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OCOTILLO WELLS SOLAR PROJECT
SINGLE AXIS TRACKER GLARE STUDY

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

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GILDRED
companies

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*Ocotillo Wells Solar Project
Draft Single 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 single axis tracking photovoltaic (PV) panel technology. The other two reports discuss fixed panel and dual axis tracking concentrating photovoltaic (CPV) technologies (POWER 2013b, 2013c).

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 will utilize single axis tracking PV solar arrays producing up to 50 megawatts (MW) of electricity. The solar panels would be aligned in north/south rows and would face to the east in the morning and to the west in the evening (see Figure 2). Specifically, this study answers the following questions related to single axis tracking PV 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:

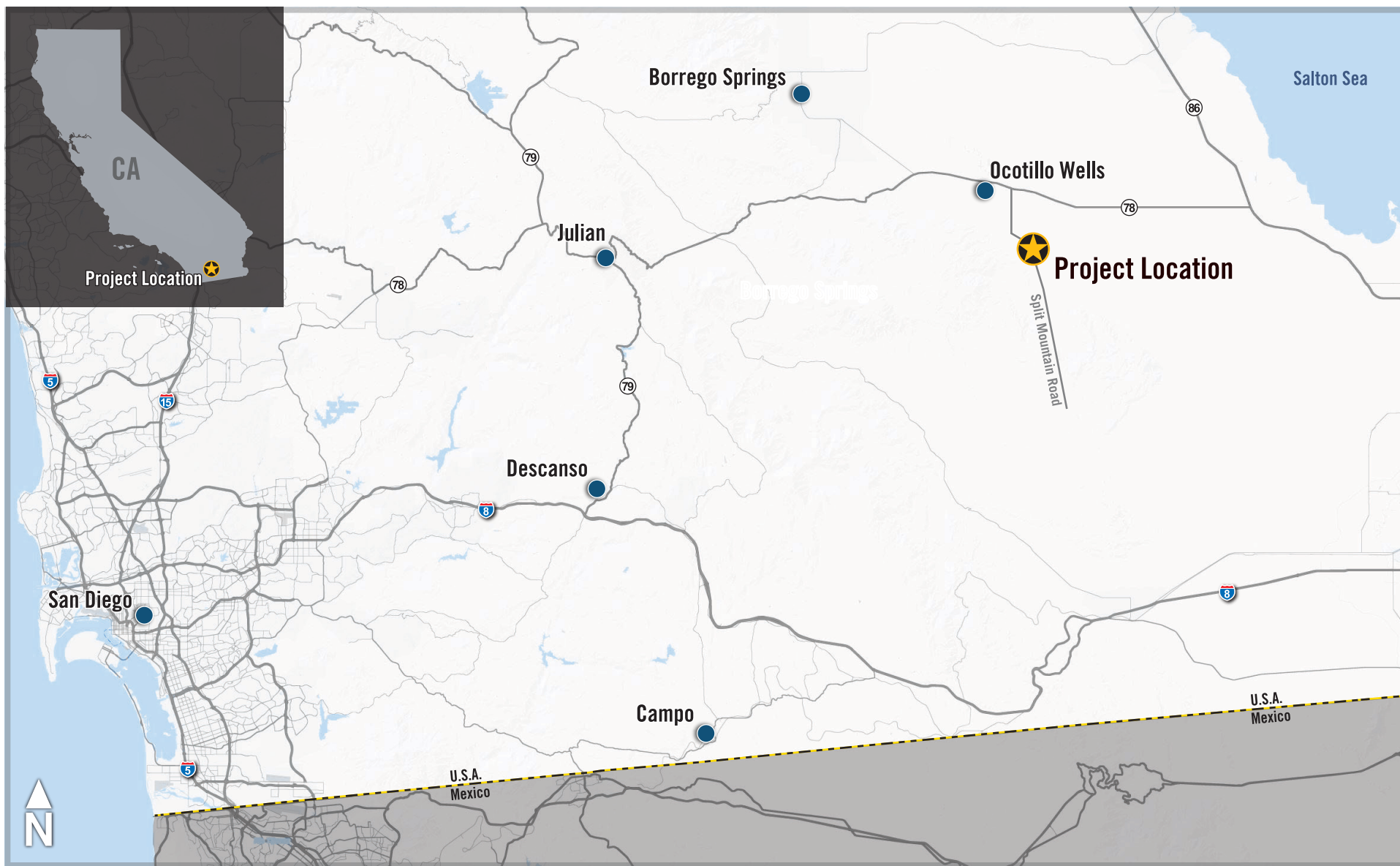
Photovoltaic Panel – Photovoltaic panels, also known as PV panels, are designed to absorb solar energy and retain as much of the solar spectrum as possible in order to produce electricity.

