DRAFT

OCOTILLO WELLS SOLAR PROJECT
DUAL AXIS TRACKER GLARE STUDY

September 16, 2013 | Prepared by POWER Engineers for The Gildred Companies

the GILDRED companies

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POWER ENGINEERS

Ocotillo Wells Solar Project
Draft Dual Axis Tracker Glare Study

PREPARED FOR: *GILDRED BUILDING COMPANIES*

PREPARED BY: *POWER ENGINEERS*

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ACRONYMS AND ABBREVIATIONS

3D	Three-dimensional
KOP	Key Observation Point
MW	megawatts
NAIP	National Agriculture Imagery Program
NED	National Elevation Dataset
POWER	POWER Engineers, Inc.
Project	Ocotillo Wells Solar Project
PV	Photovoltaic
CPV	Concentrating Photovoltaic

1.0 INTRODUCTION

POWER Engineers, Inc. (POWER) has prepared three glare studies for Gildred Building Companies' Ocotillo Wells Solar Project (Project). This report specifically addresses the potential effects related to dual axis tracking concentrating photovoltaic (CPV) technology. The other two reports discuss single axis and fixed panel photovoltaic (PV) technologies (POWER 2013a, 2013b).

The proposed Project is located in northeastern San Diego County, just east of the community of Ocotillo Wells, California (see Figure 1). The proposed Project may utilize dual axis tracking CPV solar modules producing up to 60 megawatts (MW) of electricity. The CPV modules would be aligned in north-south rows would face east in the morning and west in the evening (see Figure 2). Specifically, this study answers the following questions related to CPV technology:

- Will glint/glare be visible to sensitive visual receptors (see Section 3.1)?
- If glint/glare is visible, how long will it occur, where will it occur and when will it occur (see Section 4.0)?
- If glare is visible, what is it comparable to (see Section 5.0)?

2.0 DEFINITIONS AND DESCRIPTIONS

The following definitions and descriptions are important to understanding the methodology and results of the study:

Concentrating Photovoltaic Panel – CPV modules are designed to absorb solar energy to produce electricity. Unlike a standard photovoltaic module, CPV modules use a Fresnel lens to concentrate large amounts of sunlight onto a solar collector or solar cell in order to produce electricity.

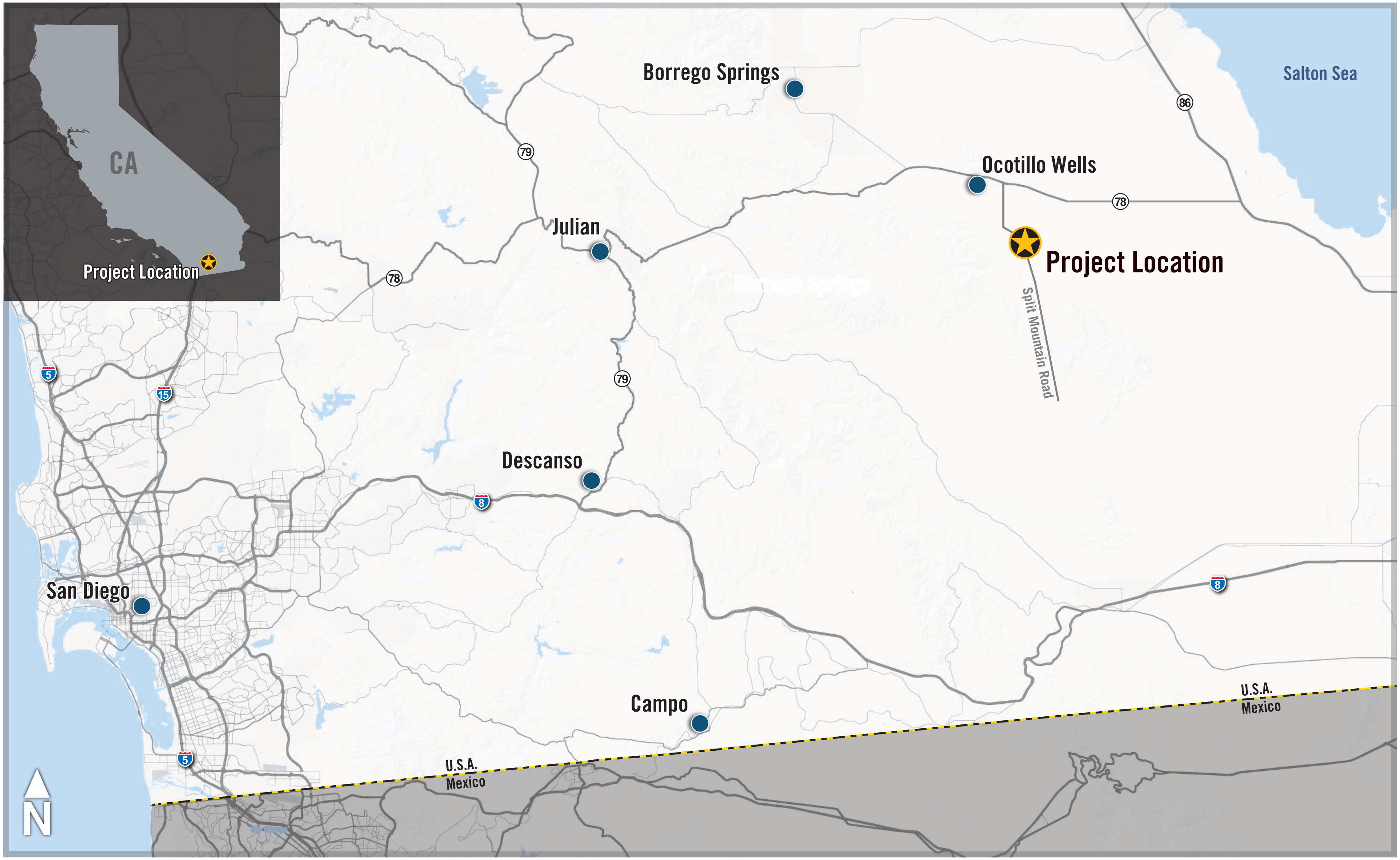
Through the use of Fresnel lenses, CPV modules have achieved concentrated sunlight energy equal to 500 suns. The sunlight is focused onto small, highly efficient multi-junction solar cells and converted to electricity (see Figure 3 and 4). CPV modules are mounted to a two-axis solar tracker that allows the module to track the sun and remain in focus with the sun throughout the day.

Two Axis Solar Tracker - A two-axis tracker uses solar algorithms to track the sun throughout the day. The two-axis rotations enable the CPV modules to maintain a perpendicular relationship to the sun's rays (see Figure 5). Concentrated sunlight will remain focused on the solar cells with a high degree of precision throughout the day, maximizing power output.

Glare – A continuous source of brightness, relative to diffuse or surface scattered lighting. For purposes of this study, glare is caused by the sun reflecting off solar panels (see Figure 6).

3D Geometric Analysis – A computer simulation incorporating a 3-dimensional (3D) terrain model, 3D solar equipment, and a solar algorithm to determine the date, time and duration of glare which may be visible during the landing approach.

Key Observation Points (KOP) – KOPs refer to viewers with potential sensitivity to glare. For this study, KOPs included sensitive public vantage points and residential structures within 1.5 miles of the Project (see Section 3.1).



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Ocotillo Wells Solar Project - Glare Study

