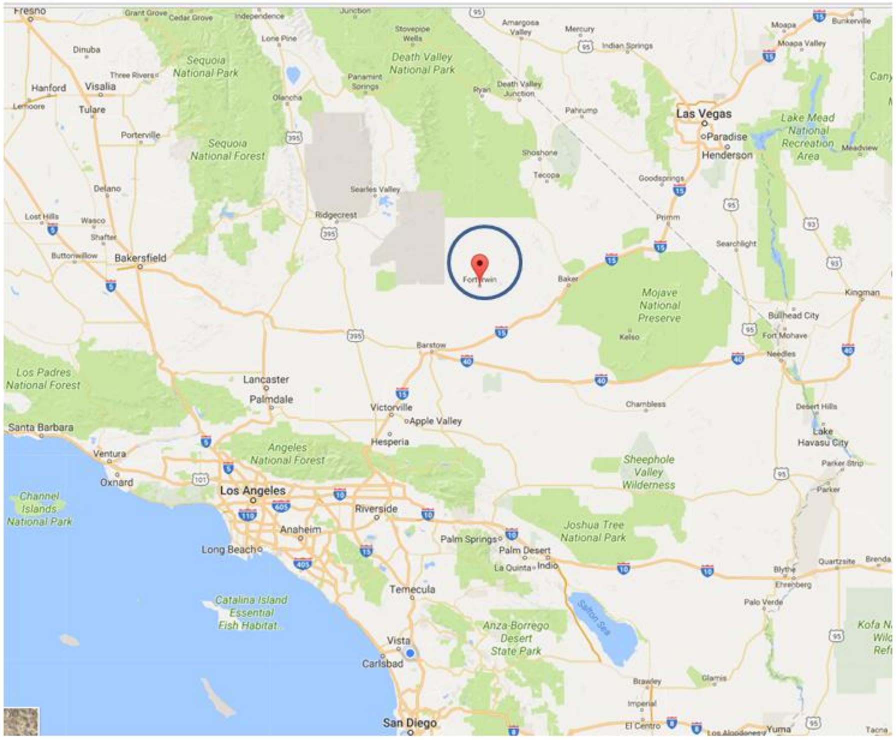

Figure 2. Fort Irwin National Training Center Location in California

4.2 FACILITY/SITE CONDITIONS

The location is representative of arid desert environments in which CPV technology performs at the highest level.

Figure 3. CPV Plant at Fort Irwin

5.0 TEST DESIGN

The broad technical approach of the proposed project was comprised of five activities:

1) Site-specific system.
2) System construction, installation and commissioning
3) System operation and maintenance
4) System performance monitoring and validation
5) Deployment of solar DNI forecasting

5.1 CONCEPTUAL TEST DESIGN

The primary scope of work involved the installation of a CPV demonstration power plant at Fort Irwin, followed by the monitoring and reporting of the operations and energy production at this plant.

a) Soitec recorded system assembly and installation times in the field using a dedicated manager witnessing crew assembly and commissioning times.
b) Soitec recorded measurements of energy and energy production performance using direct current (DC) energy meters in the control units of each tracker.
c) Soitec logged O&M activities by on-site personnel entering their activities into a Computerized Maintenance Management System.
d) UCSD provided solar forecasting services for the Project.
e) NREL provided independent monitoring and validation services over the duration of the Project.

5.2 BASELINE CHARACTERIZATION

Baseline characteristics for each of the performance objectives were as follows:

Table 5. Baseline Characteristics for Each Performance Objective

Performance Objectives	Metric	Baseline
1. Technology Installation Time	Number of days needed to install and commission the CPV systems	CPV systems were previously installed one system every two days
2. Preventive O&M Labor	Cumulative number of man-hours needed to perform annual preventive maintenance	Not applicable, due to a lack of recorded and available data for a CPV power plant of this size and location
3. Reactive O&M Labor	Cumulative number of man-hours needed to perform annual reactive maintenance	Not applicable, due to a lack of recorded and available data for a CPV power plant of this size and location
4. Energy Model Validation	Energy produced (MWh or kWh generated by the power plant and the CPV systems)	Performance Index for Soitec's power plants had been proven to be up to 106.2% over 4 years[3]
5. CPV Power Plant Availability	Energy produced (MWh or kWh) and system downtimes and failures	Availability for Soitec's power plants had been proven to be up to 98.8% over 4 years[4]
6. Long Term Performance Degradation	Energy produced (MWh or kWh generated by the power plant and the CPV systems)	No discernible degradation over 7 years using modules with similar components and technology[5]

[3] Ibid.
[4] Ibid.
[5] Andreas Gombert. 2015. Soitec's Concentrator Photovoltaic (CPV) Long-Term and Large-Scale Track Record. Soitec Corporate Presentation pg. 19.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

5.3.1 CPV Module

At the heart of the system is the M-500 CPV module, which has the following specifications:

- Dimensions: 12.0 ft x 7.84 ft x 0.335 ft
- Characteristics:
  - 2,400 SCAs
    - 12 sub-modules with 200 SCAs each
  - One air tube inlet and one outlet valve
  - One junction box located on short edge

Figure 4. Soitec M-500 CPV Module

5.3.2 Dual-Axis CX-S530 Tracker

The CX-S530 main components are grouped into parts and named as follows:

- Thirty Stringers (1)
- Two Main tubes (2)
- One dual-axis drive (3)
  - Elevation gear reduction box and motor (5)
  - Azimuth gear reduction box and motor (4)
- Twelve ribs (6)
- One Air Drying Unit (7)
- One Tracker Control Unit (TCU) (8)

The tracker has the following specifications:

- Dimensions: 47.9 ft x 24.7 ft
- Aperture: 110 m^2
- Two-axis tracking, rotational elevation
- Mast height above ground: 12ft

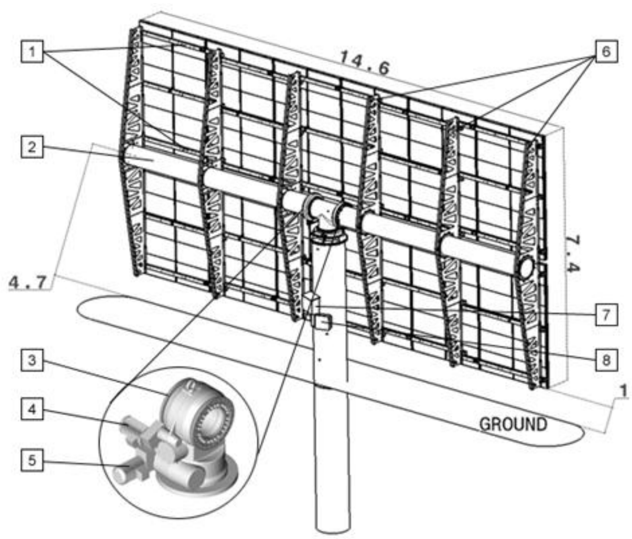

Figure 5. Soitec CX-S530 Tracker

5.3.3 Balance of System

The Balance of System (BOS) of the power plant is the electrical collection system, which collects the DC power produced by each of the trackers and transports it to the power conversion station, also known as the inverter station. The inverter station converts the DC electrical power to AC electrical power and a transformer increases the voltage to medium-voltage (MV) AC electrical power. Additional electrical collection equipment transports the AC power to the substation, or energy delivery point, where another transformer increases the MV AC power to high-voltage AC power.