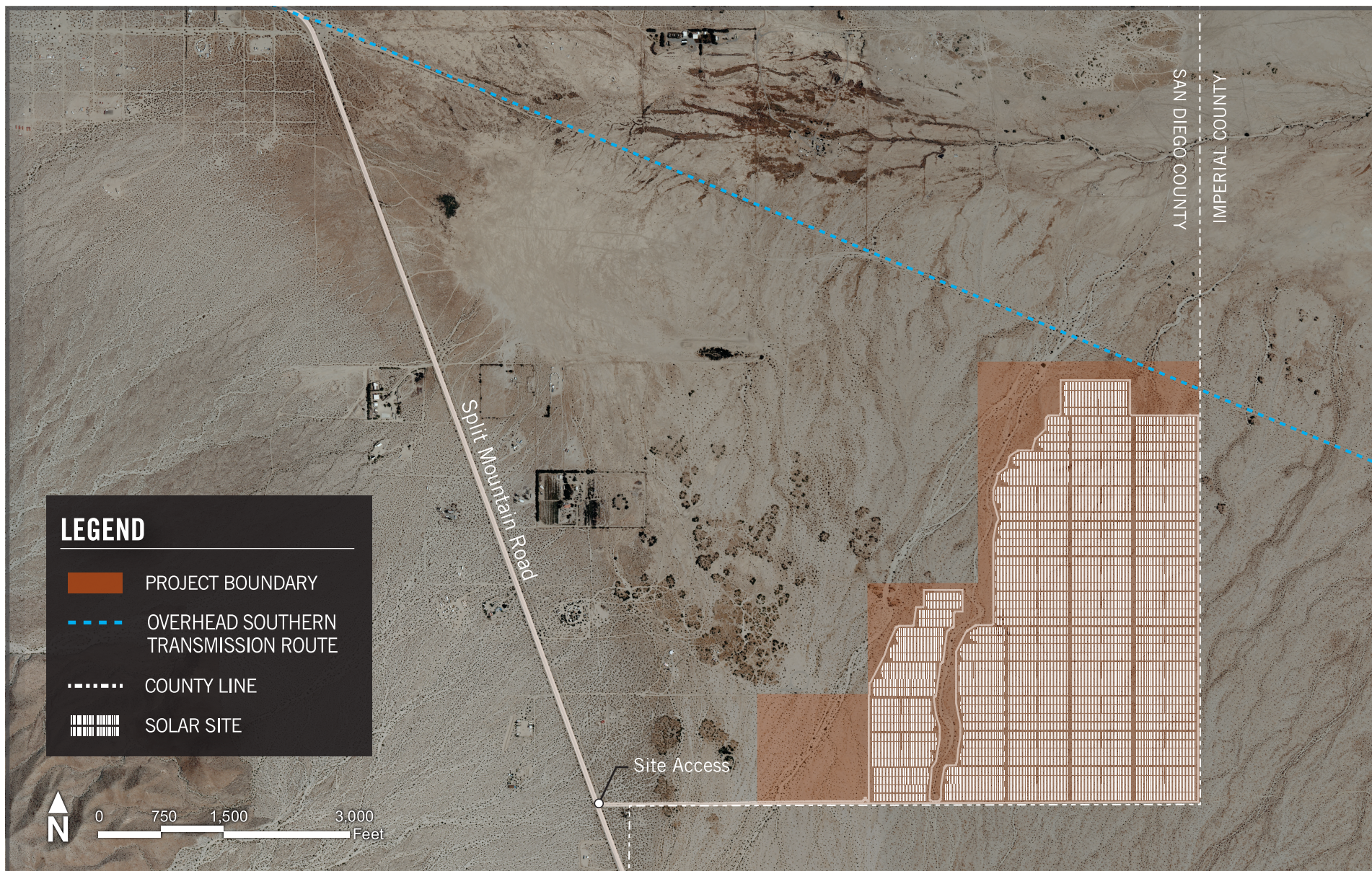
Single Axis Solar Tracker - Single axis solar trackers are designed to maximize the efficiency of a solar operation. Single axis trackers rotate around a fixed axis, allowing PV panels to track the sun's east/west position throughout the day (see Figure 3).