Figure 1 - Project Location

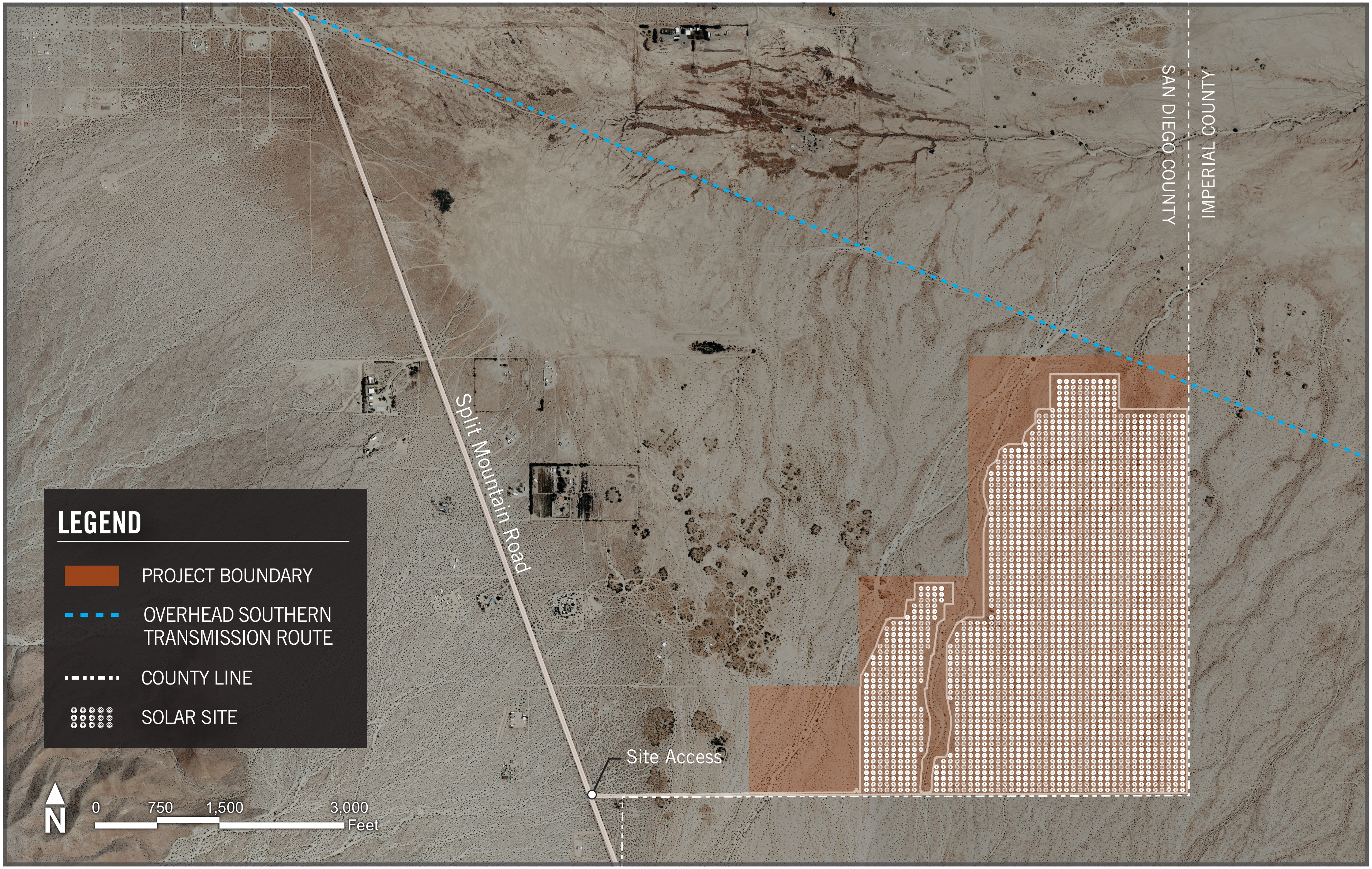

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Figure 2 - Site Map

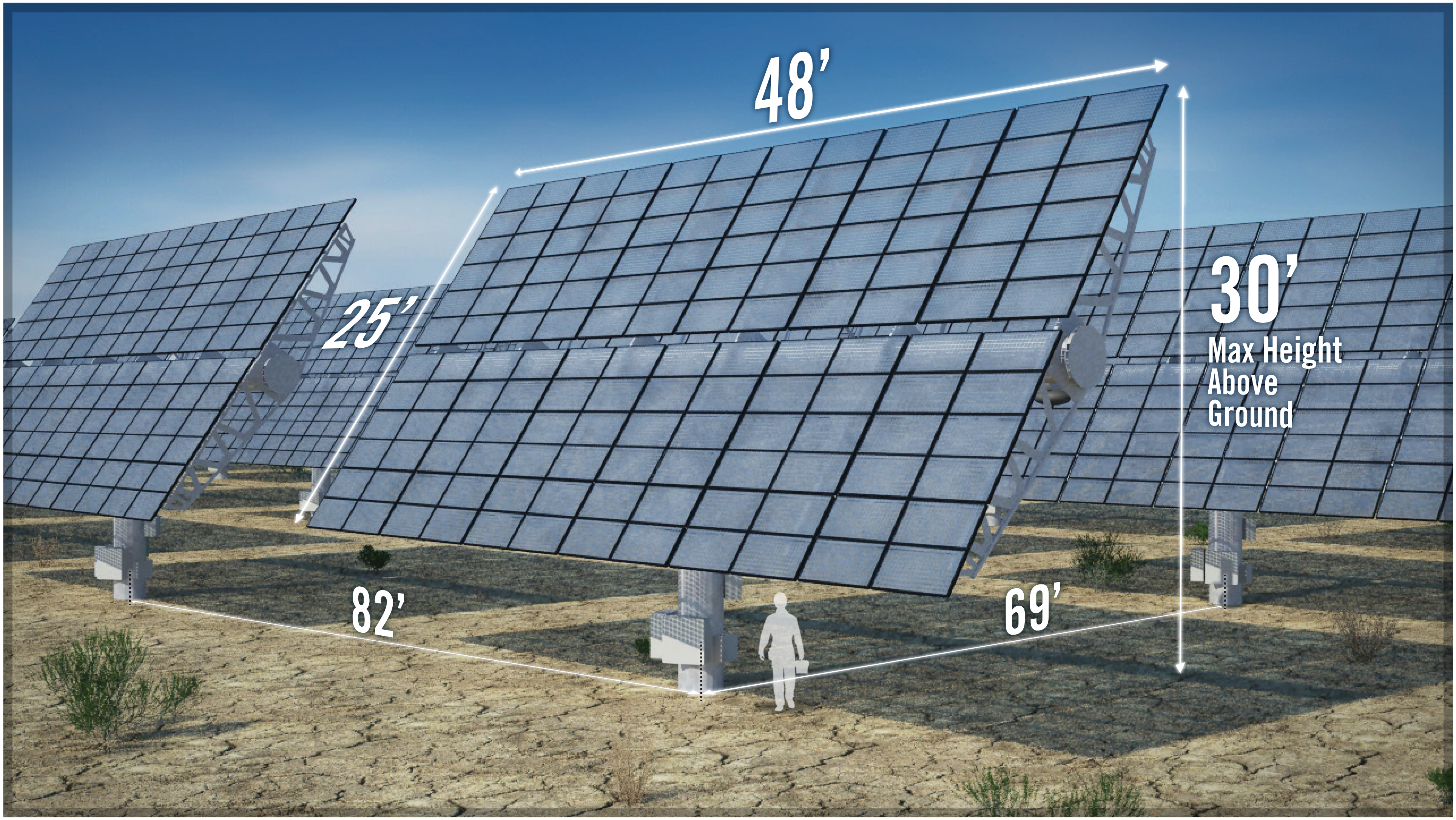


Figure 3 - CPV Technology

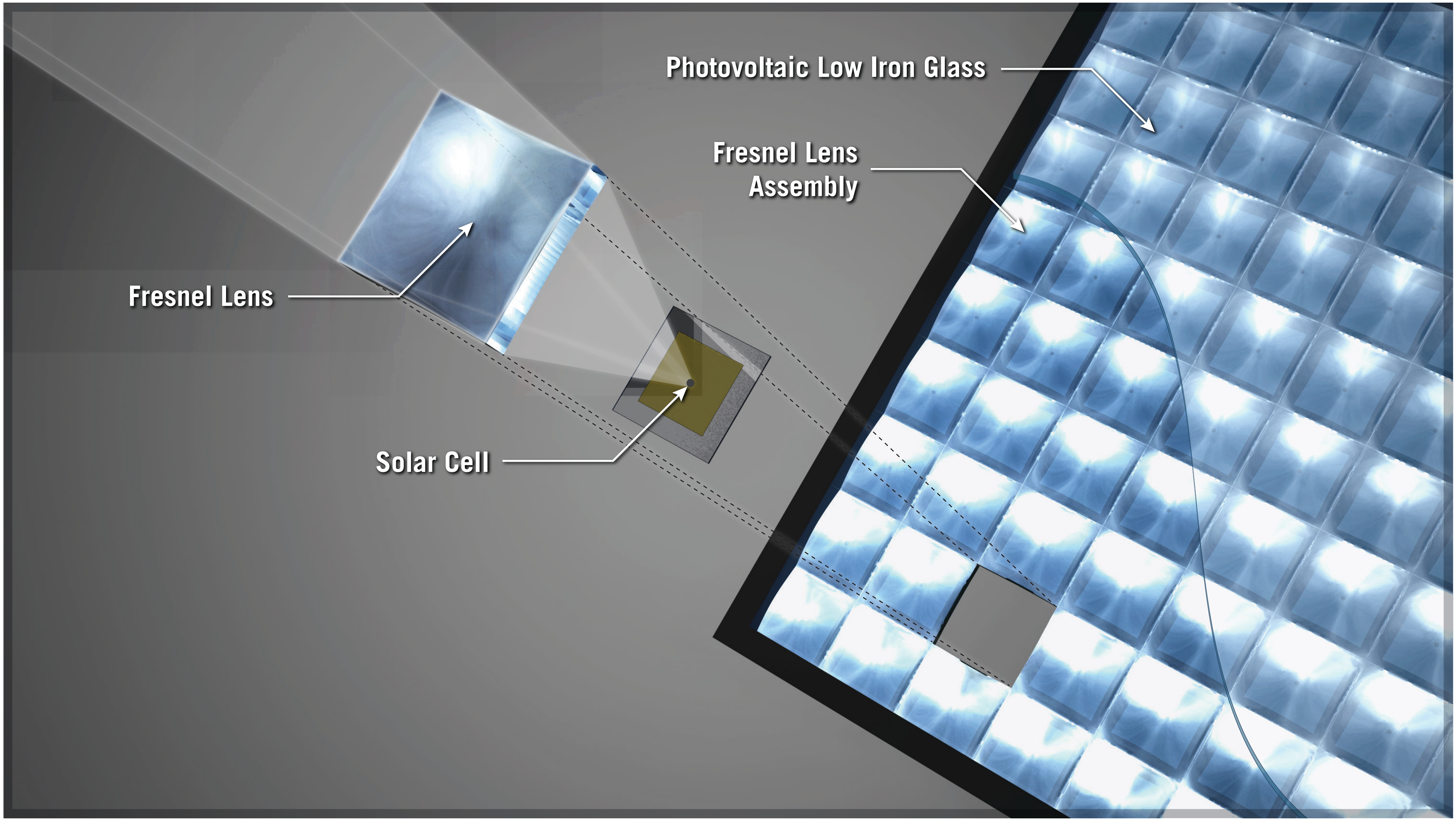
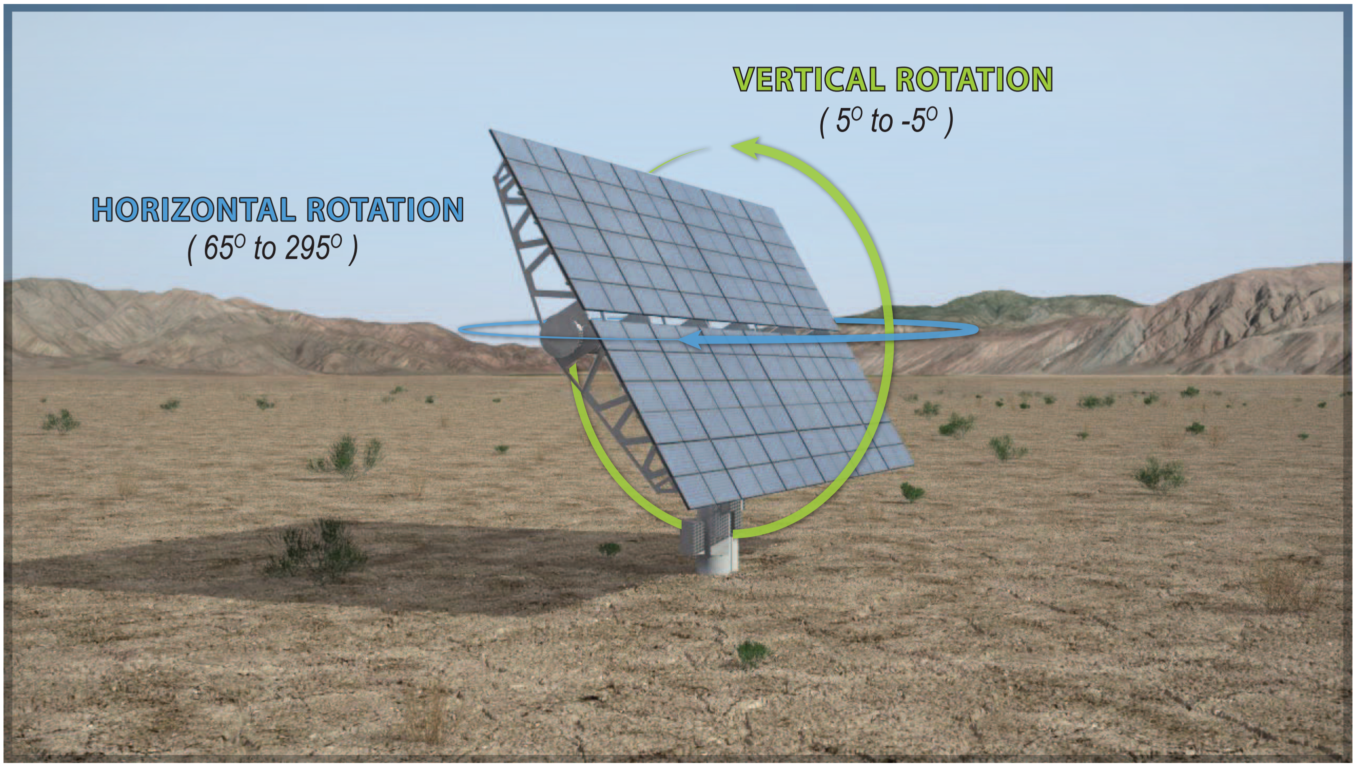
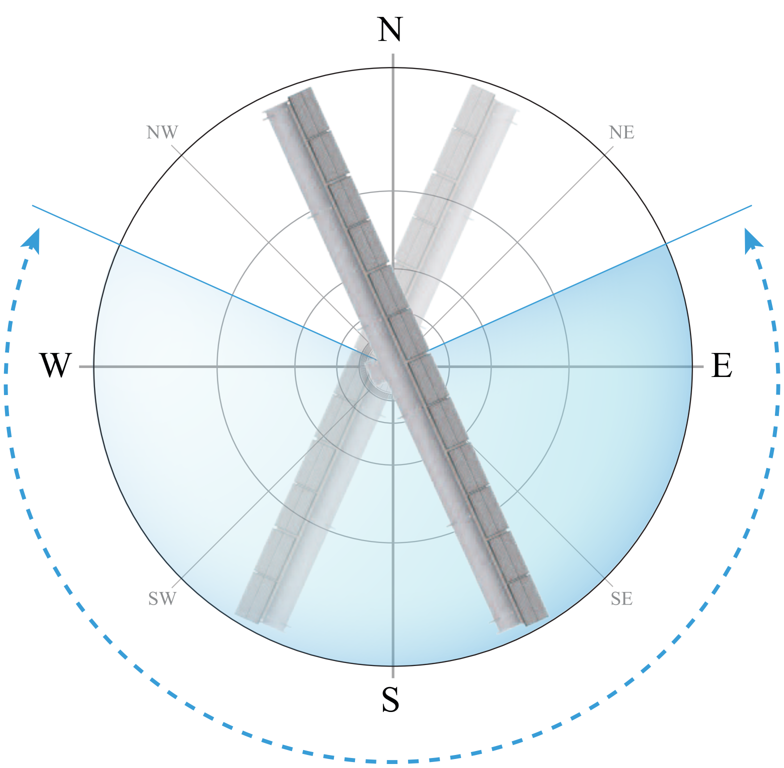


Figure 4 - CPV Module





HORIZONTAL ROTATION LIMITS *(TOP VIEW)*

(65° Facing East - 295° Facing West)

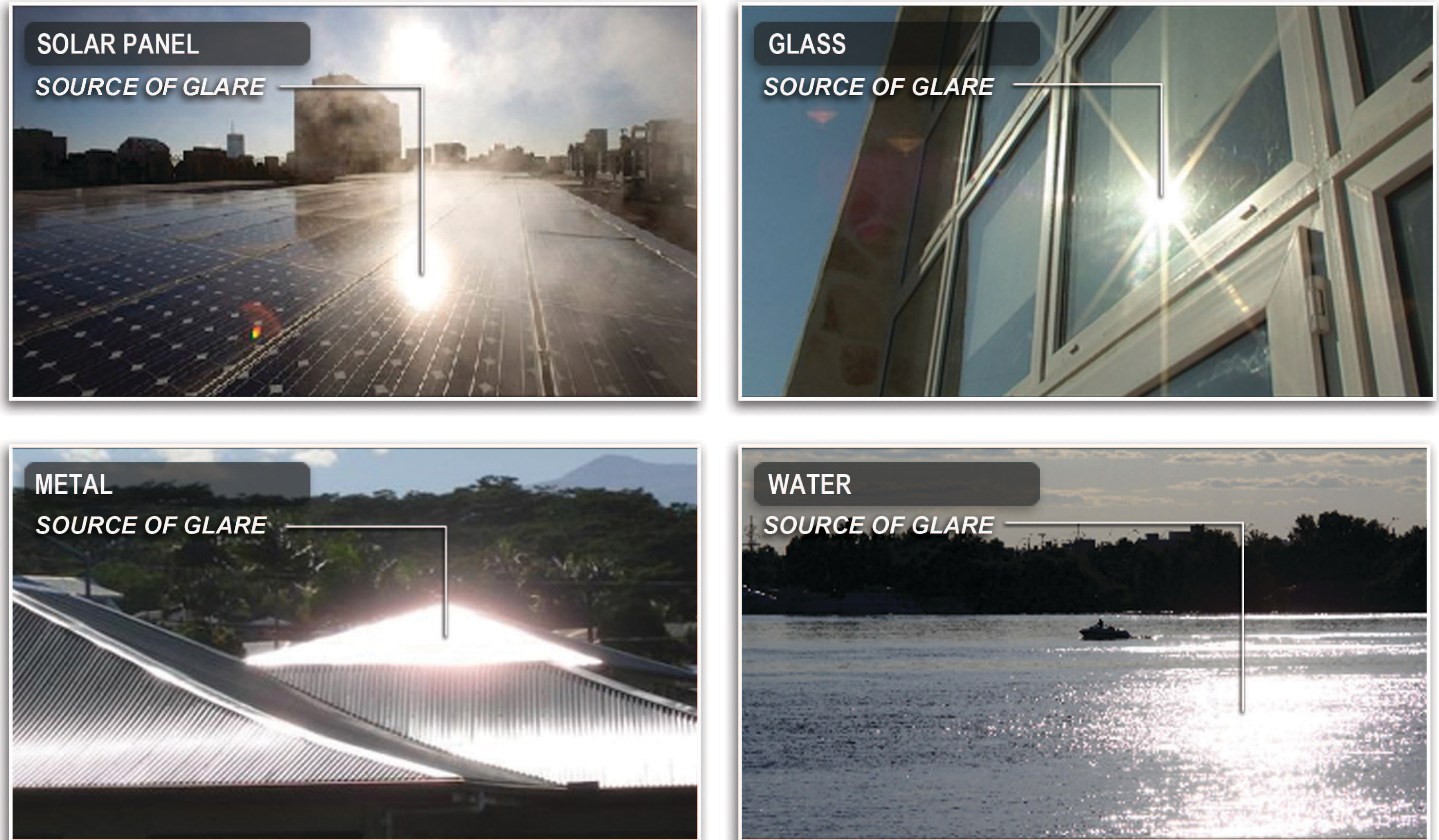


Figure 6 - Examples of Glare

3.0 METHODOLOGY

This study was commissioned by The Gildred Companies to determine if glare from proposed solar operations would be visible to any nearby residential, transportation and recreational viewers. The analysis considers the changing positions of the sun throughout the day and year, and its influence on a dual axis tracking CPV panel. POWER used the following methodology to determine the location and duration of glare:

1. *Identify Potential Glare Issues* – This study focused on potential issues where glare may be visible to sensitive viewers. The findings are based on these locations (see Section 3.1).

2. *Characterize Glare Behavior* – 3D simulations were developed to accurately create and study glare based on the behavior of the solar equipment (see Section 3.2). 3D elements within the digital scene included terrain models, 3D solar equipment, and a 3D sun system. This information was assembled in a 3D computer program to create an accurate virtual representation of the Project and surrounding area (see Section 3.3).

3. *Evaluate* – Visual analysts studied the 3D simulations under different lighting conditions and at different times of the year. These simulations were used to evaluate and document when glare may be visible to KOPs. The results of this evaluation can be found in Section 4.0.