At that point, the electrical power is placed on the transmission or distribution lines of the utility grid, whereupon it is a commodity ready for use. The 1MW Fort Irwin CPV Plant featured forty (40) CPV Systems around a central inverter station containing 2 AE 500TX (500kW) inverters.

5.4 OPERATIONAL TESTING

Phase I of the project was the project development and permitting by Soitec and the physical construction by an Engineering, Procurement and Construction (EPC) contractor under Soitec's supervision. Soitec evaluated and confirmed the tracker assembly process.

Phase 2 of the project was the operational data gathering and analysis of the power plant's performance. During this phase, Soitec evaluated and confirmed O&M costs, total energy and power production, system degradation and solar forecasting accuracy.

Phase 3 of the project was the final report development and transfer of the property (power plant) over to the host site, Fort Irwin National Training Center.

The phases are shown below in a Gantt chart format (Figure 6).

	Task Name	Duration	Cal Days Start	Cal Days Fin	Start	Finish
	Milestone Summary Schedule	**1300 dys**	**0**	**0**	**Fri 6/28/13**	**Fri 6/22/18**
	Milestone 1:Submit Table 1, Performance Objectives and Demonstration Plan	1 dy	-447	-446	Fri 6/28/13	Fri 6/28/13
	Milestone 2: Long Lead Time Equipment Ordered	1 dy	-414	-413	Wed 7/31/13	Wed 7/31/13
	Milestone 3: Q1 Report	1 dy	-322	-321	Thu 10/31/13	Thu 10/31/13
	Milestone 4: Development Design Completed and Submitted	0 dys	0	0	Thu 9/18/14	Thu 9/18/14
Phase 1	Milestone 5: Materials and Equipment Needed For Installation on Site	0 dys	85	85	Fri 12/12/14	Fri 12/12/14
	Milestone 6: Q2 Report and Site Preparations	0 dys	113	113	Fri 1/9/15	Fri 1/9/15
	Milestone 7 (Equipment Installation and Certification Underway)	0 dys	145	145	Mon 2/9/15	Mon 2/9/15
	Milestone 8: Metering Equipment Installed and Operational	0 dys	285	285	Tue 6/30/15	Tue 6/30/15
	Milestone 9: Q3 Report and Project Inspected, Approved and Commissioned	0 dys	313	313	Tue 7/28/15	Tue 7/28/15
	Milestone 10: Q4 Report	0 dys	-49	-49	Thu 7/31/14	Thu 7/31/14
	Milestone 11: Q5 Report; Six Months of Operation Demonstrated and Raw Data Monitoring	0 dys	134	134	Fri 1/30/15	Fri 1/30/15
	Milestone 12: Q6 Report	0 dys	134	134	Fri 1/30/15	Fri 1/30/15
	Millestone 13: Q7 Report	0 dys	224	224	Thu 4/30/15	Thu 4/30/15
	Milestone 14: Q8 Report	0 dys	316	316	Fri 7/31/15	Fri 7/31/15
Phase 2	Milestone15: Q9 Report	0 dys	407	407	Fri 10/30/15	Fri 10/30/15
	Milestone 16: Q10 Report	0 dys	498	498	Fri 1/29/16	Fri 1/29/16
	Milestone 17: Q11 Report	0 dys	680	680	Fri 7/29/16	Fri 7/29/16
	Demonstration 50% Complete	0 dys	651	651	Wed 6/29/16	Wed 6/29/16
	Demonstration 75% Complete	0 dys	819	819	Wed 12/14/16	Wed 12/14/16
	Demonstration Complete and Initiate Property Transfer	0 dys	1015	1015	Wed 6/28/17	Wed 6/28/17
	Milestone 18: Submit Draft Final, Cost and Performance Report	0 dys	1184	1184	Fri 12/15/17	Fri 12/15/17
	Receive Final Report & C&P Report Comments	0 dys	1222	1222	Mon 1/22/18	Mon 1/22/18
Phase 3	Submit Revised Final Report	0 dys	1248	1248	Fri 2/16/18	Fri 2/16/18
	Milestone 19: Q12 Report and Receive Final Report Approval, C&P Report Approval	0 dys	1276	1276	Fri 3/16/18	Fri 3/16/18
	Property Transfer Complete to Fort Irwin	0 dys	1373	1373	Fri 6/22/18	Fri 6/22/18

Figure 6. Fort Irwin 1MW CPV Project Phase Gantt Chart

5.5 SAMPLING PROTOCOL

The sampling protocol for each performance objective is listed in Table 6.

Table 6. Sample Collection Approach for Each Performance Objective

Performance Objectives	Sample Descriptions	# of Samples	Type of Samples	Methodology	QA Sampling	Calibration
1. Technology Installation Time	Number of trackers completed per day	40	Number of trackers completed per day	Dedicated on-site project manager data collection	Project management supervision	N/A
2. Preventive O&M Labor	Cumulative number of man-hours	Multiple	Hourly logs	Maintenance logbook entries	Maintenance supervision	N/A
3. Reactive O&M Labor	Cumulative number of man-hours	Multiple	Hourly logs	Maintenance logbook entries	Maintenance supervision	N/A
4. Energy Model Validation	Energy produced (MWh or kWh)	Multiple	DC meter readings of energy produced	See details below	Cleaning of DNI sensors	Calibration of DNI sensors
5. CPV Power Plant Availability	Energy produced (MWh or kWh) and system downtimes and failures.	Multiple	DC meter readings of energy produced	See details below	Cleaning of DNI sensors	Calibration of DNI sensors
6. Long Term Performance Degradation	Energy produced (MWh or kWh)	Multiple	DC meter readings of energy produced.	See details below	Cleaning of DNI sensors	Calibration of DNI sensors

5.6 SAMPLING RESULTS, EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES

During the demonstration, there were a few instances of data unavailability. In most cases, engineering, separate observations/studies and assumptions were used to supplement the findings and overcome the data unavailability.