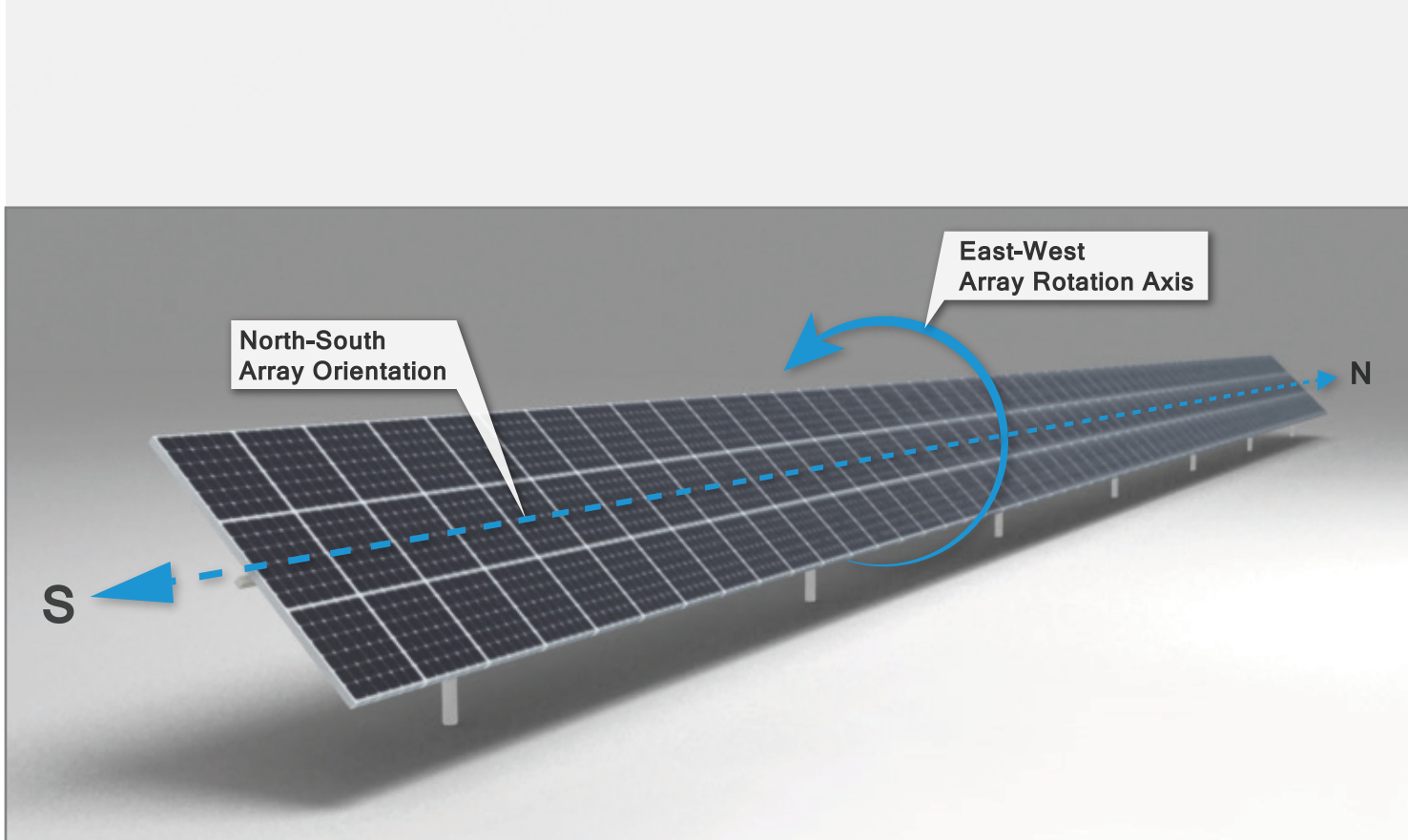
Glare – A continuous source of brightness, relative to diffuse or surface scattered lighting. For purposes of this study, glare is caused by the sun reflecting off solar panels (see Figure 4).

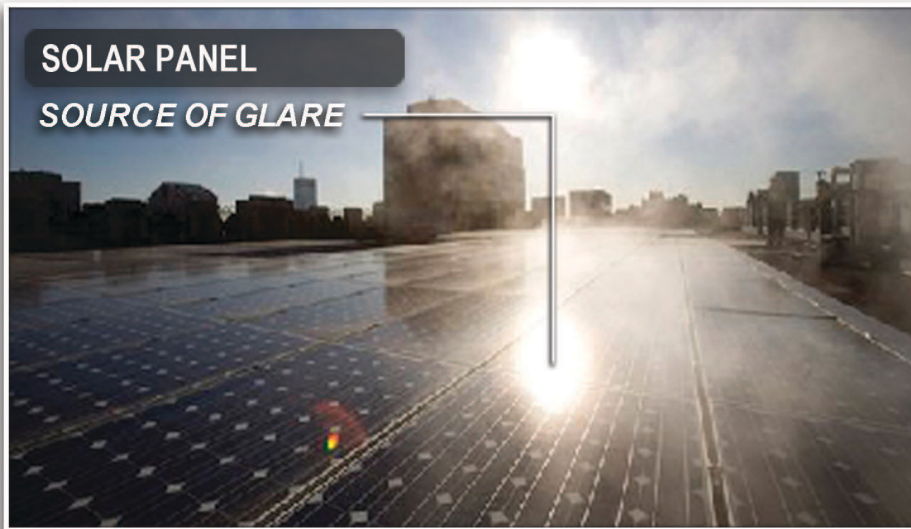
3D Geometric Analysis – A computer simulation incorporating a 3-dimensional (3D) terrain model, 3D solar equipment, and a solar algorithm to determine the date, time and duration of glare which may be visible during the landing approach.

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









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 locations, transportation, and recreational viewers. The analysis considers the changing positions of the sun throughout the day and year, and its influence on a single axis tracking PV panel. POWER used the following methodology to determine the location and duration of glare:

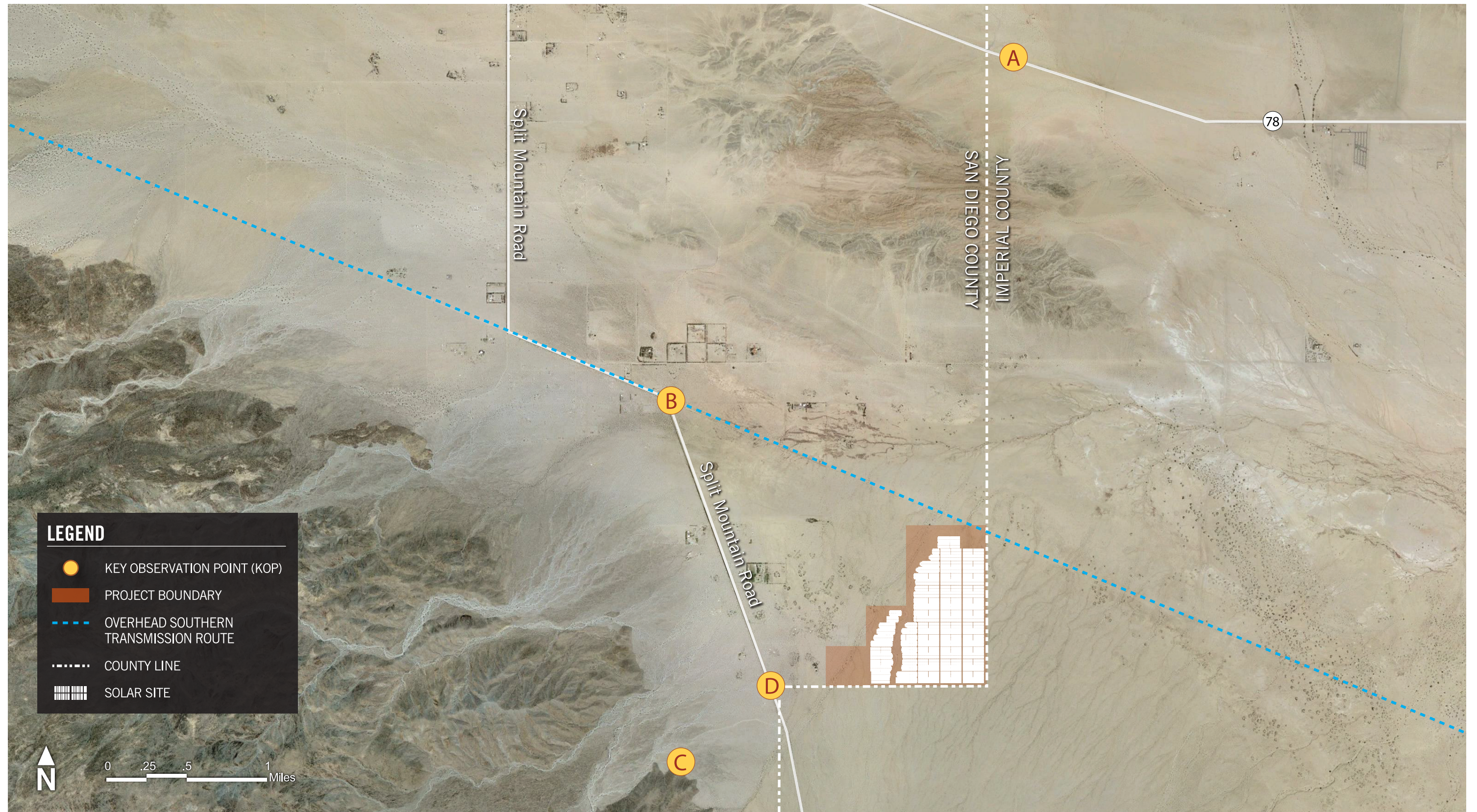
1. Identify Potential Glare Issues – This study focused on potential issues where glare may be visible to sensitive viewers. The findings are based on these locations (see Section 3.1).
2. Characterize Glare Behavior – 3D simulations were developed to accurately create and study glare based on the behavior 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.