3.1 KOPs

Solar operations were studied from four public KOPs (KOPs A-D, see Figure 7a) and 16 residential locations (KOPs 1-16, see Figure 7b). Public KOPs were provided by The Gildred Companies. Residential KOPs include residential structures within 1.5 miles of the Project Site. Residences beyond 1.5 miles were not included because no glare is possible due to minimal glare angles from the resulting technology. Impacts to the Ocotillo Airport operations were considered but eliminated from this study due to orientation and distance from the Project. Each KOP is described below:

- **KOP A** – View from State Highway 78 approximately three miles north of the proposed technology. Viewers from this location would mainly consist of vehicles traveling along State Route 78.

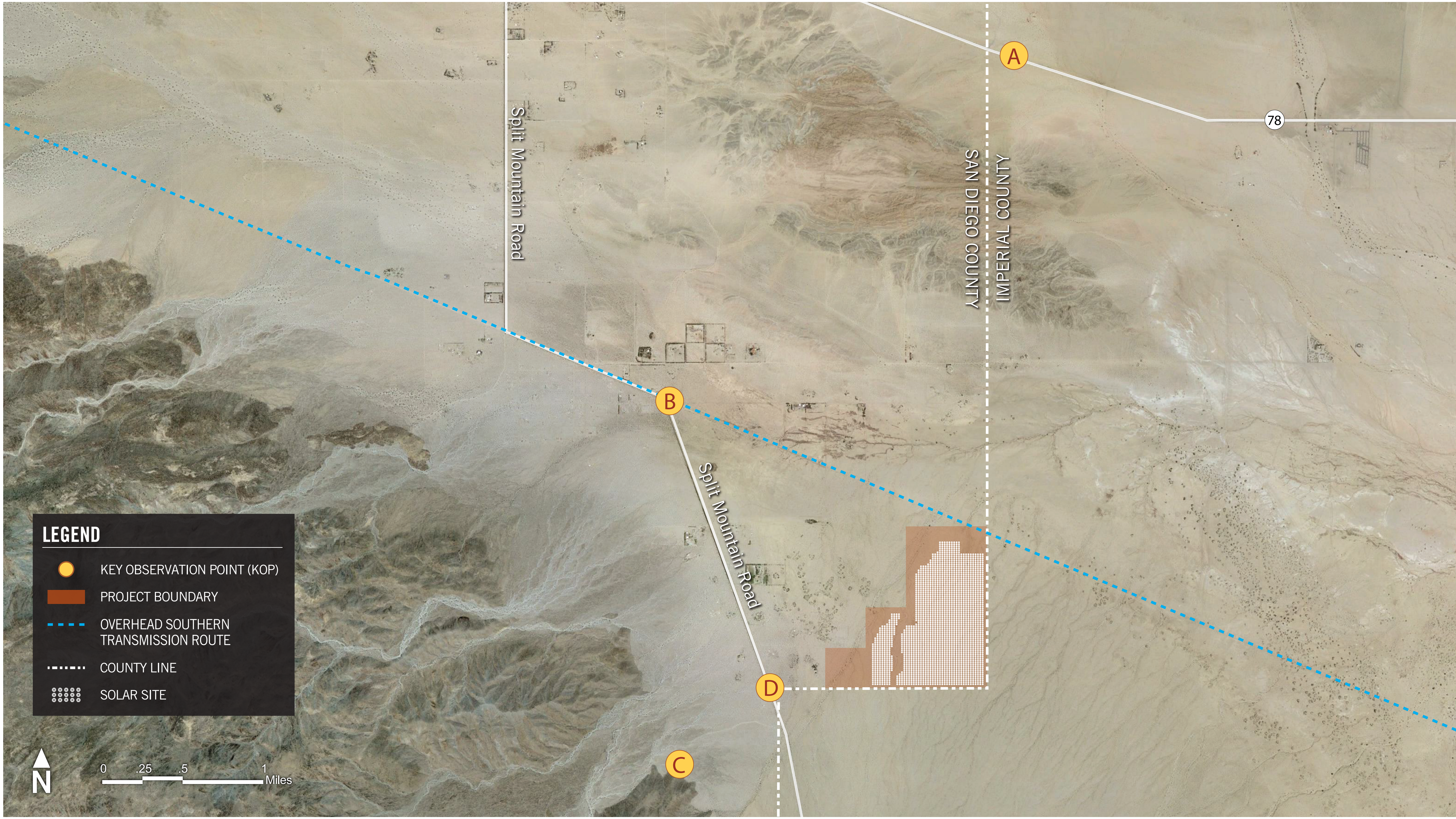
- **KOP B** – View from Split Mountain Road adjacent to the existing San Felipe Substation approximately 1.85 miles northwest of the proposed technology. Viewers from this location would mainly consist of vehicles traveling along Split Mountain Road.

- **KOP C –** View from Anza-Borrego Desert State Park approximately 1.25 miles southwest of the proposed technology. Viewers from this location would mainly consist of vehicles and visitors traveling within the State Park, utilizing trails or other recreational facilities.

- **KOP D** – View from Split Mountain Road to the Project site located approximately 0.3 mile west of the proposed technology. Viewers from this location would mainly consist of vehicles traveling along Split Mountain Road.

- **KOP 1 -** The residential structure located approximately 5,900 feet northwest of the proposed technology.

- **KOP 2 -** The residential structure located approximately 4,750 feet northwest of the proposed technology.
- **KOP 3 -** The residential structure located approximately 4,150 feet northwest of the proposed technology.
- **KOP 4 -** The residential structure located approximately 6,600 feet west of the proposed technology
- **KOP 5 -** The residential structure located approximately 5,050 feet west of the proposed technology.
- **KOP 6 -** The residential structure located approximately 5,000 feet west of the proposed technology.
- **KOP 7 -** The residential structure located approximately 5,400 feet west of the proposed technology.
- **KOP 8 -** The residential structure located approximately 4,150 feet west of the proposed technology.
- **KOP 9 -** The residential structure located approximately 4,550 feet west of the proposed technology.
- **KOP 10 -** The residential structure located approximately 3,600 feet west of the proposed technology.
- **KOP 11 -** The residential structure located approximately 2,450 feet west of the proposed technology.
- **KOP 12 -** The residential structure located approximately 1,850 feet west of the proposed technology.
- **KOP 13 -** The residential structure located approximately 4,050 feet west of the proposed technology.
- **KOP 14 -** The residential structure located approximately 4,200 feet west of the proposed technology.
- **KOP 15 -** The residential structure located approximately 1,650 feet west of the proposed technology.
- **KOP 16 -** The residential structure located approximately 3,550 feet west of the proposed technology



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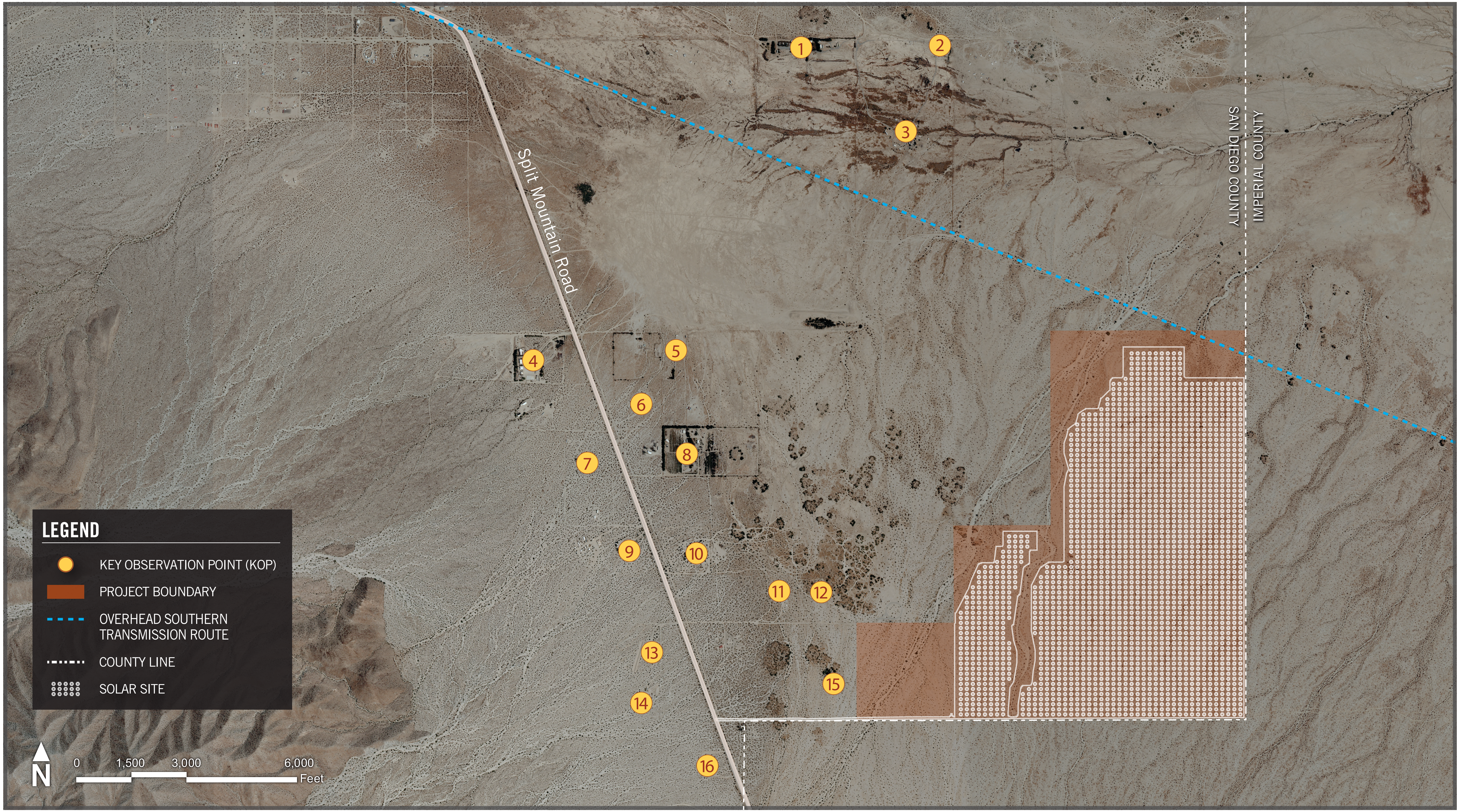
Ocotillo Wells Solar Project - Glare Analysis