Issue: Inverter Meter Data.

Discussion: Soitec planned to record AC power data from the Shark 200 inverter meters; however, due to meter compatibility issues with the IT system, AC Power data was not collected.

Solution: Soitec used the DC energy data from the CPV Systems in all calculations and analysis. This type of data is commonly used for CPV performance analysis and supporting calculations.

Issue: Missing O&M Recorded Hours

Discussion: Soitec technicians failed to record all O&M data from approximately October 2016 to February 2017 (5 months).

Solution: Soitec assumed certain CPV System and BOS reactive and preventive maintenance hours would have been consistent with the remainder of the performance period and factored these estimated hours into the calculations.

Issue: Half the CPV System's Energy Measured by TCU DC Energy Meter

Discussion: Only six (6) CPV modules (half of the twelve total modules on the CPV System) are connected to the TCUs so as to not exceed their NEC code current constraints. Therefore, the DC meters only measure half of the energy produced by the tracker.

Solution: On December 17, 2015 Soitec IT made a software change to double the measured energy from each CPV System. Prior to this date, the DC energy was recorded as measured. The change assumes that each half of the CPV System (6 modules) are performing exactly the same as the other. To obtain consistent data throughout the demonstration, DNV multiplied the energy measured prior to December 17, 2015 by a factor of two (2).

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6.0 PERFORMANCE ASSESSMENT

6.1 PERFORMANCE OBJECTIVE 1: TECHNOLOGY INSTALLATION TIME

MET OBJECTIVE. Tracker assembly and installation averaged **3.33/day**. When combining the commissioning rate this would result in an overall time (start to finish) of 14 days, yielding **2.9 trackers/ day.**

6.2 PERFORMANCE OBJECTIVES 2 AND 3: PREVENTIVE AND REACTIVE O&M LABOR

Preventive Maintenance **– DID NOT MEET OBJECTIVE**. Preventive maintenance over two years consumed 154 hours, which is 1.93 man-hours per CPV system annually.

Reactive maintenance **– DID NOT MEET OBJECTIVE**. Reactive maintenance over two years was 393 hours, which is 4.92 man-hours per CPV system annually.

6.3 PERFORMANCE OBJECTIVE 4: ENERGY MODEL VALIDATION

MET OBJECTIVE. The performance assessment was performed by DNV-GL and confirms that the Soitec CPV Systems did generally perform as predicted. The completed PVSyst prediction that was completed at the beginning of the test was modified to reflect the weather data measured during the two years of the project, as variability of the weather adds complexity to any solar-related performance assessment. DNV GL compared actual energy production with expected production as predicted using measured weather as input to the PVsyst performance simulation model supplied by Soitec.

6.4 PERFORMANCE OBJECTIVE 5: CPV POWER PLANT AVAILABILITY

DID NOT MEET OBJECTIVE. The overall Power Plant Availability was 95.6% and the CPV System Availability was 96.3%, which did not meet the availability target of 98%.

6.5 PERFORMANCE OBJECTIVE 6: LONG TERM PERFORMANCE DEGRADATION

MET OBJECTIVE. Performance actually appeared to improve by 1.6%, which is within the estimated 5% uncertainty of the performance index.

For short term module degradation caused by soiling, Soitec was not able to conduct module washings at the Fort Irwin CPV plant due to resource shortages. However, Soitec did conduct intensive soiling studies at a 1.5 MW CPV Power plant in Newberry Springs, CA[6]. Newberry Solar 1 is about 70 miles south of Fort Irwin and is also located in the Mojave Desert with approximately the same atmospheric conditions. Soitec conducted the soiling analysis at Newberry over the time span March 18th – April 14th 2014 to determine the monthly soiling loss factor for financing a larger CPV project and concluded the energy gained by cleaning the CPV Systems was not worth the cost in manpower and equipment. Soitec also concluded that the short-term degradation due to soiling does not require a cleaning frequency less than once every six weeks.

[6] Newberry Soiling Analysis March 18th to April 14th 2014. Internal Presentation, Soitec Solar Energy Business Unit.

6.6 SOLAR FORECASTING PERFORMANCE OBJECTIVE

Success Criteria: The forecasting component of this project was to be considered a success if the target values in Table 7 were achieved.

Table 7. Forecast Performance of Current Techniques versus Target Values at the End of the Project by Time Horizon[7]

Horizon	< 1 hr (RTD)	1 hr (HASP)	1-6 hrs	24-36 hrs (DAM)	>36 hrs
Averaging period	1 min	5 min	15 min	1 h	1 d
Current *s*	0.12-0.32	0.15-0.29	0.08-0.14	0.08-0.39	0.19
Target *s*	0.25-0.45	0.40	0.30	0.30	0.40

Result: Results are shown in Table 8. For shorter time horizons (<1 hr. and 1 hr. forecast time window), the targeted forecasting skills were not fully achieved since the Result *s* was not higher than the Target *s*. This means that the accuracy of the forecast (an *s* value closer to 1 is more accurate) did not meet the target accuracy. Seventy to seventy-five percent of the time the forecast values were innacurate and the actual DNI and Power values did not match the forecasted DNI and Power values. However, the obtained values are in agreement with the best performing forecasting models published in current literature[8]. The results of the effort show the great difficulty in forecasting short-term DNI from on-site sky camera data due to nature of rapidly changing atmospheric conditions and the relatively limited camera field of view.

With respect to longer horizons the demonstration met or exceeded the target values. For the forecast time window 1-6 hours, the Result s (DNI) of 0.25 to 0.39 (average of 0.32) exceeded the Target s of 0.30, meaning the average accuracy of the DNI forecast improved over two times the baseline level and exceeded the target accuracy. The forecast time window 24-36 hours ahead saw the greatest increase in accuracy with a Result s (DNI) of 0.34 which exceeded the Target s of 0.30. The forecast accuracy of the 48 hours (>36 hours) ahead forecast time window doubled during this exercise, just exceeding the target of 0.40, meaning 41% of the time the forecasts were accurate.

Improvements in accuracy forecasts for longer intra-day (1-6 hours) and day(s)-ahead horizons were greater as these forecasts incorporated satellite images and national cloud cover forecasts versus only sky images from on-site cameras. The cloud cover information contained within the on-site camera images is good for not much more than an hour and is a very weak predictor of conditions for the next day.