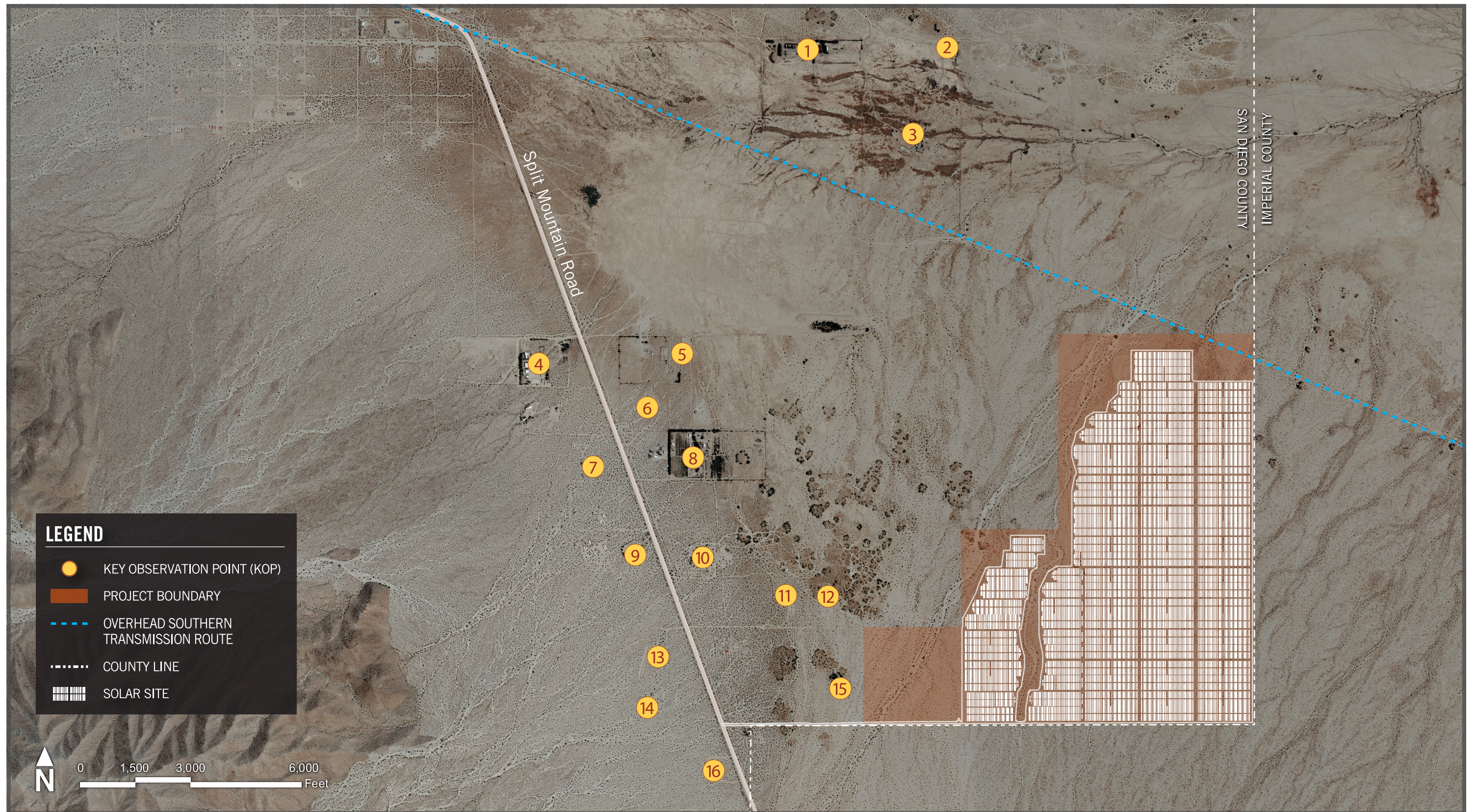
3.1 KOPs

Solar operations were studied from four public KOPs (KOPs A-D, see Figure 5A) and 16 residential locations (KOPs 1-16, see Figure 5B). 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 omitted 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 Project Site boundary.
- **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.





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 6):
 - 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 22nd, 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 Solar Equipment** – **3D Solar Equipment** – POWER developed 3D models of the single axis tracking PV panels based on manufacturer specifications including panel design and height. Additional CAD information collected included panel design, panel height, panel orientation, backtracking and tilt (-45/+45 degrees). It is important to note the 3D geometric analysis does not measure the intensity of glare. This study is focused specifically on the location, duration and conditions in which glare may occur.

A single axis solar tracker has three primary positions: tracking, backtracking, and stow positions. In addition to the three primary positions, trackers also have a ‘wake up’ procedure that brings the tracker out of the stow position and into alignment with the sun to begin tracking. These are characterized by the graphic (see Figure 7) and by the following descriptions:

- **Tracking** – The process by which the solar array maintains a 90 degree relationship with the angle of the sun.
- **Backtracking** – Backtracking is the process by which solar arrays rotate away from 90 degrees relative to the sun to ensure shading of the adjacent array is not occurring. This occurs at the beginning and end of the day when the sun is low on the horizon (see Figure 7).

- Stow – During evening hours and high wind conditions the solar arrays move into a position of five to ten degrees off of parallel to the ground surface.

Additionally, the general behavior of a single axis solar tracker, used for our study purposes is as such:

- The full range of motion of the panels will be -45 degrees to +45 degrees.
- Once the sun rises, the trackers will slowly rotate into a +45 degree angle, facing east.
- They are not moved into a +45 degree east facing angle prior to the sun rising to prevent panel shading.
- When the sun is perpendicular (90 degrees) to the panels, they will begin to track the sun throughout the day.
- When the panels reach a -45 degree angle, facing west, they will stop tracking the sun and slowly start to rotate back to a five to ten degree east facing angle.

3.3 Glare Evaluation - 3D Geometric Analysis

Once the 3D site was assembled, analysts animated the trajectory of the sun, and the behavior of the single axis tracker to determine when and where glare may be visible to KOPs. Studying the occurrence of glare is a 3D geometric analysis, which takes into account the position of the sun in relation to the angle of the solar panels to emit a path of glare. Each KOP was evaluated during daytime hours of operation during spring, summer, fall, and winter (see Section 4.0).

Spring Equinox

March 20, 2013
12 hours 8 minutes of daylight
Sunrise - 6:48 a.m.
Sunset - 6:56 p.m.