Figure 7A - Key Observation Point (KOP) Map


Split Mountain Road
SAN DIEGO COUNTY
IMPERIAL COUNTY
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
LEGEND
KEY OBSERVATION POINT (KOP)
PROJECT BOUNDARY
OVERHEAD SOUTHERN TRANSMISSION ROUTE
COUNTY LINE
SOLAR SITE
N
0
1,500
3,000
6,000
Feet

3.2 Characterize Glare Behavior

In order to characterize glare behavior, POWER created a 3D representation of the site, the sun, and the solar equipment. The 3D model allowed analysts to accurately determine when and where glare may be visible to sensitive viewers. Specifically, the 3D Model incorporated the following:

- **3D Terrain Models** – The Gildred Companies provided POWER with contours of the Project Site. This information was converted into a 3D surface model and used to place the proposed 3D solar arrays. POWER acquired five foot contour data from the National Elevation Dataset (NED) and aerial imagery from the National Agriculture Imagery Program (NAIP) for the use of 3D structure placement.

- **Solar Sun System –** The 3D computer simulations incorporated an accurate, solar algorithm based on the latitude and longitude of the actual Project. All calculations were performed using 3D software designed for calculating and animating solar cycles. Sun calculations and results were based on hours of operational daylight and solar clocks for the following times of year (see Figure 8):

    - Summer Solstice (June 21st, 2013) – where the length of sunlight hours are at its peak and the sun has reached its northern most extremes.

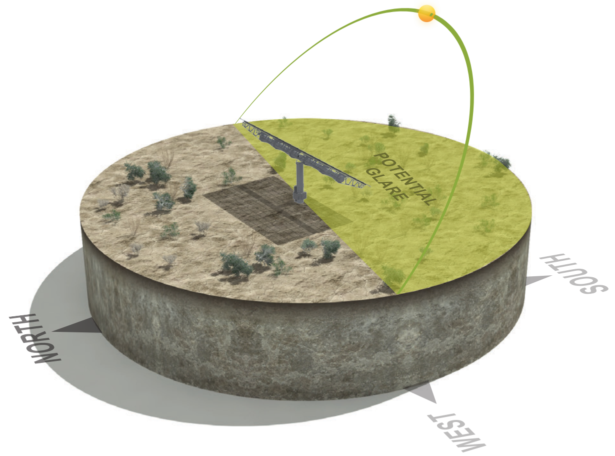
    - Winter Solstice (December 21nd, 2013) – where the length of sunlight hours are at its lowest and the sun has reached its southernmost extremes.

    - Fall Equinox (September 22rd, 2013) – where the day and night are equal in length.

    - Spring Equinox (March 20th, 2013) – where the day and night are equal in length.

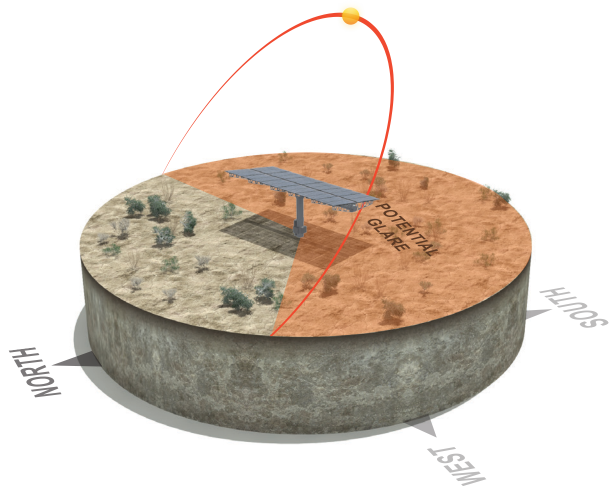
- **3D CPV Solar Equipment:** POWER developed 3D models of the two-axis tracker mounted CPV modules. Equipment spacing, layout, and spot elevation used were provided by The Gildred Companies. Additional computer aided design (CAD) information collected from the manufacturer included panel design, panel height, panel orientation, and tracking behavior. The general behavior of the two-axis solar tracker applied for the purposes of this study is as follows:

- **Wake:** Solar trackers will be in wake position facing east prior to sunrise (see Figure 9). When the sun reaches an elevation of five degrees, the tracker will follow the sun until it reaches a vertical position facing west five degrees. Trackers will return to an east-facing vertical position during the night.
- **Tracking:** Throughout the tracking procedure, the tracker will remain in position directly perpendicular to the sun's rays. In a perfect scenario, reflections will bounce directly back to the sun. However, to account for slight deviations in panel tracking movement and surface light scattering, POWER allowed for a one degree light spread from the face of the panel resulting in reflections never lower than four degrees off horizon (see Figure 10).
- **Sleep:** Trackers will remain in a near-vertical position during the nighttime hours, as well as when the modules undergo cleaning or maintenance.



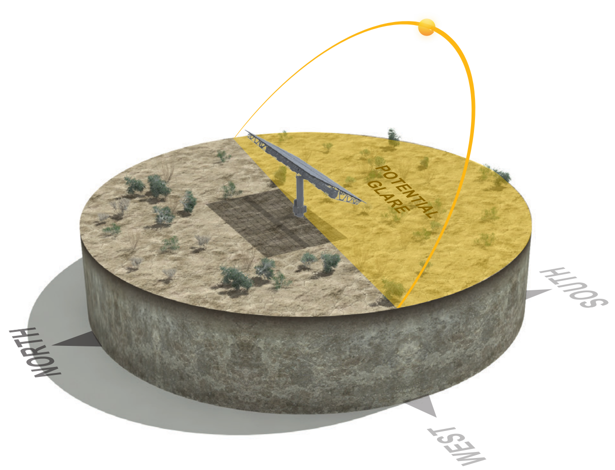
Spring Equinox

March 20, 2013
12 hours 9 minutes of daylight
Sunrise - 6:45 a.m.
Sunset - 6:54 p.m.



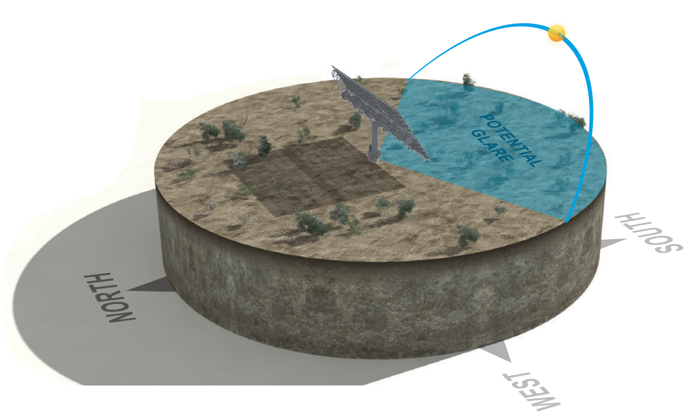
Summer Solstice

June 21, 2013
14 hours 18 minutes of daylight
Sunrise - 5:35 a.m.
Sunset - 7:53 p.m.