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[7] Note the current and project values of forecast skill in the table above also increase with the averaging period. For example, 24-36 hour forecasts are hourly averages while the 1-6 hour forecasts have 15-minute resolution. This and the decrease in accuracy of the reference (persistence) causes the 24-36 hour forecast to have higher skills.

[8] J. Antonanzas, N. Osorio, R. Escobar, R. Urraca, F. J. Martinez-de Pison, and F. Antonanzas-Torres. 2016. Review of Photovoltaic Power Forecasting. Solar Energy. 136:78–111.

The 24 to 36-hour and the 48 hour forecasts are important for regulating entities and independent system operators whose job is to schedule resources ahead of time to balance electric grids.

Table 8. Forecast Performance Result Values at the End of the Project

Horizon	**< 1 hr (RTD)**	**1 hr (HASP)**	**1-6 hrs**	**24-36 hrs (DAM)**	**>36 hrs**
Averaging period	1 min	5 min	15 min	1 h	1 d
Result *s (DNI)*	0.24-0.32	0.24-0.32	0.25-0.39	0.34	.41
Result s (PO)	0.24-0.32	0.20-0.24	0.17-0.35	0.38	.43
Success Criteria Met?	No	No	Yes	Yes	Yes

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7.0 COST ASSESSMENT

Soitec performed this section with knowledge of Fort Irwin's cost and internal corporate knowledge of cost proposals for larger CPV plants that were never constructed due to lack of financing. These cost proposals were in the final stages in 2014/2015 and should serve as a reliable estimate. Soitec also relied upon employee knowledge of conventional PV costs from the experience within that industry and from recent online research. However, it is important to note that these are only reasonable estimates. Soitec has not been active in securing better pricing from suppliers nor reducing installation costs since early 2015, due to Soitec's decision to depart from the solar business.

7.1 COST MODEL

In Table 9 below, Soitec has provided a simple cost model for the 1MW CPV System at Fort Irwin.

Table 9. 1MW CPV Demonstration System (Fort Irwin) Cost Table

DESCRIPTION	% of Total	Cost	Cost/ watt
Mobilization	4.09%	$ 97,070	$ 0.09
Site Logistics	3.84%	$ 91,174	$ 0.08
Site Grading and Trenching	2.98%	$ 70,673	$ 0.06
Tracker Assembly Area Grading	2.08%	$ 49,331	$ 0.04
Access Road	2.44%	$ 57,862	$ 0.05
Construction Entrance	1.56%	$ 37,105	$ 0.03
Dust control	3.12%	$ 73,935	$ 0.07
Erosion Contrl	1.60%	$ 38,052	$ 0.03
Seeding	1.32%	$ 31,415	$ 0.03
Fencing and Gate	4.76%	$ 112,848	$ 0.10
Security and Lighting	4.06%	$ 96,226	$ 0.09
Drive Piers/Masts	1.96%	$ 46,403	$ 0.04
Surveys	0.38%	$ 9,080	$ 0.01
Water Supply Equipment (Tank, etc.)	0.34%	$ 7,991	$ 0.01
Fire Control Equipment	0.25%	$ 5,902	$ 0.01
Backup Generator	0.77%	$ 18,161	$ 0.02
DC Cabling and Hardware	8.82%	$ 209,179	$ 0.19
Inverter Installation	15.68%	$ 372,076	$ 0.33
AC Cable and Hardware	5.05%	$ 119,694	$ 0.11
SCADA/Panel Installation	1.83%	$ 43,519	$ 0.04
Tracker Assembly	3.27%	$ 77,509	$ 0.07
Tracker Installation	2.68%	$ 63,529	$ 0.06
Tracker Terminations	0.32%	$ 7,607	$ 0.01
Tracker Commissioning	0.81%	$ 19,274	$ 0.02
Indirect Cost	26.00%	$ 616,783	$ 0.55
Insurance, Contingency, Bonding, OH&P	INCLUDED IN PRICE BREAKDOWN		
EPC Total		**$ 2,372,400**	**$ 2.12**
Non-DOD reduction (%)			
Substation and Gen-Tie	18.25%	$ 433,000	**$ 0.39**
Subtotal		**$ 2,805,400**	**$ 2.50**
BOM Cost		$ 1,346,429	$ 1.20
Owner PM		$ 104,566	$ 0.09
TOTAL Construction Cost		**$ 4,256,395**	**$ 3.80**
Engineering Cost		$ 150,000	$ 0.13
Development and Land Cost		$ 233,667	$ 0.21
Subtotal		**$ 4,640,062**	**$ 4.14**
ESTCP Pre-Construction Compliance (Legal)		$ 82,743	$ 0.07
Total Cost		**$ 4,722,805**	**$ 4.22**

In Section 7.3, these costs will serve as the basis of a lifecycle cost analysis.

7.2 COST DRIVERS

Soitec has listed and described below some of the major cost drivers of this project, as well as anticipated cost drivers that should be considered when selecting the technology for future implementation.

7.2.1 CPV System Costs

The cost of manufacturing CPV components is still higher than conventional flat plate technology, due to a lack of high volume manufacturing of CPV components needed to achieve economies of scale and cost competitiveness with conventional flat plate solar. Conventional PV single-axis tracker prices are at $0.10 to $0.21/watt[9], while conventional crystalline-silicone PV solar panels are dipping to $0.35/watt at the factory gate to $0.40 to $0.53/watt cost to integrators[10].

7.2.2 CPV Installation Costs

CPV installation costs are typically higher than conventional PV due to several reasons. First, assembly and installation requires heavy crane equipment as the tracker tables with modules weigh approximately 16,000 lbs and must be mounted on an 11' mast. Second, Soitec and the CPV industry as a whole have not had the opportunity to invest in automated equipment on a large scale because the majority of CPV power plant sizes have been relatively small. Third, the solar industry has engineered out installation costs and has gained vast experience in conventional PV installation. Fourth, the masts (or piers) required to support the massive tracker tables must be either driven or vibrated into the ground with large, custom equipment or require massive amounts of excavation and concrete for foundations. In contrast, there are hundreds of specialized pier-driving machines and experienced operators for conventional PV piers.

7.2.3 Shipping, Handling and Treatment Costs

CPV modules weigh approximately 500 lbs each, making them more expensive to ship and handle. They require forklifts and special attachments to move and install each module on site. By comparison, conventional CPV modules are distributed throughout the construction site in stacks of 30-40 modules each, then installed by hand on trackers.

7.2.4 O&M Costs

Soitec researched industry publications for O&M costs and found:

- Single-axis conventional PV O&M costs are 10-20% higher than fix-tilt arrays[11].