Summer Solstice

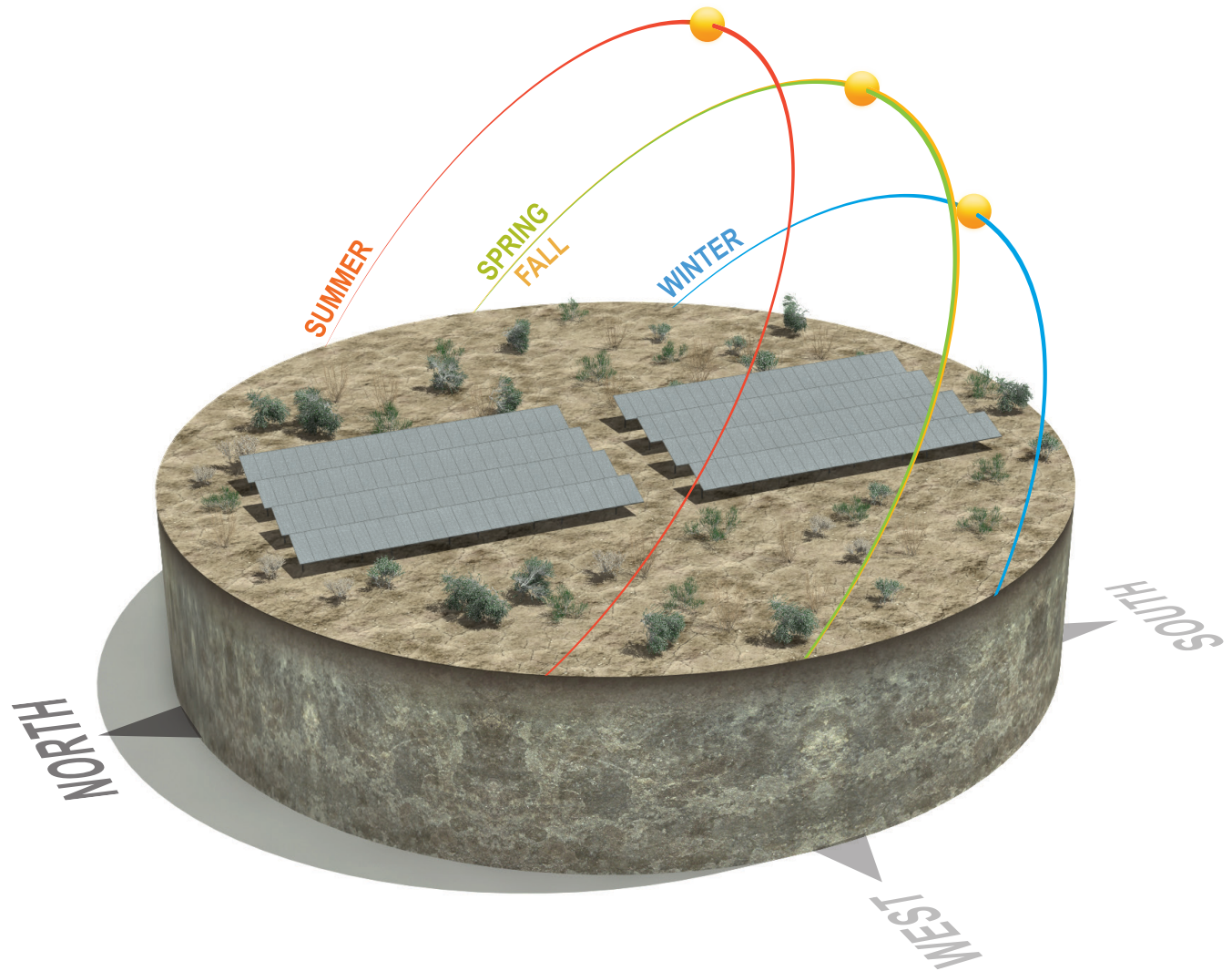
June 21, 2013
14 hours 20 minutes of daylight
Sunrise - 5:36 a.m.
Sunset - 7:56 p.m.