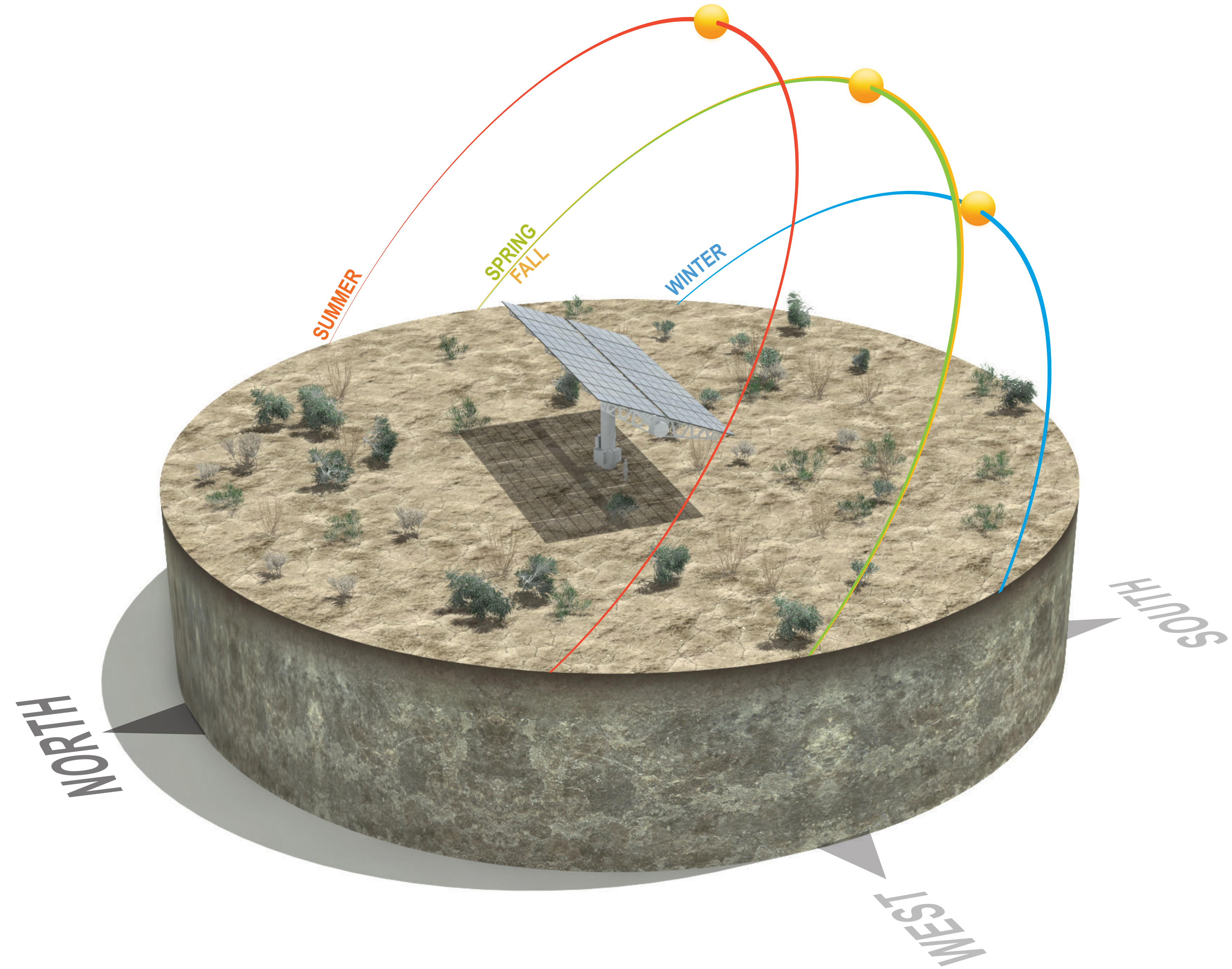
Fall Equinox

September 22, 2013
12 hours 7 minutes of daylight
Sunrise - 6:31 a.m.
Sunset - 6:38 p.m.



Winter Solstice

December 21, 2013
10 hours 1 minutes of daylight
Sunrise - 6:40 a.m.
Sunset - 4:41 p.m.



The sun changes its east-west orientation throughout the day. It also changes its north-south position throughout the year. The sun reaches its highest position in the sky at noon in the summer months and its lowest position in the sky at noon during the winter months.

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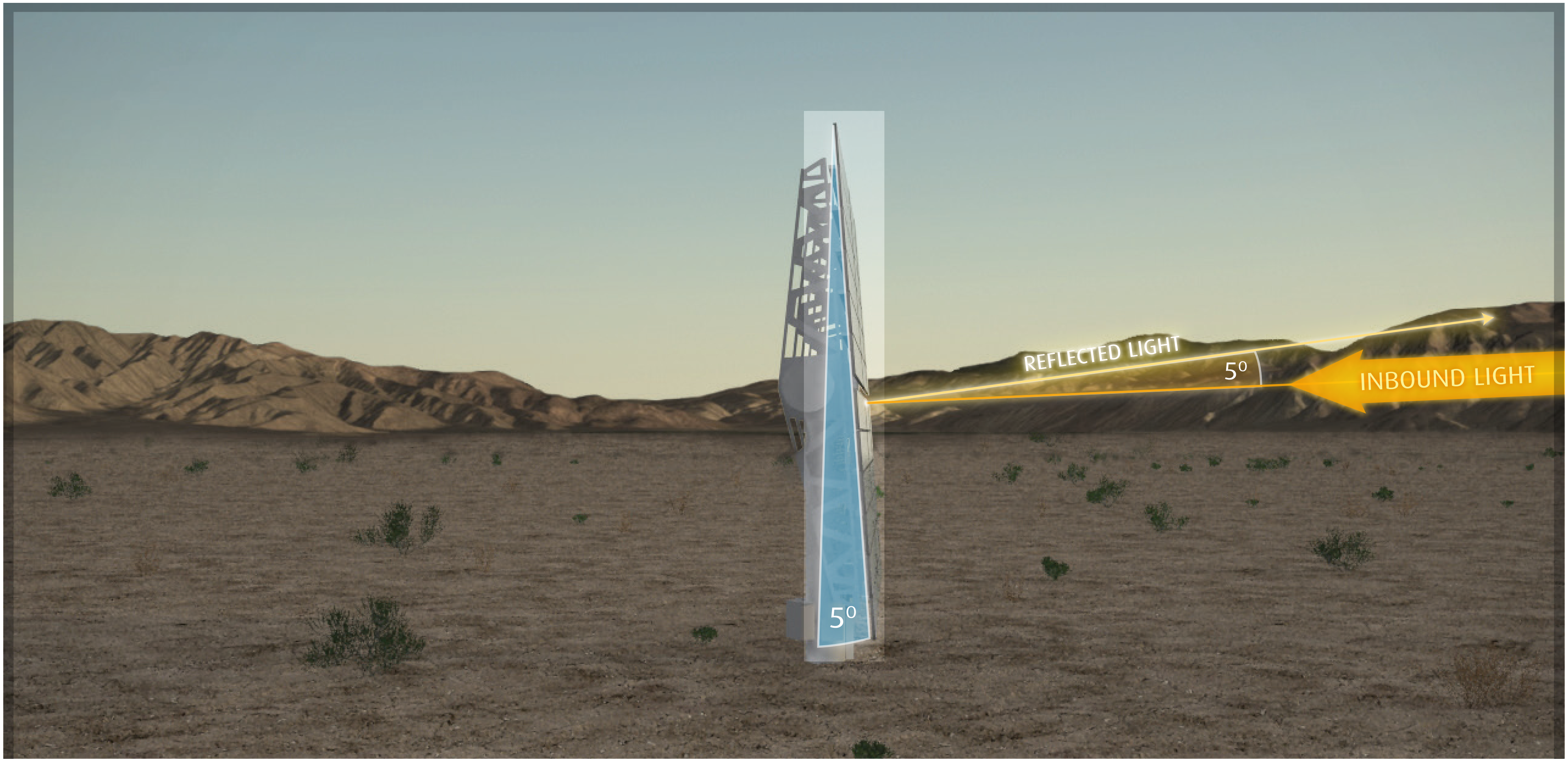
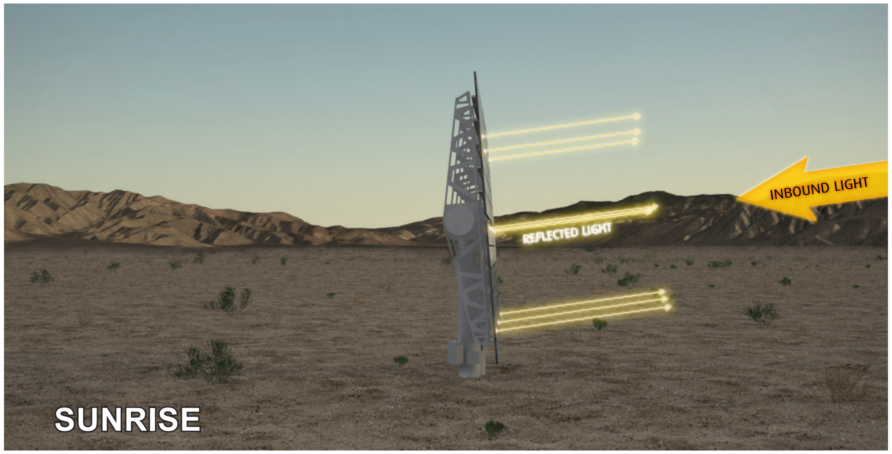
Figure 8 - Solar Sun Paths