[9] Ran Fu, David Feldman, Robert Margolis, Mike Woodhouse, and Kristen Ardani. 2017. U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017. National Renewable Energy Laboratory (NREL), pg. 35.
[10] Ibid, pgs. 13- 19.
[11] Charles W. Thurston. 2016. Trackers Thaw Solar Freeze. PV Magazine, Issue 10-2016. Online.

- Smaller systems (<1MW) can be 2-4x more expensive to maintain compared to large sites (≥10MW)[12]. For purposes of this report, Soitec assumes a 30% increase in O&M costs for a small conventional PV power plant.
- Due to the size of the CPV System components and complexities involved with dual-axis tracking, Soitec estimates the O&M costs for CPV dual-axis CPV Systems are at least 20-30% higher than single-axis conventional PV. This is due to increased equipment requirements, technology complexity and washing and maintenance requirements.

Figure 7 validates this, showing CPV estimated O&M costs to the right of the graph, approximately 21% higher than crystalline silicone PV.

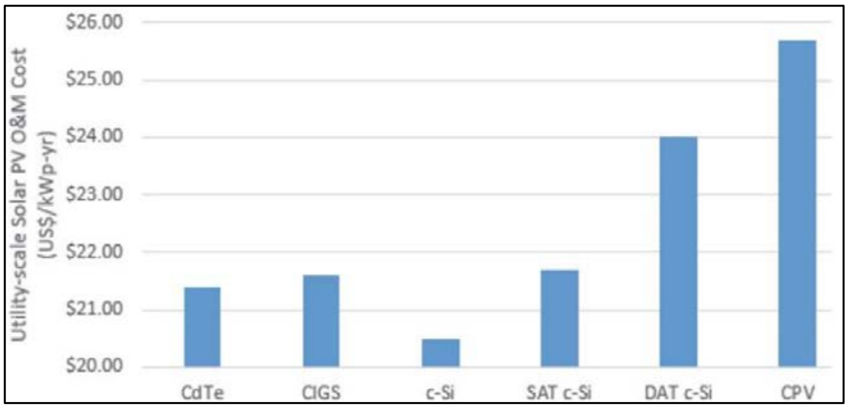

Figure 7. O&M Average Costs 2015[13]

7.2.5 Performance Costs

CPV modules are more efficient than conventional PV modules. However, CPV modules produce energy only during periods with DNI. High wind events and heavy clouds will cause CPV power production to go to zero. Conventional single-axis PV trackers will continue producing power, albeit at a reduced level, during these events.

7.3 COST ANALYSIS AND COMPARISON

Soitec included project development costs, equipment/BOM costs, installation costs and O&M costs when developing the CPV lifecycle cost analysis. For the conventional PV comparison, Soitec considered single-axis crystalline-silicon PV, not fixed tilt PV. A tilted single axis tracking system provides energy gains in the range of 30-40% compared to a tilted fixed PV panel[14] and 20+% for non-tilted panel[15].

[12] Nadav Enbar, Dean Weng, Geoff Klise. 2015. Budgeting for Solar PV Plant Operations and Maintenance: Practices and Pricing. EPRI/Sandia National Laboratories Report, pg.10.
[13] Ibid.
[14] S. P. Singh, K. Srikant and K. S. Jairaj. 2017. Performance Comparison and Cost Analysis of Single Axis Tracking and Fixed Tilt PV Systems. School of Energy and Environmental Studies, Devi Ahilya University, pg. 6.
[15] Thurston, Online.

7.3.1 Installation Cost Exclusions

Certain installation costs were excluded from the cost analysis, such as location and/or demolition of any existing site or underground utilities, concrete footings for masts/piers, removal/abatement of any hazardous materials, perimeter fencing, accelerated schedule, excessive storm drainage facilities, paved permanent access, upgrades of existing utility or meter equipment, annual SCADA/DAS monitoring agreement subscription costs, and payment and performance bonds.

7.3.2 Installation Cost Assumptions

Assumptions for the cost analysis were driven mast/pier installation only, workmanship guarantees of two (2) years from the Substantial Completion Date, direct-buried, aluminum cable, use of native soil for all backfill with no required import or export of soils, non-union work, no prevailing wages and the use of on-site water source for dust control.

7.3.3 Lifecycle Cost Approach

Soitec used historical project development costs in the lifecycle cost model, such as permitting (Major Use Permit, costs of supporting studies, surveys and reports), Interconnection Agreement costs, costs of supporting studies, surveys and reports, Power Purchase Agreement (PPA) costs and fees, legal fees, consultant costs, real estate fees and engineering costs to support project development efforts. Project development costs typical add $0.03 to $0.12/watt to the cost of the project, depending on the size of the project and the situation[16]. They would be approximately similar for CPV or conventional PV.

Project pre-construction costs would include engineering and value engineering costs, more detailed soils analysis, site plan approvals and building permits, purchase of long-lead items (e.g., main transformers, gen-tie poles/towers), and contract development costs.

The majority of installation costs involve payments to an EPC company which fills the role of a general contractor. This is normally the majority of the project's capital expenditure. For this lifecycle cost analysis, Soitec assumed that some major BOS component costs (inverters, cabling) would be borne by the EPC while modules and trackers would be provided by the Owner.

A factor for the difference in EPC costs on a conventional commercial PV plant versus CPV is that over ten years of intense competition and the increase in number of specialized vendors who have honed techniques and prices on conventional utility-scale PV power plants have driven PV pricing down dramatically. The most significant shift in pricing has been with conventional PV module manufacturers. According to NREL, average module prices were ~\$0.40 per $watt_{dc}$ during Q1 2017[17]. Average single-axis tracker structure pricing is \$0.15/$watt_{dc}$[18]. Inverter manufacturers have developed larger inverters that do not require expensive climate-controlled enclosures or shade structures and have dropped prices dramatically with foreign labor and simplified designs, down to \$0.06 to \$0.08/$watt_{dc}$[19].

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[16] Fu, pg. 39.
[17] Ibid.
[18] Ibid.
[19] Ibid.

Both installation costs and solar component costs have fallen at consistent rates, leading to overall lower costs for conventional PV plants. The average price of a 100MW single-axis tracker project in Q1 2017 is about $1.05 per watt[20]; however, this is an average price and will generally be higher for power plants under 10-20MW, where indirect costs are spread out over more MW. Soitec estimates that a 1MW conventional PV plant would cost between $1.28 and $1.35/watt. Smaller plants cost more because generally the same permits must be obtained, the same designs must be engineered, fees and taxes must be paid and the EPC's general conditions (trailers, life support, etc.) are more expensive per watt.