Fall Equinox

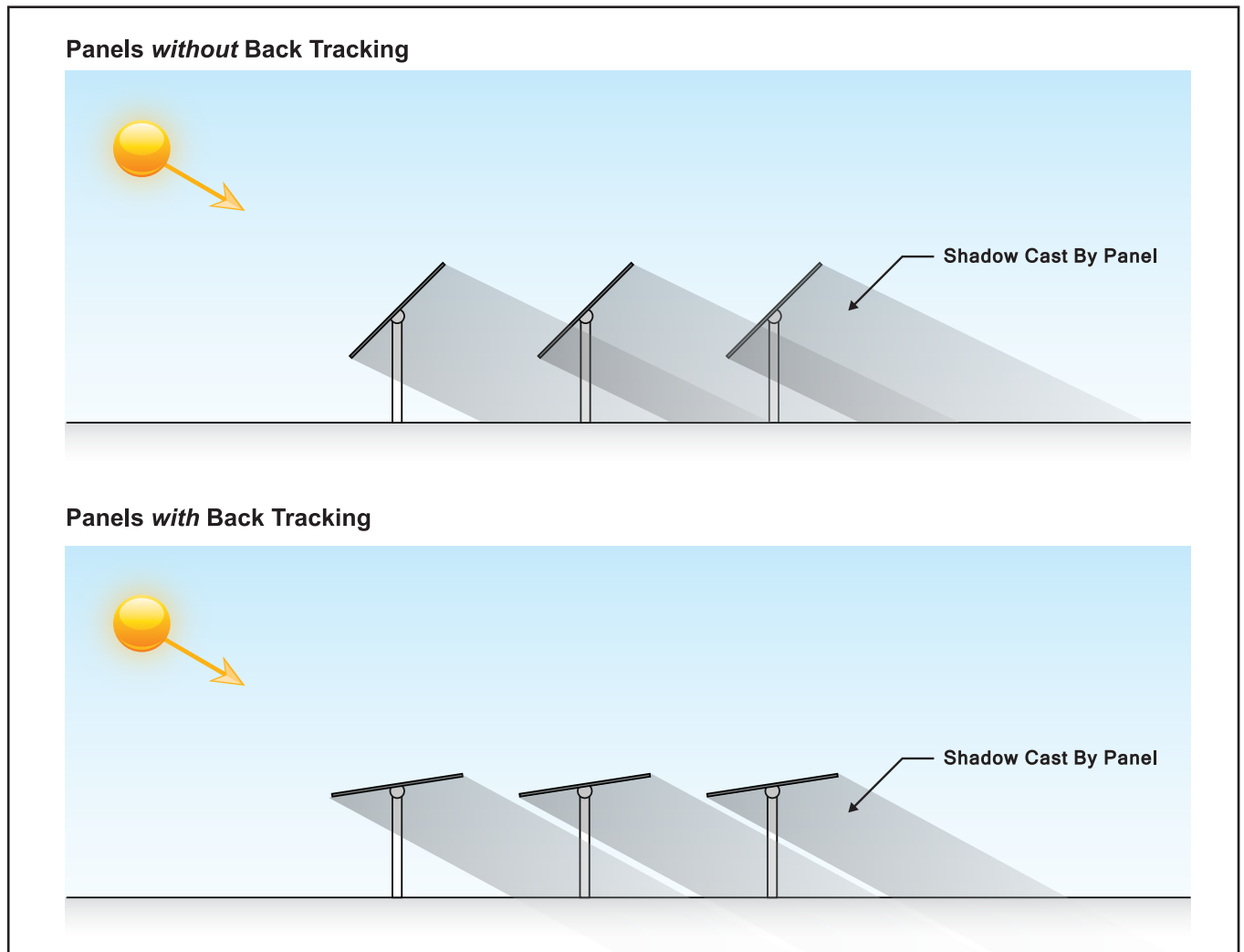
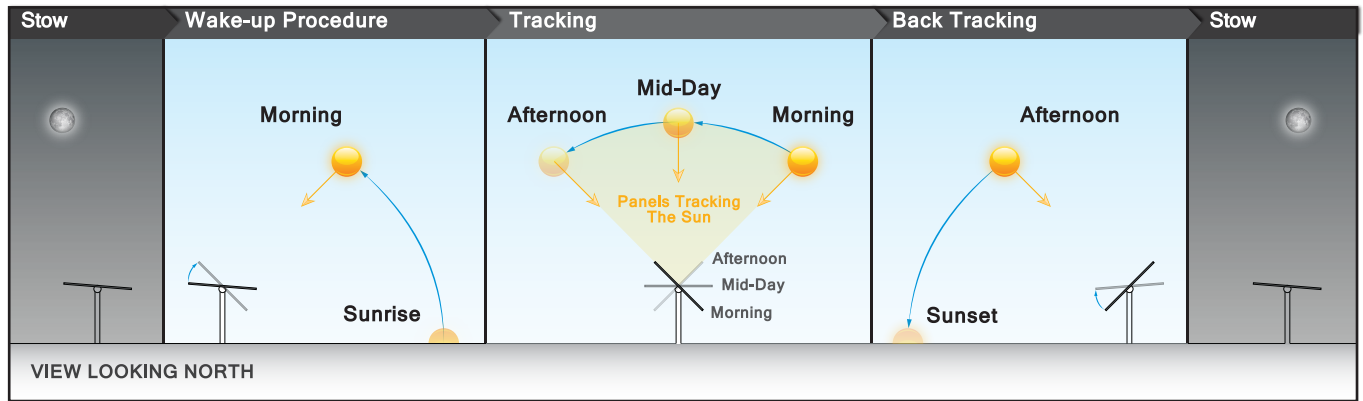
September 22, 2013
12 hours 8 minutes of daylight
Sunrise - 6:33 a.m.
Sunset - 6:41 p.m.

Winter Solstice

December 21, 2013
9 hours 58 minutes of daylight
Sunrise - 6:44 a.m.
Sunset - 4:42 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.



4.0 RESULTS

Review of the 3D geometric analysis determined no glare will be visible from the proposed solar operations due to the distance of KOPs to the Project and the orientation of the PV panels. 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.

5.0 DISCUSSION

As solar operations continue to increase in the United States, so does the concern for glare. An often asked question is, “If glare is experienced, what will the intensity be? What is it comparable to?” Glare is primarily produced from the top plate of the PV module, which reflects the sun’s image back to the viewer (making the glare comparable to building glass, and water (see Figure 8).

