Overview

- **Bifacial Test Bed**
  Motivation and Description

- **Albedo**
  Measured vs. satellite data and model impact

- **Rear Side Irradiance**
  Variability and model impact

- **Bifacial Snow Gains**
  Snow shed and increased energy production
Bifacial Test Bed

Description

- 375W monofacial and bifacial crystalline silicon modules
- Embedded in existing single axis tracking array in 2020
- Colorado location – snow, but dry and sunny
- Exterior and interior strings
  - Monofacial (blue)
  - Bifacial (green)
- AMPT DC-DC converters
  interface to plant inverters
Bifacial Test Bed

Instrumentation

- **>2 years of 1 minute sensor data**
  - Hukseflux albedometer
  - Calibrated silicon reference cells for front and rear side plane of array irradiance
  - Thermocouple (small) temperature sensors
  - Site weather station provides wind speed and humidity measurements

- **2021 year data create hourly PVSyst model**
  - 1.23 DC:AC ratio
## Albedo

### Monthly Averages

<table>
<thead>
<tr>
<th>Month</th>
<th>Data Average</th>
<th>Source 1</th>
<th>Source 2</th>
<th>Source 3</th>
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Albedo
PV Sys Model Results

Difference in Predicted Annual Energy Production Relative to Model Using Measured Average Monthly Albedo

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<tr>
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<td>-0.45%</td>
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Rear Plane of Array Irradiance
Field Measurements

Total average annual rear side irradiance fractions:

Edge Sensors: 10.9%
Center Sensors: 7.0%
Rear Plane of Array Irradiance
Energy Model Impact

Total Annual Measured Bifacial Energy Gain: 6.6%
Modeled Annual Bifacial Energy Gain, Avg. rPOA: 6.7%
(edge +1%, center -1%)
Rear Plane of Array Irradiance
Energy Model Impact

PV Syst calculated rear side irradiance fraction: 9.1%
PV Syst annual bifacial gain with calculated rear side irradiance: 4.5%
In 2021, the project site experienced

- 26 recorded snow events, some spanning multiple days
- 54 full or partial days with high ground albedo indicative of snow cover
- 20 full or partial days with module performance affected by array snow cover

Note that project site has typically sunny and dry climate characteristic of Colorado
Bifacial Snow Gains

- **Sunny, Regular Albedo**
  - Bifacial Gain: 0.49 kWh/kWp (9.1%)

- **Sunny, High Albedo**
  - Bifacial Gain: 0.9 kWh/kWp (13.3%)
**Bifacial Snow Gains**

**Overcast Day Examples**

**Overcast, Regular Albedo**

- **Bifacial Gain:** 0.11 kWh/kWp (17.2%)

**Snowy, High Albedo**

- **Bifacial Gain:** 0.53 kWh/kWp (317%)
Bifacial Snow Gains

Snow Shed Examples

Bifacial Gain: 3.11 kWh/kWp (167%)

Bifacial Gain: 1.86 kWh/kWp (50.6%)
Bifacial Snow Gains

Snow Loss Modeling Implications

- 20 days with module performance affected by snow cover account for 20% of the system's overall annual bifacial gains

- Current models overpredict snow losses for bifacial modules on single axis trackers (limited dataset)

- Useful snow loss model enhancements could include accounting for enhanced gains from snow albedo and snow shedding for bifacial modules

Credit: O. Westbrook, "Comparison of Measured and Modeled Snow Losses for Photovoltaic Systems in Colorado," PVSC 2022
Summary

• A bifacial test bed provides useful ways to understand differences in bifacial module behavior and improve confidence in PV models.
• Albedo is a non-trivial source of uncertainty in bifacial PV modeling which can be reduced by site measurements.
• Irradiance can vary widely across the rear side of a module on a single axis tracker and an average value appears to reflect bifacial energy gains well.
• Bifacial modules on a single axis tracker demonstrate faster snow shedding than their monofacial counterparts and receive a significant performance boost from ground snow-cover, which are not well reflected in current snow loss models.
The End

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