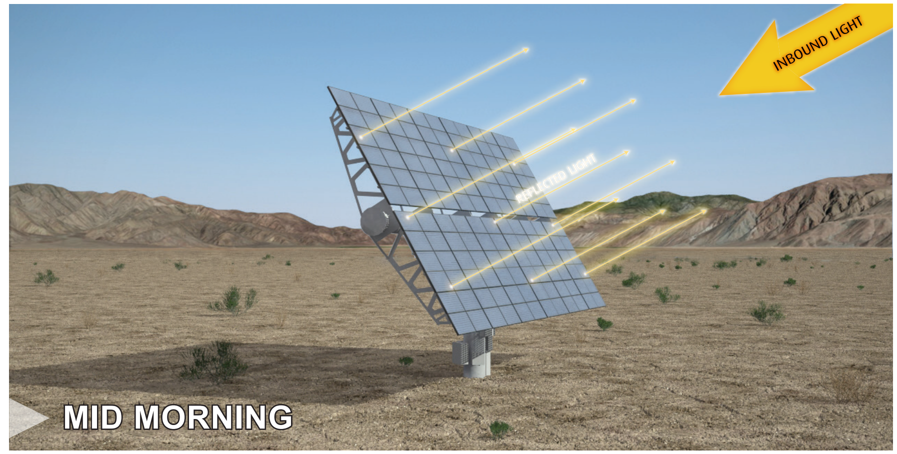


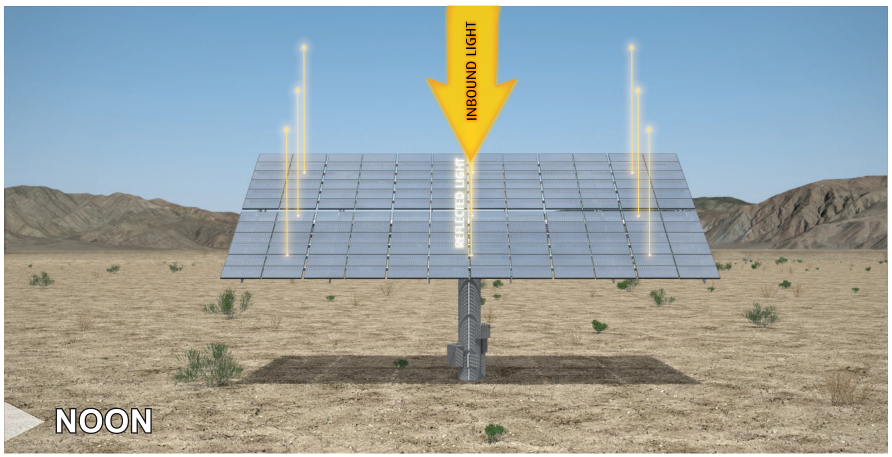
5^0 Degree Wake Position

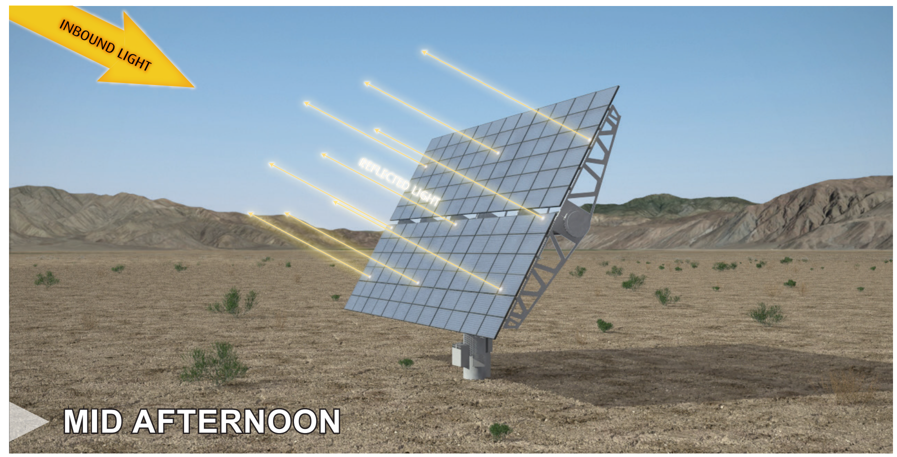
Lowest Reflection Angle

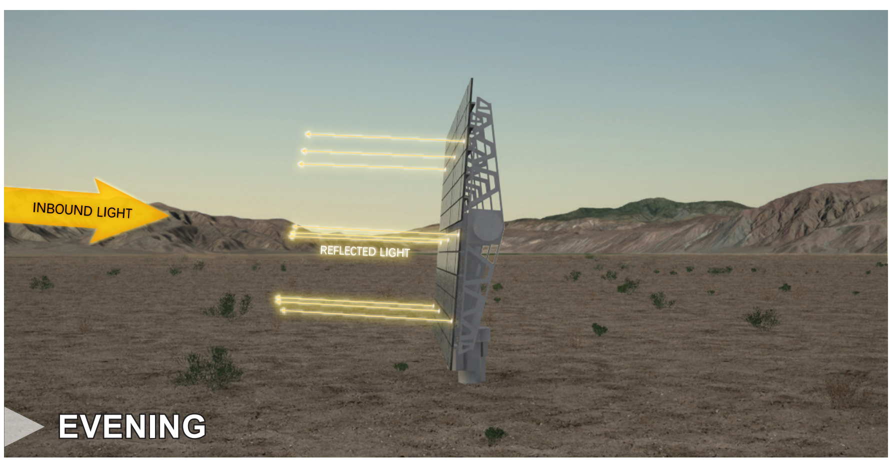
Figure 9 - CPV Wake Cycle











Throughout the tracking procedure, the tracker will remain in position directly perpendicular to the sun's rays. In a perfect scenario, reflections will bounce directly back to the sun. However, to account for slight deviations in panel tracking movement and surface light scattering, POWER allowed for a 1 degree light spread from the face of the panel resulting in reflections never lower than 4 degrees off horizon.

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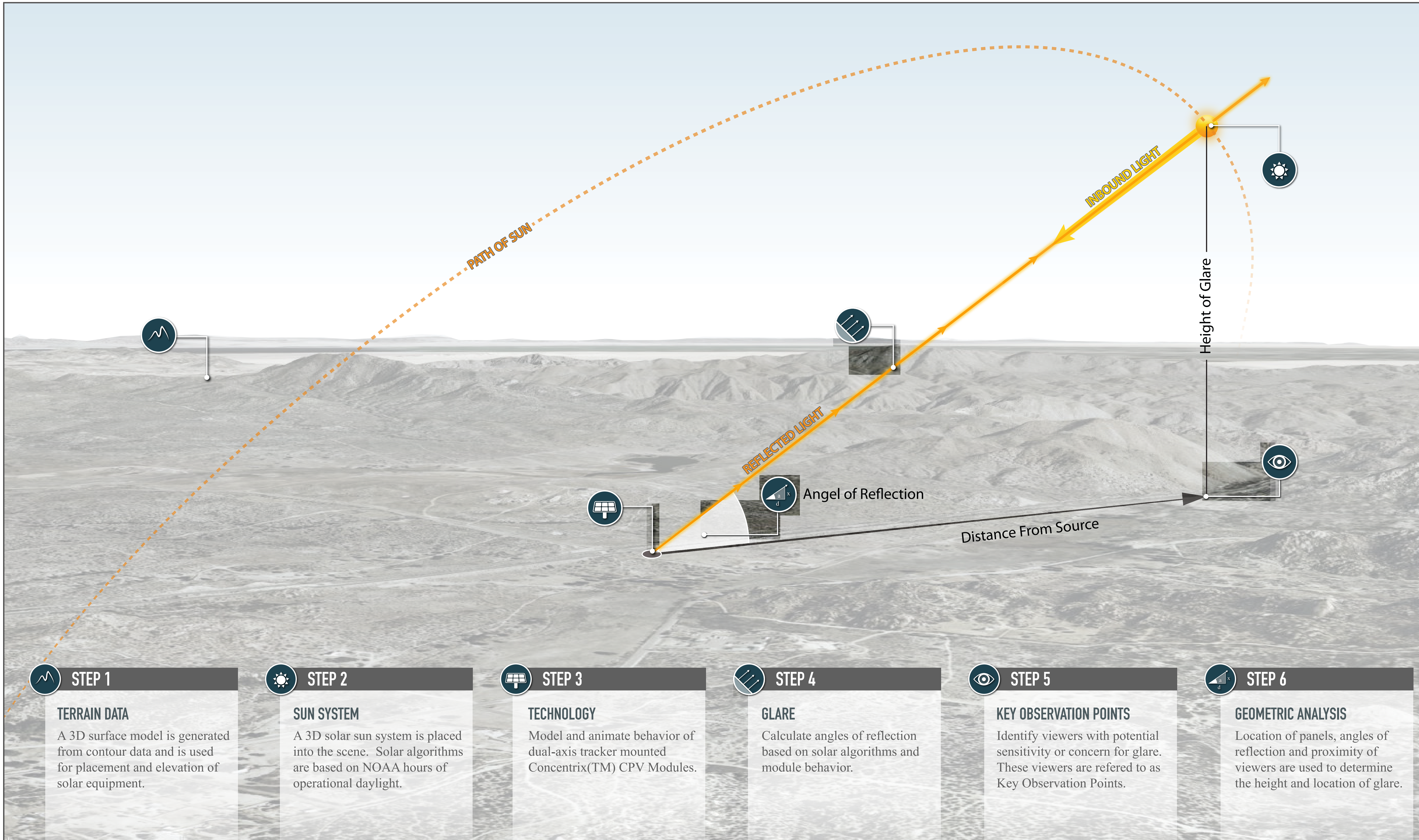
Ocotillo Wells Solar Project - Glare Study

Figure 10 - CPV Tracking Cycle

3.3 Glare Evaluation - 3D Geometric Analysis

The occurrence of glare was studied by performing a 3D geometric analysis, which takes into account the position of the sun in relation to the angle of the solar modules to determine the path of glare (see Figure 11). The computer simulation also included movement of the CPV modules during the stow and tracking phases of the operations. Once all the conditions were simulated in a 3D computer program, visual analysts were able to determine if, when, and where glare may cross into the KOPs' vision. A visual analyst recorded the occurrence of glare in a series of charts (refer to Section 4.0 for glare results).



STEP 1
TERRAIN DATA
A 3D surface model is generated from contour data and is used for placement and elevation of solar equipment.

STEP 2
SUN SYSTEM
A 3D solar sun system is placed into the scene. Solar algorithms are based on NOAA hours of operational daylight.

STEP 3
TECHNOLOGY
Model and animate behavior of dual-axis tracker mounted Concentrix(TM) CPV Modules.

STEP 4
GLARE
Calculate angles of reflection based on solar algorithms and module behavior.

STEP 5
KEY OBSERVATION POINTS
Identify viewers with potential sensitivity or concern for glare. These viewers are refered to as Key Observation Points.

STEP 6
GEOMETRIC ANALYSIS
Location of panels, angles of reflection and proximity of viewers are used to determine the height and location of glare.

NOTE: Illustration demonstrates location of glare for one solar module only. Actual analysis includes the entire solar project.

4.0 RESULTS

Review of the 3D geometric analysis determined no glare will be visible to KOPs from the proposed solar operations due to the distance of KOPs to the Project and the orientation of the CPV modules. The minimum five degree stow position of the trackers will cause any resulting glare to be redirected above all KOPs when the sun is lowest in the sky. Height of glare above KOPs increases as the sun rises in sky and the panels begin tracking operations.

5.0 DISCUSSION

CPV modules are designed to directly face and track the sun throughout the day. This design allows for maximum efficiency and energy output of the modules. By tracking the sun, reflections and subsequent glare are predictable. During hours of operation, reflections bounce directly back towards the sun. Due to operational limits, panels never move lower than five degrees off horizon. To account for slight deviations in panel tracking movement and surface scattering, POWER allowed for a one degree light spread from the face of the panel resulting in reflections never lower than four degrees off horizon.

POWER took a conservative approach when recording glare, and did not account for slight deviations in the terrain or vegetation that may block glare to off-site viewers. Even when taking a worst-case scenario approach, POWER concluded that glare will not be visible from the proposed solar operations. As distance increases from the Project sites, glare continues to rise above the surrounding terrain and KOPs.