Installations requiring prevailing wage, such as on DoD installation, easily adds 10-25% to the EPC's overall cost[21]. Therefore, Soitec estimates a 1MW conventional PV plant on a DoD installation would cost between $1.60 to $1.70/watt.

7.3.4 Annual O&M costs.

Soitec calculates that annual O&M costs for the Fort Irwin 1MW CPV project are $25.76/kW$_{dc}$-yr or $28.85/kW$_{ac}$-yr, which is approximately 14% higher than the $22.10/kW-yr for a small conventional single-axis PV plant[22]. Some of the cost impact assumptions in this case are the lack of warranties on the Fort Irwin power plant equipment, response distance to the site (50 miles for a contract O&M employee for a typical O&M company under contract), 10 hour workdays (2 hours overtime) due to the remote location and base access requirements, travel costs (service truck maintenance and mileage), two module cleanings per year, $25/hour labor, 23 year project life (25-year PPA minus 2 years already operated), and no full-time site personnel

In general, for 1 MW+ systems, preventive maintenance consumes 70-85% of available budget while 15%-30% is allocated to reactive maintenance[23]. However, Figure 8 shows the O&M category breakdown for the 1MW Fort Irwin CPV plant and reactive maintenance is unusually high in comparison to preventive maintenance. This is due to the unique requirements and complexities of the dual axis CPV System. It will be crucial to reduce this cost category in order to be competitive in the future.

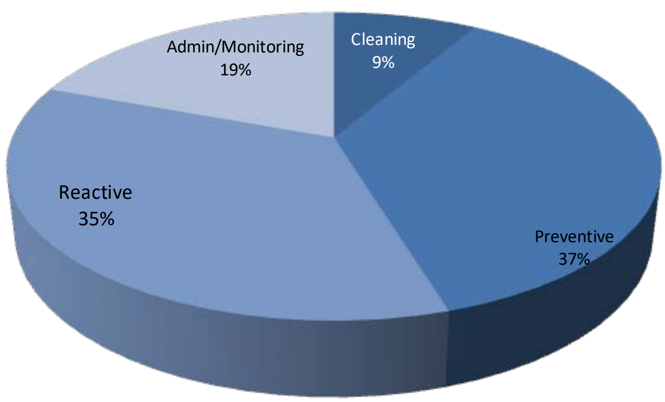

Figure 8. DoD Irwin CPV Power Plant O&M Cost Category Breakdown

[20] Ibid, pg 38.
[21] Ibid.
[22] Ibid, pg. 42.
[23] Enbar, pg.12.

For a typical 1MW CPV power plant (non-DoD installation) in 2017, Soitec estimates annual O&M costs would reduce somewhat to \$24.29/kW$_{dc}$-yr or \$27.21/kW$_{ac}$-yr due to a five-year inverter warranty, 10-year module warranty, 2-year general plant equipment workmanship warranty, and a 25-year project lifecycle.

Reasons for the difference between CPV and conventional PV O&M costs include simplicity of PV equipment, fewer module cleanings, and a robust personnel and logistics pool geared to the conventional PV industry.

See Table 10 for a breakdown of costs.

Table 10. Cost Estimate for Various Sizes of CPV and Conventional PV Power Plants