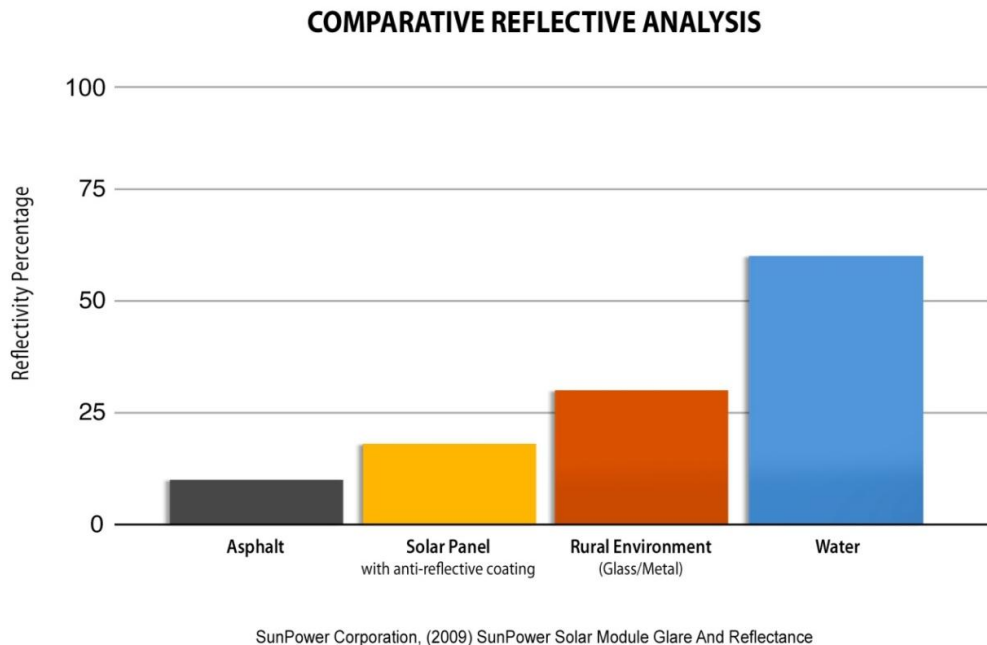
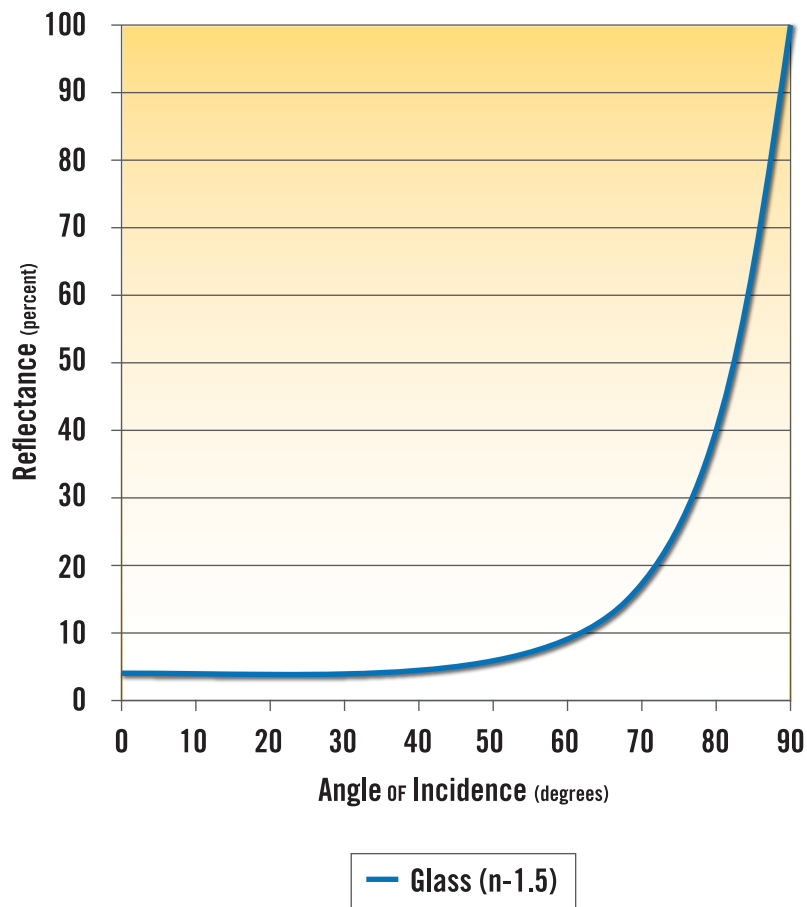
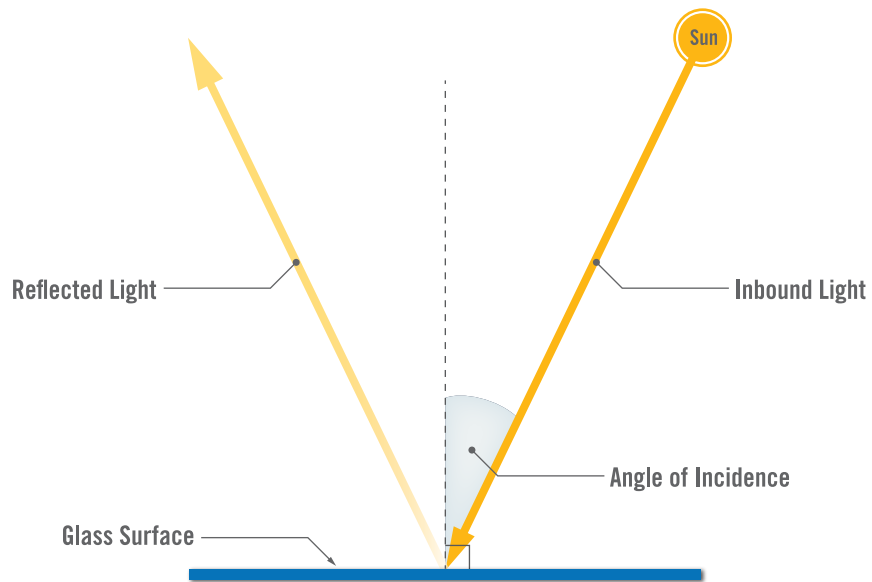


FIGURE 8 COMPARATIVE REFLECTIVE ANALYSIS

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 9). 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.

Single axis trackers tend to result in less overall glare percentages during the tracking phase than that of static PV systems. During the tracking phase, the top panel glass faces the sun and maintains a lower angle of incidence. This allows greater transmission of light and ultimately greater panel efficiency. During the backtracking procedures (early in the morning and late in the evening), single axis trackers begin to rotate away from the sun to reduce shadow casting to neighboring panels. During this phase, higher angles of incidence will result and will increase the reflectance percentage. As shown in the Sandia Labs graphic, reflectance percentage never exceeds the brightness of the sun. If experienced by an offsite viewer, the intensity of glare will be similar to viewing a sun setting over a body of water.



6.0 CONCLUSION

Review of the 3D geometric analysis determined no glare will be visible from the proposed solar operations utilizing single axis technology, due to the distance of KOPs to the Project and the orientation of the PV panels. 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.

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