In addition to the primary glare source resulting from the top glass plate, POWER's visual analysts recorded a secondary lighting effect while visiting Soitec's Newberry site near Barstow, California. Although the effect does not produce a bright glare source, it is visible to the offsite viewer as having a colored effect, changing hue with viewing angle and distance (see Figure 12).

5.1 Glare Intensity

As solar operations continue to increase in size and number throughout the United States, so does the concern for glare. Concerned parties may ask, "If glare is experienced, what will the intensity be?"

CPV Modules are designed to absorb solar energy inward towards the panel to produce electricity. CPV modules do not use mirrors to redirect the sun as seen with trough systems or heliostats, but rather use Fresnel lenses to concentrate sunlight onto a solar cell inside the module to produce electricity. CPV systems are similar in glare intensity to that of a PV panel because both technologies rely on a top glass plate to protect the solar equipment. Glare is primarily produced from the top plate which reflects a small portion of the sun's image back to the viewer, making the glare comparable to other PV technology, building glass, and water (see Figure 13).

According to a white paper presented by Reflexite Energy Solutions in 2011, the Concentrix system are designed to transmit approximately 90% of the solar energy and convert it directly to electricity, resulting in reflectance levels much lower than that of other common reflective surfaces (refer to Reflexite Energy Solutions White Paper, Appendix B). Anti-reflective coatings, high incidence angles, and high transmission glass reduce the reflectivity of solar panels to approximately 10% of the sun, well below levels to cause damage to the eyes and below many common surfaces found in both the man-made and the natural environment.

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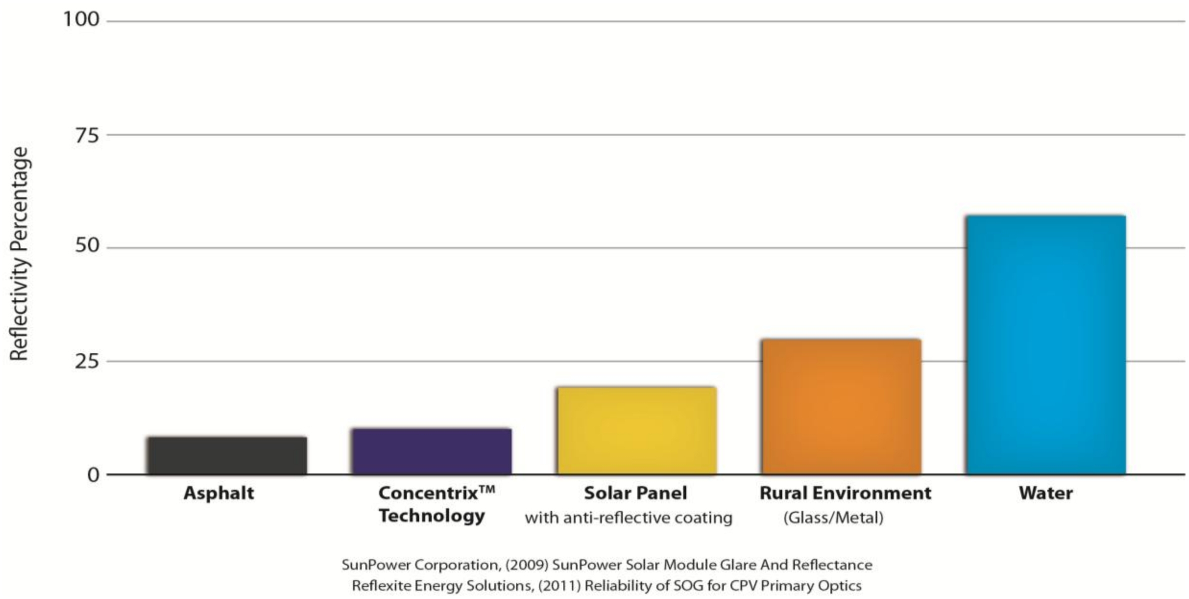
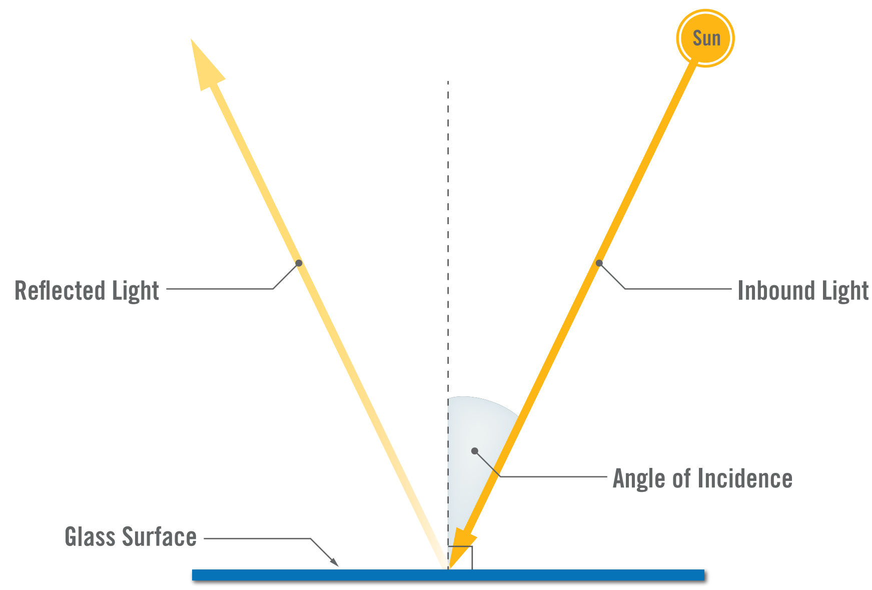
Figure 12 - Secondary Lighting Effect

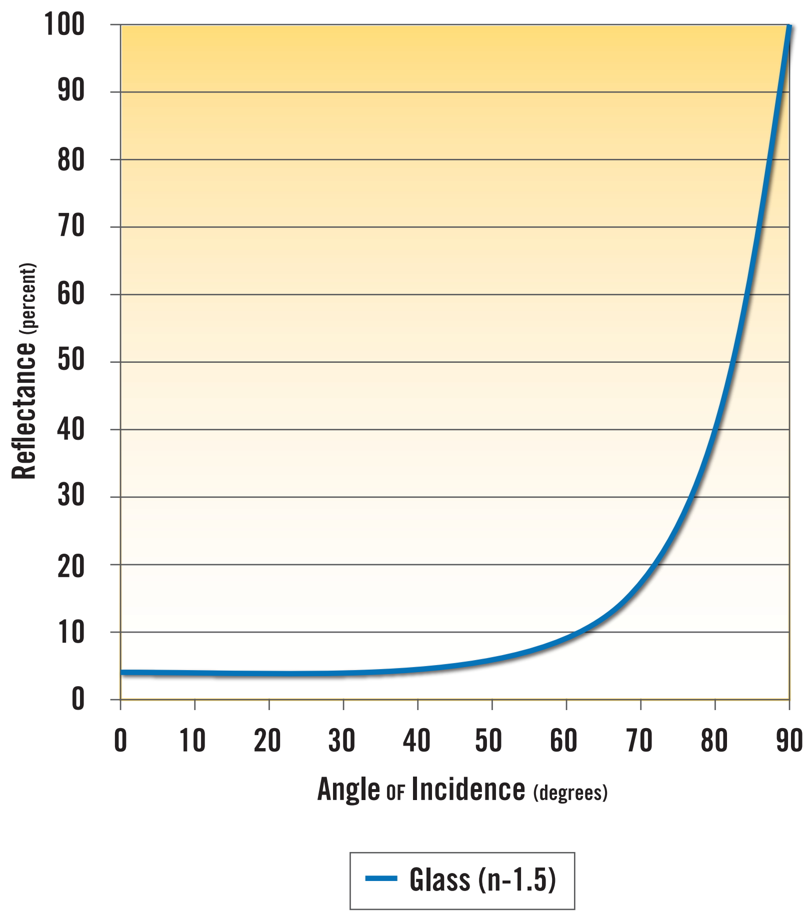
FIGURE 13 COMPARATIVE REFLECTIVE ANALYSIS



In recent years, there have been many studies reporting different levels of glare percentages associated with PV panels and panel glass. Studies range from 2% glare intensity (FAA 2010) to 25% intensity (SunPower 2009). It is important to understand that glare intensity is directly related to the angle of incidence of the sun striking the panel, and may account for the wide range of past results. As reported in a presentation by Sandia Labs, glare intensity is at its lowest when the angle of incidence is at its lowest, near perpendicular to the sun (see Figure 13). Static PV panels can see a varying range of reflection values as the sun changes position throughout the day. Angle of incidence and glare are at their lowest around noon where the sun can pass directly through the panel glass. In the early mornings and late evenings, incidence angles and glare values are higher as a result of the sun glancing off static panel glass.

CPV modules maintain overall lower reflection levels than static PV panels due to the two-axis solar tracker technology. This technology follows the sun, and maintains a continuous low angle of incidence throughout the day which results in high solar transmission and minimal offsite glare.


Sun
Reflected Light
Inbound Light
Angle of Incidence
Glass Surface


100
90
80
70
60
50
40
30
20
10
0
Reflectance (percent)
0
10
20
30
40
50
60
70
80
90
Angle of Incidence (degrees)
Glass (n-1.5)

6.0 CONCLUSION

Review of the 3D geometric analysis determined no glare will be visible from the proposed solar operations utilizing dual axis tracking technology, due to the distance of KOPs to the Project and the orientation of the CPV modules. The minimum five degree stow position of the solar panels will cause any resulting glare to be redirected above all KOPs when the sun is lowest in the sky. Height of glare above KOPs increases as the sun rises in sky and the panels begin tracking operations.

7.0 SOURCES

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