Scenario	1. 2015 Fort Irwin CPV		2: 2017 1MW DOD CPV		3. 2017 1MW CPV (non-DOD)		4. 2017 20MW CPV		5. 2017 1MW PV		6. 2017 20MW PV	
DESCRIPTION	**Cost**	**Cost/ watt**	**Cost**	**Cost/ watt**	**Cost**	**Cost/ watt**	**Cost**	**Cost/watt**	**Cost**	**Cost/watt**		
Mobilization	$ 97,070	$ 0.09	$ 77,656	$ 0.06	$ 77,656	$ 0.06	$ 517,705	$ 0.02	$ 54,359	$ 0.04	$ 388,278	$ 0.014
Site Logistics	$ 91,174	$ 0.08	$ 72,939	$ 0.05	$ 72,939	$ 0.05	$ 486,262	$ 0.02	$ 51,058	$ 0.04	$ 486,262	$ 0.018
Site Grading and Trenching	$ 70,673	$ 0.06	$ 49,471	$ 0.04	$ 49,471	$ 0.04	$ 659,615	$ 0.02	$ 49,471	$ 0.04	$ 659,615	$ 0.024
Tracker Assembly Area Grading	$ 49,331	$ 0.04	$ 34,532	$ 0.03	$ 34,532	$ 0.03	$ 230,214	$ 0.01	$ 3,453	$ 0.00	$ 46,043	$ 0.002
Access Road	$ 57,862	$ 0.05	$ 46,290	$ 0.03	$ 46,290	$ 0.03	$ 617,198	$ 0.02	$ 46,290	$ 0.03	$ 617,198	$ 0.023
Construction Entrance	$ 37,105	$ 0.03	$ 35,250	$ 0.03	$ 35,250	$ 0.03	$ 176,251	$ 0.01	$ 35,250	$ 0.03	$ 176,251	$ 0.006
Dust control	$ 73,935	$ 0.07	$ 59,148	$ 0.04	$ 59,148	$ 0.04	$ 591,481	$ 0.02	$ 59,148	$ 0.04	$ 591,481	$ 0.022
Erosion Contrl	$ 38,052	$ 0.03	$ 26,636	$ 0.02	$ 26,636	$ 0.02	$ 133,182	$ 0.00	$ 26,636	$ 0.02	$ 133,182	$ 0.005
Seeding	$ 31,415	$ 0.03	$ 21,990	$ 0.02	$ 21,990	$ 0.02	$ 109,952	$ 0.00	$ 21,990	$ 0.02	$ 109,952	$ 0.004
Fencing and Gate	$ 112,848	$ 0.10	$ 95,921	$ 0.07	$ 95,921	$ 0.07	$ 479,605	$ 0.02	$ 95,921	$ 0.07	$ 479,605	$ 0.018
Security and Lighting	$ 96,226	$ 0.09	$ 81,792	$ 0.06	$ 81,792	$ 0.06	$ 408,960	$ 0.02	$ 81,792	$ 0.06	$ 408,960	$ 0.015
Drive Piers/Masts	$ 46,403	$ 0.04	$ 46,403	$ 0.03	$ 46,403	$ 0.03	$ 928,053	$ 0.03	$ 23,201	$ 0.02	$ 403,501	$ 0.015
Surveys	$ 9,080	$ 0.01	$ 9,080	$ 0.01	$ 9,080	$ 0.01	$ 45,402	$ 0.00	$ 9,080	$ 0.01	$ 45,402	$ 0.002
Water Supply Equipment (Tank, etc.)	$ 7,991	$ 0.01	$ 7,991	$ 0.01	$ 7,991	$ 0.01	$ 39,954	$ 0.00	$ 7,991	$ 0.01	$ 39,954	$ 0.001
Fire Control Equipment	$ 5,902	$ 0.01	$ 5,902	$ 0.00	$ 5,902	$ 0.00	$ 30,000	$ 0.00	$ 5,902	$ 0.00	$ 30,000	$ 0.001
Backup Generator	$ 18,161	$ 0.02	$ 18,161	$ 0.01	$ 18,161	$ 0.01	$ 181,608	$ 0.01	$ -	$ -		$ -
DC Cabling and Hardware	$ 209,179	$ 0.19	$ 125,508	$ 0.09	$ 125,508	$ 0.09	$ 2,510,152	$ 0.09	$ 100,406	$ 0.07	$ 2,510,152	$ 0.092
Inverter Installation	$ 372,076	$ 0.33	$ 148,830	$ 0.11	$ 148,830	$ 0.11	$ 2,480,508	$ 0.09	$ 148,830	$ 0.11	$ 2,480,508	$ 0.091
AC Cable and Hardware	$ 119,694	$ 0.11	$ 71,817	$ 0.05	$ 71,817	$ 0.05	$ 1,436,333	$ 0.05	$ 57,453	$ 0.04	$ 1,436,333	$ 0.053
SCADA/Panel Installation	$ 43,519	$ 0.04	$ 34,815	$ 0.03	$ 34,815	$ 0.03	$ 174,077	$ 0.01	$ 34,815	$ 0.03	$ 174,077	$ 0.006
Tracker Assembly	$ 77,509	$ 0.07	$ 54,256	$ 0.04	$ 54,256	$ 0.04	$ 1,085,127	$ 0.04	$ 32,554	$ 0.02	$ 361,709	$ 0.013
Tracker Installation	$ 63,529	$ 0.06	$ 44,470	$ 0.03	$ 44,470	$ 0.03	$ 889,401	$ 0.03	$ 26,682	$ 0.02	$ 296,467	$ 0.011
Tracker Terminations	$ 7,607	$ 0.01	$ 5,325	$ 0.00	$ 5,325	$ 0.00	$ 106,498	$ 0.00	$ 3,195	$ 0.00	$ 26,624	$ 0.001
Tracker Commissioning	$ 19,274	$ 0.02	$ 13,492	$ 0.01	$ 13,492	$ 0.01	$ 269,842	$ 0.01	$ 8,095	$ 0.01	$ 89,947	$ 0.003
Indirect Cost	$ 616,783	$ 0.55	$ 462,587	$ 0.34	$ 462,587	$ 0.34	$ 1,541,957	$ 0.06	$ 370,070	$ 0.27	$ 1,541,957	$ 0.057
Insurance, Contingency, Bonding, OH&P	INCLUDED		INCLUDED		INCLUDED		INCLUDED		INCLUDED		INCLUDED	
EPC Total	**$ 2,372,400**	**$ 2.12**	**$ 1,650,263**	**$ 1.21**	**$ 1,650,263**	**$ 1.21**	**$ 16,129,335**	**$ 0.59**	**$ 1,353,644**	**$ 1.00**	**$ 13,533,458**	**$ 0.50**
Non-DOD reduction (%)				**$ -**	**10%**	**$ 0.00**	**10%**		**10%**		**10%**	
				$ -	**$ 1,485,237**	**$ 1.09**	**$ 14,516,401**	**$ 0.53**	**$ 1,218,280**	**$ 0.90**	**$ 12,180,112**	**$ 0.45**
Substation and Gen-Tie	$ 433,000	**$ 0.39**	$ 433,000	**$ 0.32**	$ 300,000	$ 0.22	$ 900,000	$ 0.03	$ 300,000	$ 0.22	$ 900,000	$ 0.03
Subtotal	**$ 2,805,400**	**$ 2.50**	**$ 2,083,263**	**$ 1.53**	**$ 1,785,237**	**$ 1.31**	**$ 15,416,401**	**$ 0.57**	**$ 1,518,280**	**$ 1.12**	**$ 13,080,112**	**$ 0.48**
BOM Cost	$ 1,346,429	$ 1.20	$ 1,360,000	$ 1.00	$ 1,360,000	$ 1.00	$ 27,200,000	$ 1.00	$ 752,857	$ 0.55	$ 15,057,143	$ 0.55
Owner PM	$ 104,566	$ 0.09	$ 104,566	$ 0.08	$ 50,000	$ 0.04	$ 500,000	$ 0.02	$ 50,000	$ 0.04	$ 500,000	$ 0.02
TOTAL Construction Cost	**$ 4,256,395**	**$ 3.80**	**$ 3,547,829**	**$ 2.61**	**$ 3,195,237**	**$ 2.35**	**$ 43,116,401**	**$ 1.59**	**$ 2,321,137**	**$ 1.71**	**$ 28,637,255**	**$ 1.05**
Engineering Cost	$ 150,000	$ 0.13	$ 150,000.00	$ 0.11	$ 150,000	$ 0.11	$ 600,000	$ 0.02	$ 150,000	$ 0.11	$ 600,000	$ 0.02
Development and Land Cost	$ 233,667	$ 0.21	$ 233,667	$ 0.17	$ 250,000	$ 0.18	$ 1,400,000	$ 0.05	$ 250,000	$ 0.18	$ 1,400,000	$ 0.05
Subtotal	**$ 4,640,062**	**$ 4.14**	**$ 3,931,496**	**$ 2.89**	**$ 3,595,237**	**$ 2.64**	**$ 45,116,401**	**$ 1.66**	**$ 2,721,137**	**$ 2.00**	**$ 30,637,255**	**$ 1.13**
ESTCP Pre-Construction Compliance (Legal)	$ 82,743	$ 0.07	$ 82,743	$ 0.06	0	$ -	0	$ -		$ -	$ -	$ -
Total Cost	**$ 4,722,805**	**$ 4.22**	**$ 4,014,239**	**$ 2.95**	**$ 3,595,237**	**$ 2.64**	**$ 45,116,401**	**$ 1.66**	**$ 2,721,137**	**$ 2.00**	**$ 30,637,255**	**$ 1.13**
System Cost (Total Cost - Development Cost)		$ 4.01		$ 2.78		$ 2.46		$ 1.61		$ 1.82		$ 1.07
O&M Cost	$ 25.76		$ 24.29		$ 24.29		$ 17.00		$ 22.10		$ 17.00	

7.3.5 Lifecycle Cost Analysis

Soitec calculated the lifecycle cost of California CPV and PV power plants of various sizes, both on DoD installations and for a typical non-DoD Independent Power Producer. The scenarios are as follows:

1) DoD Irwin 1MW CPV (2015 installation)
2) DoD 1MW CPV (2017 installation)
3) Non-DoD 1MW CPV (2017 installation)
4) Non-DoD 20MW CPV (2017 installation)

5) Non-DoD 1MW Conventional PV (2017 installation)
6) Non-DoD 20MW Conventional PV (2017 installation)

For all scenarios, Soitec used the following assumptions:

Table 11. Lifecycle Cost Assumptions

$70/MWh peak PPA, $40 off-peak PPA price	2.2% discount rate during operations
25 year system lifetime	Depreciation 90% - five year MACRS 5% - fifteen year MACRS 0% - twenty year MACRS 5% – fifteen year S/L 0% - twenty year S/L
30% Investment Tax Credit	8.25% state tax rate
5% residual value	35% federal tax rate
$0.025/w inverter major repair cost after 13 years	2% annual escalator
3% discount rate during construction	2,269 kWh/kWp ratio
32% on-peak production	Land cost of $5,000/acre., considering 8 acres/MW
0.7% CPVmodule degradation rate[24]	0.4% PVmodule degradation rate[25]

For the 2017 1MW and 20 MW installations, Soitec used a 1.36 DC/AC ratio instead of the 1.12 DC/AC ratio for the DoD Irwin project. This is a more efficient DC/AC ratio. The Fort Irwin DC/AC ratio was due to contract constraints at the time.

Table 12. Lifecycle Cost Analysis

Scenario	1	2	3	4	5	6
LCC Input/ Assumption Description	**DOD Irwin 1MW CPV**	**2017 1MW DOD CPV**	**2017 1MW CPV (non-DOD)**	**2017 20MW CPV**	**2017 1MW PV**	**2017 20MW PV**
System Size (MW DC)	1.12	1.36	1.36	27.20	1.36	27.20
System Cost ($/w dc)	$ 4.01	$ 2.78	$ 2.46	$ 1.61	$ 1.82	$ 1.07
O&M Costs ($/kWh)	$ 25.76	$ 24.29	$ 24.29	$ 17.00	$ 22.10	$ 17.00
Development Cost ($/w d	$ 0.21	$ 0.17	$ 0.18	$ 0.05	$ 0.18	$ 0.05
Annual Module Degradati	0.70%	0.70%	0.70%	0.70%	0.40%	0.40%
NPV ($)	($1,209,031)	($722,237)	($564,671)	$4,000,723	($119,781)	$10,997,870
IRR (%)	-2.61%	-0.97%	-0.51%	3.54%	1.51%	7.00%
Payback Period (years)	40	40	40	14	20	10

[24] Soitec CPV Module CX-M500 Product and Performance Limited Warranty. 2013. Soitec Solar GmbH Corporate Document.
[25] SunPower Limited Product and Power Warranty for PV Modules. 2012. Sunpower Document#: 503170 Rev A. Online.

The lifecycle cost analysis results in Table 12 show that CPV power plants of any size today would have great difficulty getting financed due to the low internal rate of return (IRR) that is driven by the high construction and operating costs. The IRR, as defined by Investopedia, measures "the profitability of potential investments. IRR is a discount rate that makes the net present value of all cash flows from a particular project equal to zero". Developers and investors look for a minimum of 7-8% IRR for solar power plants. Even small conventional PV power plants present a financing challenge and would have to be supplied with higher PPAs and/or other financial incentives to provide an attractive IRR. At the 20MW size, using the constraints and settings of this model, conventional PV power plants start to become attractive in terms of IRR. In summary, much progress needs to be made on closing the gap between CPV construction and operating costs and conventional PV construction and operating costs in order for CPV technology to be considered for future solar power plants.

8.0 IMPLEMENTATION ISSUES

In addition to the limitations of CPV technology discussed in Section 2.1.2, Soitec has found most end-user concerns revolved around the financeability of the CPV technology. These concerns are categorized as such:

8.1 DUAL-AXIS DRIVE

The drive unit, though composed of a standard housing, slewing rings, worm gearing, reduction gearboxes and AC motors, was a source of end-user concern. Major worries were how the drive would handle the large tracker loads (especially during wind or seismic events), if the drive's precision would support the exact pointing requirements of the CPV tracker (especially over time as the gear teeth experienced wear) and the general lifecycle of the drive. Soitec notes that the dual-axis drives on other, larger projects have functioned quite well for several years without a single internal drive issue with the slewing rings and worm drives.

8.2 O&M COSTS

End-users were concerned at the lack of real O&M cost data, realizing that the CPV technology was unproven and would require intensive preventive and reactive maintenance over the life of the plant.

8.3 LACK OF COMMERCIALIZATION OF CPV SYSTEM COMPONENTS.

At the time of construction of the DoD Fort Irwin project, the Soitec Bill of Materials were a combination of standard commercial off-the-shelf items, custom-built parts, or newly commercialized parts.

Also, at the time this power plant was commissioned (summer 2015), Soitec announced its exit of the solar business and subsequent inability to sell the business to a buyer willing to continue development of CPV tracking technology. Therefore, over the past two years Soitec has not moved forward with project, supplier or technology development/refinement and, until recently, most CPV development has stalled. During the same time period, conventional PV module efficiency has risen moderately and prices have fallen precipitously. Therefore, Soitec expects CPV technology would face even stiffer competition with conventional PV today.

Soitec envisions paths forward that would allow CPV to approach the economic offerings of conventional PV power plants. These paths would include breakthroughs in the multi-junction cell efficiency, improvements in tracking software and firmware, reductions in reactive maintenance costs, reductions in module washing requirements, the introduction of secondary optics in CPV modules, a new lighter tracker design, and the commercialization of currently custom-built parts.

In late 2016, Soitec sold its CPV technology to Saint-Augustin Canada Electric Inc. (STACE), a world-class supplier of large electrical equipment in the power generation industry. With this acquisition, STACE became the technological leader of the CPV industry and stated it would continue to improve the technology and maintain the collaboration with the recognized Fraunhofer Institute for Solar Energy Systems ISE, based in Freiburg, Germany[26].

[26] Saint-Augustin Canada Electric Inc.(STACE) acquires Soitec solar CPV technology. 2017. News Release. http://www.stacelectric.com.

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